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1953

TEAMWORK IN RESEARCH

TEAMWORK IN RESEARCH

Edited by

GEORGE P. BUSH

AND

LOWELL H. HATTERY

FOREWORD BY HOWARD A. MEYERHOFF

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FOREWORD

The Third Institute on the Administration of Scientific Research and Development, sponsored by The American University, the National Research Council, and the American Association for the Advancement of Science, was primarily concerned with problems posed by team research. Like so many things that acquire sudden prominence, team research may currently be glorified beyond its merits, and there are those who lack the historical perspective to recognize its antiquity, as well as those who exaggerate its importance to the point of claiming that the "uncommitted" research of the individual worker is as much an anachronism as the horse is in the realm of transportation, and that both will soon be appropriate museum pieces.

Although the participants in the Institute devoted themselves enthusiastically and single-mindedly to the subject of team research, this volume is evidence that they did not lose their sense of perspective. Just as the geologist, the naturalist, or the engineer knows that the horse is the only means of locomotion along a mountain trail, so in every specialized field of science the patient labor—whether inspired or plodding—of the highly trained expert is still indispensable as a means of adding to the factual base upon which the foundation of effective teamwork is laid. Impressive as are the figures that Dr. Bush has assembled in his concluding chapter to show the startling rise of team research as reflected by the increase in joint authorship in publications during the past thirty years, no less significant is the fact that there has been no falling off in the number of individual authors, much as they have decreased percentagewise. One must conclude from these figures that science is claiming more devotees, and perhaps a different kind of person, though the problems created by the personalities of team members suggest that, even in larger numbers, scientists are still rugged individualists who are persuaded to put the fragments into which science has been broken by specialization together into new patterns that never existed under the old general classifications.

The isolation of the phenomenon of team research is still too new to appraise either its good or its ill effects. It has vastly accelerated the tempo of investigation. It has achieved results be-

yond the ken of the individual worker and beyond the limitations of individual inspiration, for in many projects two or more heads are far better and more versatile than one. We do not yet know, however, whether teams are putting back into the pool of basic knowledge as much new basic information as they are withdrawing for application. We are not sure whether they are making the most efficient use of the finite resources of manpower. We cannot even make valid comparisons between the performance of teams and the performance of individual researchers because the latter have rarely, if ever, been accorded comparable advantages. In most instances problems have been assigned, or at least suggested, to teams, and with the assignments have gone financial resources, the most modern equipment, adequate space, and auxiliary personnel, all of which are usually denied to an individual. Granted that the latter would necessarily confine his genius to a somewhat more restricted project, it is not known how much the gifted researcher could accomplish in comparison with a team, were he given adequate assistance and equipment to accomplish his objectives.

As the authors of this volume imply, and as Dr. Bush lucidly indicates in his final chapter, the obvious conclusion is that two distinct methods of research must hereafter be distinguished. There is the specialized project, involving knowledge and techniques drawn from a single field of science, and for which the individual specialist is still the logical choice; and there is the interdisciplinary project demanding skills that no one worker can possess and for which the team is the only possibility. It is not easy to say which of the two presents the more difficult problem to the administrator. An only child in the family is more likely to be a problem than half a dozen youngsters who work out their own salvation by attrition and adjustment. In the pages that follow the problems presented by the research family—the team—are set forth by people who have successfully dealt with them. Inevitably the book breaks new ground; and if it does not leave the broken ground perfectly graded and landscaped, it is hoped that it will prepare it for those who can apply new experiences to the art of management and administration.

HOWARD A. MEYERHOFF
Administrative Secretary
American Association for the
Advancement of Science

Washington, D. C.

INTRODUCING THE TEAM

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Robert B. Curry is Assistant Director of the Applied Physics Laboratory of The Johns Hopkins University and has had several years' experience as an industrial consultant and governmental fiscal officer including an assignment as Special Assistant in the Office of the Secretary of Defense.

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Albert F. Daggett, Ph.D., is Dean of the Graduate School, University of New Hampshire. From 1928 to the present time he has served on chemistry faculties at Columbia University, Hunter College, and the University of New Hampshire. In addition to his duties as Dean of the Graduate School, Dr. Daggett is also Coordinator of Research at the University of New Hampshire.

Ralph E. Gibson, Ph.D., is Director, Applied Physics Laboratory, The Johns Hopkins University. From 1929-1945, he was a faculty member of George Washington University. He joined the Applied Physics Laboratory in 1946, becoming Director in 1948. He was Vice-Chairman of Section H, National Defense Research Committee during 1941-1944. From 1943-1945, he served as Chairman, Rocket Propellant Panel, Joint Chiefs of Staff. During 1944-1946, he also was Director of Research at the Allegany Ballistics Laboratory.

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David B. Hertz, Ph.D., is Assistant Professor of Industrial Engineering at Columbia University. He has been an industrial consultant, and is the author of *The Theory and Practice of Industrial Research*.

Frank A. Howard is retired as President of the Standard Oil Development Company and Vice President of Standard Oil Company (N. J.). After brief service as an examiner in the U. S. Patent Office and practice in a private law firm, Mr. Howard joined the Standard Oil Company (N. J.) in 1919. He was responsible for research, development, patent and chemical manufacturing activities with Standard Oil until his retirement.

Ralph G. Meader, Ph.D., is Chief of the Grants and Fellowship Branch, National Cancer Institute of the U. S. Public Health Service. From 1925-1948 he served on biology faculties at Hamilton College, Wesleyan College, and the Yale School of Medicine. He became affiliated with the National Cancer Institute in 1948 in his present capacity.

Thornton Page, Ph.D., is Deputy Director, Operations Research Office, The Johns Hopkins University. From 1938-1941 and 1946-1950, he taught astrophysics at the University of Chicago. During 1941 and 1942, he was engaged in naval ordnance research. In 1946 he returned to the University of Chicago, becoming Assistant Professor of Astrophysics in 1947.

George S. Pettie, Ph.D., is Deputy Director, Operations Research Office, The Johns Hopkins University. He taught at Harvard University 1933-1941. From 1941-1942 Dr. Pettie was liaison officer with the Office of Production Management, War Production Board and Chief, Official Sources Division, Bureau of Intelligence, Office of War Information, 1942-1943. From 1945-1947 he was Associate Professor of Political Science at Amherst College. He served on the staff of the Committee on Foreign Affairs, U. S. House of Representatives, from 1947 until joining the Operations Research Office.

Edwin W. Pike, Ph.D., is a staff member of Wallace Clark and Company of New York City, management consultants. He taught on the faculty of the University of Pennsylvania from 1921 to 1947. He then served as Director of Research and Development for the

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Addison M. Rothrock is Assistant Director of Aeronautical Research, National Advisory Committee for Aeronautics. He was a physicist at the National Advisory Committee for Aeronautics, Langley Field, from 1926-1942. From 1942-1945, he was Chief of Fuels and Lubricants Division, Lewis Flight Propulsion Laboratory, and Chief of Research from 1945-1947. During 1948 he acted as consultant, Atomic Energy Commission. He was Vice-President of the Society of Automotive Engineers in 1949.

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Albert F. Siepert is Executive Officer of the National Institutes of Health, U. S. Public Health Service, Federal Security Agency. He has served in administrative and research assignments with various Federal agencies. He joined the staff of the U. S. Public Health Service in 1946.

Howard R. Tolley is Consultant to the Ford Foundation. From 1915-1946, he was associated with the U. S. Department of Agriculture as an agricultural economist except for 1930-1933 when he was Professor of Agricultural Economics at the University of California and Agricultural Economist and Director of the Giannini Foundation. He returned to the U. S. Department of Agriculture in 1933 as

Consulting Specialist and was appointed Chief of the Bureau of Agricultural Economics in 1938-1946. In 1946 he became Chief Economist and Director of Economics and Statistics, Food and Agriculture Organization, United Nations.

Merle A. Tuve, Ph.D., is Director, Department of Terrestrial Magnetism, Carnegie Institution. He was a member of the faculty of Princeton University during 1923-1924, and of The Johns Hopkins University during 1924-1926. In 1926 he became associated with the Department of Terrestrial Magnetism as physicist and was appointed Director in 1946. From 1942-1946, he served as Director, Applied Physics Laboratory, The Johns Hopkins University. From 1940-1945, he was Chairman, Section T, Office of Scientific Research and Development.

Lawrence W. Wallace, Dr.Engg., is Management Consultant for the Defense Production Administration. He was a member of the faculty of Purdue University from 1906-1917. From 1917-1919, he was with the Diamond Chain and Manufacturing Company, becoming Assistant General Manager. From 1919-1921, he was Director of the Red Cross Institute for the Blind, Maryland. From 1921-1934, he was Executive Secretary for the American Engineering Council in Washington, D. C. From 1934-1937, he was Director of Engineering Research of the Association of American Railroads. During 1937-1941, he was engaged in engineering and research for the Crane Company. From 1941-1947, he was Vice-President of the Trundle Engineering Company. In 1947 he became a private counsellor on management.

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INTRODUCTION

1: NATURE OF RESEARCH TEAMWORK

LOWELL H. HATTERY

As group research has become the *modus operandi* the concept of the team has evolved in the consciousness of those responsible for the results of research and development work. Research administrators have gradually discerned the necessity for a quality of administration different from the hierarchical, military type of administration. The nature of the research function and of research personnel requires a special environment, a special concatenation of men and relationships for the optimum productive situation. The concept of teamwork seems the best analogue to the recognized need.

Published remarks on research administration show only the beginnings of recognition of the need for teamwork in the research situation. Indeed, only recently has any substantial attention been devoted to research organization and administration. Only in recent years have the increase in numbers of research personnel, the hybridization of research fields, the accelerated demand for useful research results and other factors resulted in extensive "group" research. This is true for both industry and government research. Even the scientist not formally associated with others in a group endeavor is usually committed to activity in an institutionally established program of research. President Conant remarked in this connection :

"Both science and invention in the twentieth century are characterized by an increasing trend toward programmatic research; the uncommitted investigator is becoming a relatively rare social phenomenon."¹

The organizing of research, although attended by substantial scientific advances, has resulted in misgivings among scientists and observers who fear that the creativity of basic research is largely sacrificed in the programming and organizing process. Some assert that basic research cannot, by definition, be organized. Yet even the lone researcher in much of contemporary science needs the

¹James B. Conant, *Science and Common Sense* (New Haven: Yale University Press, 1951), p. 317.

assistance of technical aides to construct and operate equipment, assemble and treat data and carry on other functions which modern equipment and methods render necessary. This situation in itself requires organization of scientist and assistants. Hiring, paying, evaluating and other administrative procedures are necessary.

We must be seriously concerned with the asseveration that individual creativity is threatened by the process of organizing scientific personnel, since it is a highly precious value in our society. We must strive assiduously to preserve the value of creativity despite the apparent inevitability of the organizing process.

Frank Jewett, W. I. B. Beveridge, W. A. Hamor, David Hertz, Paul Freedman and others have referred to the idea of teamwork in group research and development activity. The word and the idea occur with increasing frequency in the writing and discussion of research organization and administration. The increasing attention to the idea of teamwork is, I believe, a belated recognition that *many of the standard principles and methods of organization and administration are not applicable to scientific endeavor without modification*. However, by turning attention to teamwork as a conceptualization of research organization and administration we may conserve and realize creative potential of our scientific talent in the very process of increasing institutionalized, group research.

What is teamwork?

The concepts of "teamwork" and its administrative and organizational configurations may vary. A dictionary definition of "teamwork" is "work done by a number of associates, . . . all subordinating personal prominence to the efficiency of the whole."² Perhaps the suggestion of "subordination" underlies the strong feelings of some that group research smothers individual creativity.

On the other hand the dominance of a group or team objective may be a stronger motivating force than the scientist's inner drive alone. Nor should we neglect the possibility of complementary personal abilities or qualities which may result in a team product the quality of which is better than that to be expected from the individual capacities of team members, or the more obvious situation of complementary knowledge, skill and insight.

²Webster's *New International Dictionary of the English Language*, Second Edition, Unabridged. (Springfield, Mass.: G. and C. Merriam Company, 1945), p. 2589.

Frank B. Jewett, former President of Bell Telephone Laboratories, has referred to the importance of the "coordinated team" in large research organizations with "specialists and specialized facilities in many fields."³ Dr. Jewett states:

"Experience has shown that this is the most powerful, effective and economical method of handling complex problems. It is greatly superior to any scheme of farming out portions of the problem to individual laboratories. This results from the fact that at all stages of the work the several elements react on one another and that what can or cannot be done in one field determines what can or cannot be done in another. Facility for intimate daily intercourse between the research and development expedites progress, eliminates much false work and insures a better end-product."⁴

At any rate, there seems to be assumed in the term "research team" something beyond the term "research organization." The research organization may be established in classical hierarchical arrangement with vertical divisions by branches of science and engineering. Despite this organizational structure, day to day operations may reveal that one man consistently consults with another in a different organizational unit and with a third in another organizational unit. Thus an *informal team* is established with an informal leader. Perhaps through this "natural" grouping will come the highest order of cooperative scientific effort. Perhaps too this concept of the team accounts for the dogmatic statement by one outstanding scientist that there is no such thing as a research team in excess of four persons. I suppose he assumes that artificial interference of administrative procedure interferes with the natural group arrangement beyond this point.

At the other extreme one might think of the full resources of scientific personnel of the nation as our "national research team." Officers of the National Science Foundation and others concerned with national manpower resources may think of these resources as a national team or the potential for a national team. Somewhat in this grosser perspective is the attention to the Section T pattern of research organization which is discussed elsewhere in this volume. The teamwork in the Section T system is effected through the confluence of a central laboratory and contractually associated laboratories toward a single objective.⁵

³*The Future of Industrial Research* (New York: Standard Oil Development Company, 1945), p. 18.

⁴*Ibid.*, pp. 18-19.

⁵*Infra*, Chapters 13, 14 and 15.

Research, development and invention

Perhaps by definition teamwork illustrated in the Section T system is applied to development and not to research. It is difficult to treat organized scientific activity precisely since not only do research, development and invention have the nature of a continuum, but the terms themselves are defined differently by many and carry different connotations to each of us. Scientific activity spreads through the entire continuum, however, and the concept of teamwork is applicable throughout though its configurations may vary from one point on the continuum to another. Of course the configuration will vary too in some degree at any one point in the continuum with differences in the personalities of the scientists, the nature of the problem, the nature of equipment to be used, and other factors. We are concerned with the progress of science from both pure and applied research work, and must depend on the writer, the reader and the discussant to keep thinking in focus as to the "kind" of scientific activity we may be concerned with.

Inter-discipline teams

The most frequent reference to the research team in current literature is directed toward the multi-discipline team arising out of problems which are not soluble with the knowledge and methods of a single traditional scientific field.

W. I. B. Beveridge, Director of the Institute of Animal Pathology at the University of Cambridge, observes:

"Team work is essential in research in the investigation of problems which overlap into several branches of science, for instance, the investigation of a disease by a clinician, bacteriologist and biochemist."⁶

Dr. Beveridge adds that "team work is often required to develop discoveries which have originated from individual workers."⁷

The emphasis on "operations research" in recent years has brought a new demand for teams of individuals with different technical specializations, and for that reason the operations research team is given attention in this symposium.⁸

⁶W. I. B. Beveridge, *The Art of Scientific Investigation* (London: William Heineman, Ltd., 1950), p. 120.

⁷*Loc. cit.*

⁸*Infra*, Chapters 7 and 16.

Other types of research teams

Another type of research team overlooked by many writers but mentioned by Dr. Beveridge is the team "to increase the capacity of the brilliant man beyond what he could do with only his hands and technical assistance."⁹ Too often the leader has become involved in administrative, supervisory duties and his time is siphoned off from creative and inspirational activity. This eventuality is not inherent in the team built about the brilliant scientist, however. This type of team, Beveridge points out, is also very helpful to the young scientist who thus receives training from a man of outstanding experience and ability.

Dr. Beveridge refers to the frequent division of scientists into two types, variously labeled. W. D. Bancroft, Beveridge points out, divides scientists into "guessers" (in the sense of making a shrewd judgment or hypothesis in advance of the facts), who tend to follow the deductive or Aristotelian methods; and "accumulators" who accumulate data until the hypothesis or generalization becomes obvious and tend to follow the inductive or Baconian method. Beveridge himself distinguishes the types as "speculative" and "systematic." Mathematicians have been classified as "intuitive" and "logical."¹⁰

If scientists could be placed neatly into one of these two pigeon-holes it might provide a basis for assuming that the establishment of a research team would depend on whether or not the scientists on the staff were the "speculative" or the "systematic" type; if one desired to develop team research, it would seem to follow that scientists of the systematic, Baconian type should be employed.

This is not a realistic view, however, since these two categories are much too broad and are not mutually exclusive. Individual scientists may embody the characteristics of both types suggested and there are many gradations within each quality of "systematic" or "speculative."

On the other hand, emphasis on the research team has resulted in attention to personality factors in the selection of individual scientists for an organization. For example, Earl Bartholomew, of the Research Laboratories of the Ethyl Gasoline Corporation, in his array of characteristics sought in young research engineers cited

⁹Beveridge, *op. cit.*, p. 120

¹⁰*Ibid.*, p. 144.

"honesty" first, then, "cooperation" which includes "willingness to submerge personal desires in joint accomplishment."¹¹

Professor Hertz carries analysis of the research team a step further by suggesting that, "There is a particular composite of creative mentalities which will be most efficient in a given instance."¹² "It is necessary," he says, "to analyze a problem into its elemental components before proceeding with the choice of the creative mentalities and the resources for its solution; an individual will bring to a problem definite attitude or 'set' which may or may not be the most fruitful for the analysis of the situation."¹³

One may theorize at length about teamwork in research, and if kept within appropriate limits theorizing can be useful, even necessary. However, we cannot for each new research problem place the elements of our problem into an automatic computer which will identify the ideal combination of talent; nor can we then depend on a magic genie personnel officer to produce for us that ideal combination. The research administrator must operate within practical limits.

Administrative concept of teamwork

A few writers in administration have recognized the importance of the teamwork concept in any group endeavor.¹⁴ From these writings which have found their way into the practice of too few administrators, there are important suggestions for research organization and administration. They include the ideas of supremacy of group over individual objectives, maximum participation of each and identification of the individual with the group.

The challenge to research administrators is the application of the principles and methods of the concept of teamwork as they have been developed in general administration to the group research

¹¹Earl Bartholomew, "Modern Engineering Research" (a paper read before the Harvard Engineering Society, April 17, 1935), p. 9.

¹²David B. Hertz, *The Theory and Practice of Industrial Research* (New York: McGraw-Hill Book Company, Inc., 1950), p. 85.

¹³*Ibid.*, pp. 86-87.

¹⁴See, for example, Henry C. Metcalf and L. Urwick, *Dynamic Administration* (New York: Harper and Brothers, 1942); Catheryn Seckler-Hudson, *Processes of Organization and Management* (Washington, D. C.: Public Affairs Press, 1948); Paul Pigors and Charles A. Myers, *Personnel Administration* (New York: McGraw-Hill Book Company, Inc., 1947); Ordway Tead, *The Art of Administration* (New York: McGraw-Hill Book Company, Inc., 1951).

situation. The successful formulae will not be easily discovered and applied. However, we believe this symposium represents an entry into the problem which is an essential approach—the presentation and analysis of experience in group research with special attention to the concept and realization of teamwork. Through the documented analyses of experience and the comparative study of the principles and methods of general administration we may move toward a more productive organization of scientific personnel and scientific work.

PART ONE

ORGANIZATION FOR TEAMWORK

2: PLANNING RESEARCH FOR TEAM ATTACK

EDWIN F. PIKE¹

Edisonian research is laughed at today. "Team Attack" is spoken of glibly by everybody associated with research but few people have the proper concept of what it is, when to use it, and how to apply it.

However, research of the Edisonian type was, in fact, team attack. I know this because I have browsed around the old Edison Laboratory in Fort Myers and have seen the evidence that Edison had chemists, physicists, gardeners, and others working as a team for him. If you ask why the gardeners were there, the answer would be that they raised plants from which fibres were developed, and these gardeners were important to the over-all picture. There was another effective member of the team—an old colored man—who used to push Thomas Edison's wheelchair around, and he was an important member of the team because if he had not pushed the wheelchair Thomas Edison would not have been in the laboratory. So the idea of team attack really is not very new.

There is, however, a great difference between Edison's method and today's method. I think this difference can be broken down into the following elements:

a) Research used to savor more of invention—the flash of genius—than it does today.

b) The number of people involved is greater today.

c) The number of specialized skills required to be brought to bear on a problem is greater.

d) The fact that corporation funds rather than the money of an individual are being spent means that the dollar yardstick is applied at more points and oftener than before.

e) Government money is now responsible for a great deal of research, of both kind and quantity, that did not previously exist.

f) There are social implications to modern research that have been recognized only recently and to which I shall refer later.

g) The standards of performance of the end results of modern research are higher today than ever before.

¹An arrangement was made with Dr. Pike whereby he printed this talk as an article in *Industrial Laboratories*, March 1952, pp. 80-86.

The first requirements in planning today's research are to determine what you want to do, the direction of the research you plan to undertake, and what work areas are to be investigated. Therefore, it is necessary to define some terms which will be used in this discussion.

Fundamental research means that the results of that research will produce an increase of basic knowledge. Fundamental research is, therefore, the investigation of the relation between cause and effect in material phenomena. On the other hand, industrial research, as has been stated by Mees,² always starts with the intention to apply the results of research to technology, and this is the kind of research that I mean throughout this discussion.

Since the intent is to apply the results of research to a company's products, the research effort must include those steps that are required to get the products into production. Development, therefore, must be defined as the improvement of existing, or the introduction of new, products and processes. Once in production, you must get the products to the customers and keep them there. Thus, technical service must be considered in this discussion, not as such, but because of the work load it throws back into the laboratory. We have, therefore, defined industrial research, development, and technical service for the purpose of this discussion.

Now we must define a team. There are two kinds of teams defined in the dictionary. The first is: "A number of persons associated together in any work." I call this the horse-team, where you have two or more people doing approximately the same kind of work to achieve a single objective or aim. The second is: "A group of workmen capable of completing one of a set of operations." This I call the football-team. The first, or horse-team, represents division according to fields of science, and the second represents division according to the field of investigation, or stage of application.

To return to the first requirements, which are to determine what you want to do, and the direction of research. Usually this is determined long after a research group or department already exists. The necessity to make these decisions is usually brought to the attention of management only when it appears that ten men are running off in twelve different directions at the same time. Only once in my experience has a company determined *first* what was required to be done.

²Mees, C. E. Kenneth and John A. Leermakers, *The Organization of Industrial Scientific Research*. New York: McGraw-Hill Book Co., Inc., 1950.

The determination of what you want to do is probably the most difficult job in any research program because some research employees are already "old hands," some have established "little empires," and some have married the president's daughter. These men already know what they can do, like to do, or want to do, or they think they know these things, but the real question is: What ought the company to do?

The determination of what the company ought to do is not a static thing. This question must be reexamined and reestablished constantly, and the element of planning must be reviewed continuously.

There are certain guideposts that one can use to determine what a company ought to do:

1. *What is the historical background of the company?*

It may have an excellent reputation for making a certain product, and thus it would be indicated that further research might be done in the particular field of that product. One must remember, however, that the viewpoint of the company must not be limited by this historical background. For example, the du Pont Company used to be a powder company and very recently it was characterized with good reason as a textile company.

2. *What men have you got now?*

This must be answered not only in terms of the scientists, but also in terms of the management men.

3. *What background of knowledge and experience do your men possess?*

4. *What raw materials do you control, if any, or what are you accustomed to using?*

In many cases a company's final research setup will be determined by the raw materials it has or uses.

5. *What are the company's present economic conditions?*

6. *What plant facilities do you now possess?*

7. *How much "guts" has the company got?*

Some companies call copying a competitor's products, or chiseling his quality, research. Some companies call plant and customer trouble-shooting, research. What I mean to ask is, *does the company have a real appreciation of research?*

8. *What would the company like to do?*

This is an important question, because a company, like a person, does best what it likes to do. It is important also because the corporate mind should be one that looks over the fence and

thinks the grass looks sufficiently green to be investigated further.

9. *How much money is available?*

Notice that this is one of the last questions to be asked, because good answers to all of the previous questions will tell you how to use most effectively whatever money you have, and how to get the most out of the research dollar.

10. *If you do what you think you ought to do, will it be worthwhile?*

This question involves not only profit, but the ever-increasing social implications as well. We must recognize the increasing part that social implications play in arriving at many research decisions. Particularly is this true in the case of the pharmaceutical industry where the team attack on a research problem promises the fastest route to production of drugs, antibiotics, and chemicals that show even a slight promise of controlling or curing disease. Previously the profit motive largely governed research of this kind, but in recent years the social implications have had an increasing influence, at least in the initial stages.

In order to answer these questions which I have posed, some scheme of communication must be set up within the company and I would like to tell the story of an approach that was used by my firm recently.

The management of a client company felt that it wanted to do research. It thought it had to do it in order to maintain the favorable position which it held in its industry at the moment. But it really did not know why it ought to establish a research department, and it did not have the slightest idea how to go about it. Therefore, it did something that I would recommend to many companies, even though the company has had a reasonably long history of research. It called in experienced counsel from the outside to advise them what to do and how to go about it.

We first talked with the men who were working in the existing laboratory, and then with several technical consultants employed by the firm. We asked the question of each of these men: "If there were in this company an adequate research department, what problems would you throw into the research hopper?" Then we talked with the men in the plant, including not only the department heads, but foremen and some workmen, and asked the same question. Next we put the question to management.

Finally we talked with some suppliers of raw materials and to

some of the company's customers and asked them: "What would you like to see this company do in the field of research that would help its relationships with you in the most practical sense?" We also talked with some of the client company's salesmen who had the responsibility for getting the products into the hands of the consumer. To all of these people we put the question: "What would you throw into the research hopper?"

These individual answers were then tabulated and it was a surprise to management to discover that these independent, individual answers were duplicated many times; it was also surprising to find how many of these answers emphasized problems that had not been recognized as important by top management. Each answer, whether it was given by one person or many, was discussed with management against the background of management's own plans for the company, both now and in the future.

Following this discussion, management was asked to assign priority numbers to each problem. By this simple method a number of things were accomplished. First, top management was forced to face the issue squarely as to exactly what it wanted to do and how far it would go in conducting a research program. Second, a broad spectrum of interests was brought into view. Third, all phases of the company's business that would touch, or be touched by, research were examined. Fourth, knowing the objectives and end results, it was relatively easy to determine what manpower, equipment, money, et cetera, were required to do the job.

By this time you are asking, "When is he going to talk about planning research for team attack?" Up to this point we have described only the methods for deciding what you are going to attack. Even a buck private knows that the composition of your forces is determined by your objective and that the plan of attack is conditioned by your estimate of the strength and disposition of the enemy. Therefore, you must determine what your objective is and what you need to accomplish it, then match that up with your resources. You can then determine how to plan the attack.

Let us be honest and state right off that you do not need any team if the research problem, or area, is so small that one or two men can do the job. It is even possible that splitting any job into too many small pieces will so disorganize the attack that the problem may never be solved, or solved at too great cost of time and money. The question at this point is, therefore, whether you need

a team approach. So let us look at the kinds of teams or groups that we can set up:

1. We can set up the group, or groups, according to the fields of science or technology; for example, chemistry, metallurgy, electronics. Then we can staff each group with men trained in a particular phase of science—physical chemistry, organic, inorganic, colloidal, analytical, et cetera.

Here I should like to emphasize that one must never forget that research is done by individuals, but we must also recognize that each man's work must be integrated with that of others in a group. Later, the work of a group may be integrated with other groups, sections with sections, and departments with departments. Where integration first becomes necessary, and at all subsequent levels of integration, planning is of the utmost importance.

2. We can choose fields of investigation; for example, high polymers, fuels, et cetera. Then we might take the field of fuels and break it down into basic research, processes, products, technical service, et cetera.
3. We can choose a stage of application; for example, fundamental research, applied research, development, pilot plant.

Obviously, it is impossible in a discussion like this to state a hard and fast rule that will apply to all cases, for they will differ in kind and degree.

I think the decision to employ what we call the "team attack" can best be resolved along these lines:

1. If the company is small, its plant and customer problems few, and its finances limited, no team is required. A well-trained and broadly experienced man, with a lab boy, may well suffice.
2. When the industrial research group consists of several departments, or even a single man in each department, each responsible for a particular kind of activity, we have the necessity for the horse-team where two or more horses are pulling the same cart, in the same direction, and each doing about the same type of work. Here you may have a group studying fundamental problems, a development group devoting its attention to processing studies, and a products service group concerning itself with specific problems dealing with finished products. But the kind and degree of skill in each group are about the same as in each of the other groups.

3. As a company grows and its technical problems increase both within and outside the company, there comes a time when two things become true:

- a) The various technical groups have gone fairly far in the direction of specialization.
- b) Long-range planning becomes a principal concern of the company.

As departments become larger and more specialized, their points of view become more rigid and restricted, and they may show an increasing tendency to approach a question from these restricted viewpoints. We acknowledge that it is well sometimes to have a problem looked at from more than one viewpoint, and it is frequently advantageous to have two entirely separate groups attempt to solve the same problem from independent approaches because one kind of approach may be a lot more successful than the other.

Further, with the growth of the company there comes a time when the research group must assume positions as consultants to all sorts of people in the company who may need help in the fields of their specialization. This fact alone may justify the specialization of which we spoke previously.

Long-range thinking constantly necessitates highly specific comment from these specialized points of view, which only a team of the second type can supply. This is the football-team, where each man or group is capable of completing one of a set of operations. The ends, tackles, guards, and various backfield men complete in their own way a set of operations to put the ball across the goal line. To carry this example further, the objective (to put the ball across the line) is a single, definite one. To accomplish this definite end result, specialized talents are assembled and then directed by the coach—in our case the research director. Strategy may, and even must, be changed as the game is played. This is precisely what is required for a successful team attack in research.

The most important problem in planning for team attack is to define the objective and this is frequently the most difficult thing to do successfully; and I might also add that it is the one usually thought of last.

The next problem is to assemble the team as to its components, or skills, or fields of endeavor, with particular attention to the individual's own temperament and capacity as well as scientific ability.

The type of team chosen will be influenced by a kind of geography and the kind of thinking resulting therefrom as the direct result

of communication. For example, here are three possible setups which are representative of actual situations:

A) This is a single plant employing about 1000 workers, making high unit value products requiring a great deal of control in manufacturing. Its products are usually sold by still larger companies under their own names and brands, so that a great deal of liaison of technical nature is essential. Further, a tremendous amount of fundamental knowledge is required regarding the products; development of both a mechanical and chemical character is very large in volume and detail; and above all, because of the character of the products, end use places a heavy load on research.

This company requires a team of the horse type, developed according to fields of science with the overlap of interests taking care of a wide range of problems most expeditiously and economically. For instance, the chemical group and the physics group are expected to handle problems in the field of physical chemistry by virtue of the overlapping of interests of the two groups.

B) A second company represents a food producer with six plants scattered across the country, employing about 2500 people. Each plant is located primarily because of raw material availability. Each of the plants produces widely different food products, but they are all concerned with a certain basic field—nutrition. Each plant has its own individual kinds of production and control problems which require laboratories in each plant. Here the team in the Central Laboratory is set up on the basis of stage of application with a strong liaison between the Central Laboratory and the Plant Laboratories.

C) A third company represents a much larger organization, operating in five different categories of products. There are about 20,000 employees. The laboratories are scattered over the United States and four foreign countries. Long-range planning is well established as a continuing and continuous function of management. Because of this long-range attitude of management, a Central Laboratory is located where not only research of a broad, general, but still fundamental nature, is carried out, but each division has its own laboratory carrying out research, development, pilot plant, and technical service activities. In turn, many of the plants have laboratories concerned with development and pilot plant work.

The difference between the Central Laboratory carrying out all

four functions and the laboratories assigned to each division carrying out the same four functions is this: if a problem cuts across the lines of the division laboratories, work on it is initiated in the Central Laboratory. If critical review of the work done in the division laboratories is required, the Central Laboratory handles it. If the problem is a Board of Directors problem, it is usually put into work in the Central Laboratory because the personnel of this laboratory functions to a large extent as a technical advisory board to the Directors.

I would like to go back and pick out some key words and phrases that I have used and among these are:

1. Communication
2. Integration
3. Long-range thinking
4. Long-range planning
5. Liaison
6. Overlapping interests of various groups
7. Strategy

The problem really is to put these words and the requirements they represent together in an effective manner. And this is best done by introducing a definite and regular and formal scheme of planning for research into operation. This scheme must show what is to be done, who is to do it, when it is to be started and how long it will take.

Immediately, someone will yell, "Since when can you put a stop watch on a man's creative mind?" The answer is that planning of research has been done by us since the beginning of World War II and must be done to make "team attack" possible. To revert to the football simile, where do you think a football team would get if the detailed planning of "skull practice" had not been carried out and the sequence and timing of each man's play carefully scheduled? This planning is the most important part of "team attack" and the one least understood and most seldom practiced by many of our laboratories.

In this discussion I speak from my own experience and from "what I read in the papers." There is no single answer, or method, or scheme, about which I know, that will solve all problems in planning research for team attack. What I have tried to do is to indicate methods of approach only.

3: ORGANIZING THE RESEARCH TEAM

L. W. WALLACE

There appear to be 57 conceptions as to what constitutes research. Kettering has said, "Research should be an organized effort to find out what you are going to do after you cannot keep on doing what you are doing now." He also said, "Research is for the purpose of keeping our customers reasonably dissatisfied with what they have." Then he adds, "The Sales Department sometimes objects to that on the grounds that a satisfied customer is the best advertisement a company can have. He may be a good advertisement, but he's an awfully poor buyer."

In an article on research which appeared in *The Journal of Engineering Education* some years ago, it was stated that in pronouncing the word "research" some stress the first syllable and look with contempt upon those who emphasize the second syllable. In academic circles you are sometimes told, in great confidence, that there is a wild-eyed professor across the campus who calls commercial testing research. You are also told that Professor Smith thinks he is engaged in research because he is discovering what everybody knows. We are told there are those who spend their time with cosmic rays and test tubes who point with ridicule to those who travel to far and out-of-the-way places to search the ruins of past civilizations for facts concerning those civilizations. We are told that some of those who sit for hours with their eyes glued to the microscope or telescope look with derision upon those who ascend to the stratosphere and those who descend to the lower regions of the sea.

We know there are those who work with guinea pigs and electrons and who study the breeding habits of bees and other insects who do not consider that the industrial chemist, physicist, metallurgist or engineer do research. Those people rather sneer and say that laboratory and road investigations of the performance of trucks, tractors, cars, locomotives and their appliances are merely commercial testing. They love that word "commercial." Each time they use it their jaws smack with delight and that ends it as far as they can understand. There are men in each of the groups mentioned, as well as in other groups, who say, according to the

type of research to which he is glued, that because the industrial chemist, metallurgist or engineer may not use a guinea pig, or a male or female bee, or go up in the air or sink to the depths of the sea, they therefore do no research work and consequently industries have never enjoyed the advantages of research. Such babbling of tongues relating to what constitutes research, its types, its field of application, and its technique, is absurd and childish. It is just as absurd to think that research is something elusive, fantastic or mysterious, and that its appropriate and only environment is the cloister. There is nothing uncanny or impracticable connected with research, nor is there any limitation as to what or where it may be applied.

The process of research of whatever type and regardless of when, where or to what applied, is nothing more or less than an *organized, diligent investigation to discover facts*. The facts to be discovered may relate to the stars, the fish, the color of the eyes of snakes, the habits of human kind, the performance of a locomotive, or to a myriad of other things. Daily we apply the process of research because daily we are concerned with the facts of life.

In a large degree, research is an attitude of mind, that attitude which prompts one eternally to be asking the question "Why?", which does not permit one to close his mind, which leads one to ascertain what other people are doing in other lines of work and adopting what is adaptable to his own work. It is that attitude which recognizes that nothing is static—that change is the law of the universe and he who would win must constantly be changing his methods of procedure.

There is needed a standardized classification of the types of research. Such classification might clarify the situation and remove some of the existing confusion. It would certainly contribute to a better understanding and appreciation of research. That there may be no confusion as to what is meant by research in this discussion, I shall, with some danger of being challenged, define research and three types thereof.

Research is an organized, diligent investigation to discover facts. There are three types of research, namely, fundamental or scientific, creative and applied. Other designating words might be used with as much logic. I prefer those selected. It is recognized that in this classification, as is the case with all classification systems, there are twilight zones between the types of research where lines of demarcation are indistinct.

Type I—Fundamental Research

The word "fundamental" means "of or pertaining to the foundation or basis." As a noun it means "a principal which serves as the ground work of a system." Therefore the primary objective of fundamental research is to discover the basic principles underlying the universe and the circumstances of life. The principles so formulated serve as the ground-work of a system. The work of the astronomers, some economists, sociologists, physicists, chemists, mathematicians, engineers, and others, fall within this type of research. They are not primarily interested in adding to the financial assets of the world, but rather their interest is to broaden intellectual horizons. This work is indispensable to the progress of mankind, for in order to utilize the resources of the universe we must understand the laws governing its elements.

Type II—Creative Research

The word "creative" means "having the power or quality of creating: originitive; productive." The primary objective of creative research, therefore, is to discover, invent or produce new materials, new processes, new equipment, or to find new uses for existing materials. This type of research is characterized by the work of some chemists, physicists, engineers and others, whose work is largely based upon the principles discovered by those engaged in fundamental research. The results of creative research express themselves in types of materials or substances as Dow metal, Bakelite, Duco, radio tubes, a variety of equipment and a myriad of other things.

In creative research the financial incentive plays a more important role than in the case of fundamental research. Creative research may be designated as producers' research, through which means producers are enabled to manufacture and sell new and improved commodities. Notwithstanding the financial incentive aspect of this type of research, there often flows from it a large measure of data which does directly contribute to an understanding of the basic principles underlying the universe and to the broadening of intellectual horizons.

Type III—Applied Research

The word "applied" means "to put to practical use; also sometimes, concerned with concrete problems rather than with fundamental principles." Therefore the primary objective of applied research is to determine ways and means of adapting to concrete problems the knowledge, materials, equipment and processes made available by fundamental and creative research. In other words, the primary objective is to determine what basic principles, new

materials, equipment and processes may be applied to the solution of concrete problems in order that increased efficiency and economy may be realized in daily operations. It is a process through which the user or purchaser intelligently selects the materials, processes and equipment best adaptable to his purposes and needs.

As far as the well-being of the human race is concerned this type of research is just as necessary, valuable and commendable as either of the other two types of research. They form a trilogy, to use a literary term. Between the three there is an unbroken two-way traffic. There is passed down from one to the other indispensable fuel which each independently uses as required. Likewise there is passed up from one to the other information as to the requirements of the human race which is constantly struggling with the mundane affairs of life. This interchange of information serves as a spur to workers in each type of research to strive to bring forth additional knowledge, materials and equipment. Each type of research is necessary for the advancement of the intellectual, social, spiritual and economic status of the human race.

The remainder of this discussion is based upon the foregoing understanding of the meaning, place and essentiality of fundamental, creative and applied research. You may emphasize either the first or the second syllable as you like. I hold that each type is necessary, there is no conflict between them and only by an appropriate and adequate coordination of the three as to concepts, procedures and utilization of findings will there follow the largest possible returns on the time, effort and money expended.

I hold that the process of research of whatever type and regardless of when, where or to what applied, is nothing more nor less than an organized diligent investigation to discover facts. The facts to be discovered may relate to the stars, fish, animals; habits of man, performance of locomotives, or to a myriad of other things. Daily most men, unwittingly in many cases, apply the process of research because daily they are concerned with the facts of life.

I hold that research is a type of production and as such should be planned, budgeted, scheduled and controlled. This has been and is being done. This is because research is no longer a one-man cloistered enterprise—instead it is big business. Today tens of thousands of men and women are employed and hundreds of millions of dollars are being expended annually in the business of research.

It is fortunate for this country that there is a large area of

wholesome and realistic attitude toward research. It is reassuring that there is a large section of American business and industry which regards research as an essential working tool—one indispensable to progress and security of position. It is stimulating to know that the number of laboratories and the number of people engaged in research is constantly increasing. It is in these things that a large measure of the strength of this country rests today and through which its economic security of tomorrow is to be assured.

While research presents all the potentialities indicated, it is not something which operates automatically. The measure of actual accomplishment will depend upon the intelligence and skill with which research activities are organized and directed.

On any scale, high-grade executive direction is essential. This is true because research, in a modern sense, is not an individualistic undertaking. The day has almost passed when a cloistered individual can hope to make real and timely progress. This does not mean there will not be individual accomplishments nor that there will be no occasions when the solution of some problem will largely depend upon the knowledge, skill and effort of some one person. However, such occasions do not predominate now, and the number will probably decrease in the future.

Research Organization Important

There are several pertinent reasons why individual effort is being replaced by an organization. One of these is the element of time. Frequently, if the results of research are to fulfill the specific need which gave rise to the project, the project should be completed in the shortest time possible consistent with sound and thorough work. If this is not done, the advantage to have been gained may be largely lost. Therefore, to guard against such an occurrence, an organization is used whereby more manpower and skills are focused upon the solution of the problem. This begets not only a quicker but a broader answer than an individual could obtain.

Another important reason for research organizations is the extending boundaries of the several disciplines and the increasing importance and appreciation of their relationships and reactions one upon the other. The vastness and importance of these factors are beyond the grasp and manipulation of an individual.

Not only has scientific knowledge become more extensive in scope, but it has become more intensive within a given field. The cumulative effect of an era of research and discovery has raised the level of knowledge in every branch of science. As one graduate has

expressed it, "A fellow has to have a tremendous amount of knowledge these days in order to be merely even with the board." Therefore, reliance must be placed upon the cooperative effect of specialized, intensive work in the various branches of science. This presupposes a definite organizational structure. It is not uncommon to find industrial research organizations with men trained in each of the disciplines of engineering, metallurgy, physics, chemistry, acoustics, photography and others.

Not to focus upon the solution of any problem the knowledge and skill of men trained in the disciplines involved is to run a great risk; a risk which may cause either a long delay or an unnecessarily large expenditure or both; a risk which may cause a loss of place in the market owing to some improved or cheaper product or material of equal or better merit supplanting the existing product or material. In the case of national defense, the risk may be the very life of the nation.

It is for such reasons that research organizations have largely replaced individual effort. As they increase in number, in size, in the number of people engaged, and in the amount of money spent annually, the managerial phases become more complex and pressing. The managerial phases involve organizational structure and procedures; personnel selection, training and compensation; research project selection, rating, planning, scheduling and budgeting; demarcation of the functions and responsibilities of the several sub-divisions of a company with respect to product development; and many related matters. All such phases have to be resolved into a practicable, coordinated organization and plan of action if the largest possible returns are to be realized.

There are at least two types of research teams. The one is that of a commercial or industrial company, the other that for institutional, professional, commercial or industrial groups.

In organizing a research agency team one is guided by the particular circumstances confronted. If the assignment is that of projecting a research department for a reasonably large company, there are many factors to consider, very similar to those present when organizing any type of business or industry, the major difference being, except for usual office and staff requirement, the type of equipment and the character and scope of the training and experience of the technical staff required. To decide upon the range of technical and scientific skills required is no easy task. It is my feeling that too frequently an error is made in employing people who are by training and experience too highly specialized. There

are times when the specialist, in the strictest sense, is needed, but not in the supervisory area of the organization, nor generally in the run-of-the-mill day-to-day procedures. When a specialist is needed, engage one in a consulting capacity.

Another type of research organization or research team is needed for such situations as confront institutional, professional, and commercial and industrial groups. Usually the type of problems such groups deal with vary a great deal as to scope and character. Today the character and scope of problems which will be confronted one year hence cannot be anticipated fully and adequately. Therefore, in such situations it is highly advisable and desirable to maintain a flexible condition as to the research personnel.

In such cases it is wise to have a small but a very competent permanent organization. The personnel should have such training, experience and vision as to be competent to select the research programs which should be undertaken in its field and to plan, schedule, budget and control each selected program. Moreover, it should be so versed in the availability of the necessary facilities and personnel required as to be able to locate and contract for the facilities and personnel services needed for the particular program. When the program is completed the facilities and personnel will be released as per previous arrangements and agreements.

The advantages of such an arrangement are these:

- (1) Facilities—reduces the cost by not having to purchase equipment which may not be needed frequently or even again.
- (2) Keeps to the minimum the number of people on the permanent payroll. Moreover, it has a greater advantage and that is the opportunity of engaging the best qualified person for a given assignment. This permits employing a specialist when needed rather than carrying him on the payroll for periods when his special knowledge and skill is not utilized to the best advantage.

In organizing a research team such concepts, conditions and objectives as have been discussed require careful consideration, not only as to the importance to be given each, in a given case, but just as important and in some cases of major importance, their respective relationships. It is my feeling that a great many serious mistakes have been made because inadequate consideration has been given to relationships and inter-relationships and, therefore, of their influence upon organizational structures, policies and practices.

4: COORDINATION OF RESEARCH, DEVELOPMENT AND INVENTION

FRANK A. HOWARD

My assignment is to discuss the coordination of research, development and invention. I should like to start by quoting the definition of industrial research which I used in the 1945 forum on "The Future of Industrial Research," which was arranged by my own company, Standard Oil Development, to celebrate its twenty-fifth anniversary. This definition is:

"New industries, and the advancement of old industries, depend first of all on increase in the sum of human knowledge—and that, of course, is the function of scientific research. But they depend even more on the new application of existing knowledge—and that is development. The amount of scientific knowledge already available which ought to be applied to an industry, and has not yet been applied, is almost always far greater than the new contributions to human knowledge which any industrial research organization can hope to make. Quantitatively, therefore, industrial research work is mainly development work and it is now common to refer to it as 'research and development.'

"The third component of industrial research is the unpredictable one, invention. By invention, new concepts seem to appear suddenly on the earth, or, more commonly, new applications of existing knowledge seem to spring into existence. But the record shows that in an environment of organized research and development effort, the inventive mind reaches a level of productiveness beyond all past experience.

"These three—scientific research, development and invention—are the components of technical progress in industry. It is the function of industrial research to harness the three components in a sustained common effort, and to keep the effort headed in the right direction."¹

The practical question, of course, is how best to harness these three components into an efficient team which will pull together, and always in the direction which leads toward advancement of the company's interests. This involves not only the relations within

¹*The Future of Industrial Research.* (New York: Standard Oil Development Co., 1945.), pp. 3-4.

the group specially charged with research, development and invention, but also their relations to the business as a whole.

I think it is helpful to start with this latter point first. Industrial research laboratories or research departments have had a very confused history in their relation to the other branches of an industry. Often they were an outgrowth of chemical laboratories maintained for product control purposes or for inspection of purchased materials. These laboratories were, of necessity, under the general manager of manufacturing, and usually stayed there when they took on research functions. Only a few particularly strong leaders of industrial research in the early days managed to achieve an independent status for their laboratories. The function which we now call "development" is historically an outgrowth of the experimental department, or inventions department, also an appendage of manufacturing. The patent department sometimes started under the wing of an inventor-executive-promoter of the Edison type, and sometimes under the wing of the corporation legal department. A few of the oldest and best organized patent departments both in Europe and in the United States had become almost completely independent of all control save that of the chief executive of their companies before internal patent departments achieved any wide acceptance in industry at large.

With such varied origins and historical growth, it was not to be expected that the three functions, research, development and invention, would be easily harnessed together into a single team. Opinions on organization varied quite widely, but up to the end of the First World War, I think the dominant opinion was that the research laboratory ought to be as independent as possible, the experimental or development department ought to be a branch of manufacturing, and the patent department a branch of the law department. This does not look like a very good start for close teamwork and the fact was that the most effective teamwork was the exception, not the rule. The situation could be described fairly accurately in the words of Dr. Westbrook Steele, Director of The Institute of Paper Chemistry. "The example of research accomplishments attendant to the prosecution of World War I lead to a condition that might well be classified as research worship rather than an understanding of research."

In approaching the question of organization, I have found it very helpful to start by trying to divide industrial organizations according to the general pattern of the oldest of all organized industries—which is, unhappily, war. To conduct a war, an army

has to consist of two groups—the line organization and the staff organization. Similarly all industrial operations really break down into the conduct of the day-to-day business of manufacturing and selling on the one hand, and on the other hand a variety of staff operations which do not form a part of the day-to-day business but are used to support, plan and guide the day-to-day operations. A battle can be won without a staff and an industrial company can survive and even grow for a time without a staff, but in both instances the success is apt to be very short-lived.

The analogy to military organization is not too close and every different type of industry has its own special collection of line and staff branches. For our purpose I think the staff branches can be divided into two categories—the technical staff branches and the non-technical staff branches. An example of the non-technical branch is finance and law. Examples of the technical staff functions are general engineering (as distinguished from plant maintenance engineering), research, and development. A staff activity, which has one foot in the non-technical group and one foot in the technical group, is the patent department.

What is the function of this group of technical staff activities? The first definition is negative. It is not their function to manufacture or sell products. The positive definition is that it is their function to apply science and invention to the improvement of products, to the improvement of plants and methods of production, and to the development of new branches of the industry in question.

Perhaps it would be well at this point to make it perfectly clear that these technical staff departments have no monopoly of scientific or engineering or inventive brains. The line departments of manufacturing and sales require for their day-to-day operations and for the planning of those operations on the basis of existing knowledge, large and competent staffs of men trained in various branches of applied science, and they always breed inventors also. Like the technical staff organizations they are intent upon improving products, methods and equipment in every possible way. The difference is simply that the technical staff organization has the primary responsibility for making investigations and efforts, in the laboratory, in the pilot plant, and at the designers' desks, for advancing the industry technically, whereas the line organization has a different primary responsibility, which is that of conducting the operations of manufacture and sales in the current technical pattern most effectively.

No one has ever questioned the fact that the various branches of the line organization need effective common control. In a small industry, the only common control may be in the chief executive himself, or it may be in a general manager. Quality or type of product to be produced, quantity to be produced, methods and cost of production and sales to the available market, all these threads must eventually wind up in a single guiding hand, if current operations are to be adequately planned and efficiently carried out.

Let us now turn back to industrial research. If its work is to advance the business, it must be because the final result is a new or better product, or a new or better method of making or using the product. Finally the new product, or method, or machine must be one which can be made, sold and used without infringement of others' patents, or under a reasonable license, if a license is necessary. If at all possible, it should be covered by a patent owned by the company. In the average case, this complete function—and it is only the completed act which counts—involves the constant interplay and cooperation of laboratory research, experimental or pilot fabricating or processing operations, design of new production plants or producing equipment, market studies, and adjustment of all of these to the realities of a complicated patent picture. I don't think it is necessary to labor the point further.

Theoretically there may be many ways of accomplishing coordination of departmental responsibilities. The simplest and most direct of all ways is to put them under a single executive. No one really disputes this, the only difference is the point in the organization at which complementary departmental lines converge into one pair of hands. That obviously depends on the size and complexity of the business and upon the executive personnel. All the lines can converge only at the level of the chief executive, or they can converge in a vice president who is in effect the general manager of all line operations and of all staff operations directly connected with present or future production and sales. A third possibility, which has worked very well both in large and middle-sized companies, is to bring all the lines of the staff technical functions together in the hands of a single executive who may be called Technical or Engineering or Scientific Manager or Director. The organization concept seems quite simple and clear, and it does work. If the industry in question is a mass production chemical or mechanical industry, the leader of all the technical groups is

quite apt to be an engineer. In a pharmaceutical or fine chemical industry, he will probably be a chemist.

I am well aware that such a plan of organization is not by any means universally accepted, nor can it be contended that it is the only effective plan, or the best one in all cases. It happens to be the one which has been very widely followed in the oil industry, and to a lesser extent in the chemical industry in general, although there are exceptions.

Questions can properly be raised at every point on this matter. There are many successful research leaders who adhere to the theory that a research laboratory must maintain its independence at all costs and that more is lost than can possibly be gained by making it a division of a larger group of technical organizations. The plan of including the general engineering department, or its equivalent, along with research and development in a technical group under a single chief executive is also unacceptable to many very good organizations. The organization status of the patent department seems never to be settled to the satisfaction of everyone.

In reviewing this problem, I think it would be helpful perhaps to state the general reasons in favor of grouping all staff technical organizations together under a single general executive.

1. Fundamentally the reason is to promote teamwork among them. In the vast majority of cases, each is dependent upon the help of all of the others to make profitable application of science in a new way to the industry in question. Each educates the other on what is needed, on what is possible, and on what is practicable.

2. The technically trained personnel of all these groups is interchangeable to a very large extent. The work load can be shifted back and forth from one of these groups to another to a surprisingly large extent to meet shifting demands for greatly expanded technical effort in some particular phase.

3. Salary scales and classifications should be kept closely in line for all of these technical groups, in fairness to all and to promote good morale.

4. All of these groups need the same type of library service and technical information or intelligence service.

5. The promotion line can logically lead upward from any one of these groups to the top of the entire pyramid of technical staff organizations. This is not only theory, it is practice.

The patent department is admittedly one of the most difficult to straighten out from an organization standpoint to get the best teamwork. To test for its best position, perhaps one can analyze

its relation to the research and development departments and the legal department. There are large areas of joint operating responsibility which are necessarily shared by an industrial patent department with these other departments. The principal joint operating responsibilities which are shared by the patent department and the research and development departments are:

1. Planning of research to fill in weak spots in the company's patent position.

2. Educating technical personnel to become patent conscious so they will recognize the possibilities of patent protection based on the results of inventive thinking as well as on the results of experiments. One good inventive scientific imagination can sometimes equal a whole research section in effectiveness, so far as the company's patent position in a new competitive area is concerned.

3. Maintenance of a technical record system adequate for providing date of conception, diligence and reduction to practice of inventions.

4. Planning of laboratory tests and factual and expert testimony.

5. The building up and the maintenance of the scientific and patent library and the maintenance of a staff capable of making reliable searches and reports in this library and, where necessary, in other libraries. Legal opinions on patentability, scope, validity, and infringement are in fact nothing more than conclusions drawn from technical reports on "state of the art" as shown by such searches.

6. If the size of the organization justifies the expense, the library staff may also get out and circulate to the technical and patent personnel a Technical Digest, which will summarize all current patents, scientific articles, and trade news of technical interest.

There are five groups of employees who divide these joint responsibilities of the research and development departments and the patent department among themselves. The groups are: the research and development organizations proper, the patent liaison men in these organizations, the scientific and patent library staff, the patent solicitors, and the patent lawyers. These five groups have overlapping responsibilities and largely interchangeable personnel, and the work load among them can be shifted to a considerable extent without loss of efficiency.

The patent department also has a smaller but very important clearly defined area of responsibility which it shares with both the

legal department and the research and development departments. This area is made up of two principal subdivisions: patent litigation and patent negotiations and contracts. A typical question in this area is whether to take a license from an outsider on some new development which the company wishes to exploit, or to try to develop an independent non-infringing operation. The problem must first be studied as a joint project of the patent and research and development groups, and their joint conclusions reviewed by the legal department before any recommendation can be made to the chief executive of the company.

Another typical three-way problem is the negotiation of a patent contract which covers also know-how or experience and future improvements. Here the patent considerations become inextricably mixed with the technical effort and obligations of the technical staff, and this creates another joint project of the research, development and patent groups, which must be reviewed by the legal department.

Another important area of joint responsibility which the patent department must share with other departments is made up of two phases: foreign patents and outside licensing of established commercial processes. The first phase is an annual expense item which may be large, the justification and value of which cannot be determined by the patent department itself or by the research or development groups. The licensing of established commercial processes primarily for revenue can be an important income item. If kept in the patent department it may loom so large financially as to dominate the activities of the patent department.

Because of these extensive and important joint operating responsibilities which the patent department shares with other departments, there is considerable difference of opinion as to the best organizational setup. There are three general plans:

1. An independent patent department responsible directly to the chief executive of the company.
2. A patent department forming a division of the legal department.
3. Where the research and development departments are combined under one management, the patent department may form a third coordinate division of this group.

It is a basic principle of corporate organization to avoid large areas of joint and overlapping responsibilities, and large organizations only develop and succeed because they find means to divide responsibility, authority, and personnel along lines which do not

tangle too much. There must be some effective common executive control wherever overlap exists, and current operating problems of this kind cannot be placed on the chief executive of the corporation. In the case of the patent department problem, there is no way of eliminating some important joint and overlapping responsibilities with other departments. It is, however, clear that the largest area of overlap is with the research and development staffs, and that this is also the area in which personnel and work load are interchangeable to the maximum extent. This situation, therefore, may logically be considered the dominant one in the final decision on the organization position of the patent department, and it is difficult to escape the conclusion that where the major scientific and technical staff groups of a business have been placed under a single executive officer, either for administration or for "contact," the patent department should also be here.

There is one more aspect of the teamwork problem, which is not covered by departmental organization alone but which can be provided for, to a very useful degree, by the expedient of technical meetings. To be most effective, such meetings should be very well organized following the lines of a good professional society meeting, with a general chairman and sub-chairmen for various branches of the program. Every phase of the current program of research and development should be covered at such meetings as soon as it is possible and wise (considering patent or competitive considerations) to make a progress report. As in the case of any well-arranged scientific meeting, the papers, or summaries of them, should be supplied in advance to the maximum extent possible, and each paper should be assigned to one or more members of the staff for study and criticism at the meeting; in other words, there should be a discussion leader for each paper. Programs of this kind carried out once or twice each year have been found to be a very effective method of educating the entire organization, not only the major divisions of the technical staff itself, but also the technical organizations forming a part of the manufacturing and sales groups. This is their opportunity to see the work and thinking of the research, development and engineering groups. This is their opportunity to present their own problems and views. A very large share of the productive technical projects and programs of the company will be found to arise quite directly out of these meetings, and the opening of new vistas which they bring about. They are also of the greatest use for the patent organization in giving its leaders a coordinated view of the entire technical picture

of the company. For the general leader or leaders of the technical programs as a whole, and for general executives of the company who can find time to attend such meetings, the picture of the competitive status of the company in science and technology which results from the discussions at such a meeting is invaluable.

Finally there is one last common expedient for promoting teamwork in major development projects. This is the organization of a special team to take jurisdiction over all work—research, development, engineering and patents—connected with a development which has gone far enough and which is important enough to justify such treatment. Revolutionary advances in old industries, such as the fluid catalytic cracking process for oil, and brand new industries, such as that of producing Butyl rubber from petroleum, can usually be handled only by formal teamwork set up especially for this purpose.

Recapitulating, my own picture on the coordination of research, development and invention to get the best teamwork to promote the technical progress of an industrial company is about as follows:

1. The research laboratory, the development department, and the patent department are essentially central staff organizations, having no responsibility for day-to-day operations of manufacturing or sales. The general engineering department, if such an organization exists, is of the same type.

2. These staff groups have no monopoly of the ideas or work which will result in technical progress since technical organizations which necessarily form a part of manufacturing and sales are indispensable and will be an important source of technical progress.

3. For large organizations, all of the technical staffs, that is, research, development, patents and engineering, can very effectively be grouped under a single technical executive. This may be a centralized type of organization with a rather complete headquarters staff reporting directly to the executive in charge, or it can be a decentralized type of organization where the executive in charge is mainly a contact officer with little or no organization of his own.

4. A detailed examination of the overlapping functions between the patent department and research and development shows the necessity for coordination and the opportunity for teamwork.

5. Interchange of information between the central staff organization and the line technical groups attached to manufacturing and sales is the best breeder of teamwork in the company as a whole. Regular formal technical meetings, in which all of the senior men participate all the time and the junior men on a

rotation basis, is a tried and effective plan for getting this interchange of information and ideas, and it is found that a large part of the productive work of the technical staff organization arises out of such meetings.

6. For major development projects, a special team setup, cutting across all departmental lines, to make up a team of scientists, engineers and patent attorneys, is a direct means of bringing every resource of the organization into the attack on the major development problem.

5: ORGANIZED UNIVERSITY RESEARCH

ALBERT F. DAGGETT

I have been asked by Dr. Hattery to prepare for you a case history covering the development of a modest sponsored research program in an educational institution. It has been my thought in preparing this material to outline the various practices and principles that have been followed in this development. Perhaps this material will be helpful to others, at least to the extent of acquainting them with some of the problems with which a small university must contend. The "team" concept in this presentation is the total scientific personnel for teaching and research. This dualistic concept we consider essential since "education" is our prime objective to which our research is always related.

Before turning to the material in point, it might be well to consider for a moment a few fundamental questions, such as: "Why should educational institutions be interested in sponsored research?" "Is it important to the welfare of the country that the colleges and universities carry on such work?"

In almost every discussion of research it is pointed out that the colleges and universities have been in the past and continue to be the prime movers in the field of basic research. My definition of "basic research," as used here is that which I recently heard Dr. Waterman¹ use—"basic research" is that for which applications are irrelevant." It is not my purpose in this paper to attempt to support the thesis of the importance of the colleges and universities in basic research, but as partial evidence of the fact I would like to refer to an address² given by Dr. Charles A. Kraus of Brown University at the time he was presented with the Priestley medal by the American Chemical Society. In his discussion of research in academic institutions, Dr. Kraus made it clear that he was referring to basic research. He confined his attention to the sources of basic research papers appearing in the *Journal* of the American Chemical Society during the year 1949 and during the first half of the year 1950. His data, which apply to chemical research, are admittedly incomplete so far as over-all academic research is con-

¹Alan Tower Waterman.

²Published in *Chemical and Engineering News*, Vol. 28, No. 38, page 3203 (1950).

cerned, but they are probably indicative to a considerable degree of academic research activity as compared with that of industrial and governmental laboratories.

His study revealed that out of the 1086 papers published in the *Journal* during 1949, 694 or 64.0% were from academic laboratories, 203 or 18.6% were from industrial laboratories, 94 or 8.7% were from governmental laboratories, with 95 papers or 8.7% from other sources including those foreign. It is of further interest to note the origins of the papers contributed by academic institutions. Of the 694 papers from academic institutions, 396 or 56% came from 44 publicly controlled institutions, and 308 or 44% came from 54 privately controlled institutions. Of even greater significance it should be noted that four institutions supplied 25% of the papers, 12 supplied 50%, 28 supplied 75%, and the remaining 25% was supplied by 70 institutions. From these data Dr. Kraus concludes that, "it is apparent that in this country, research is concentrated in a comparatively small number of institutions. Publicly controlled institutions are more active in research than are privately controlled colleges and universities, and that the concentration of research in a small number of institutions reflects a similar concentration of graduate students in the same institutions."

From the above facts and in the light of the great need for scientific manpower by our country, it would appear that it is high time that attention is given to the matter of broadening the basis of academic research activity. I believe that the prime reason for this fact of so few academic institutions being involved in research is that of their limited income and facilities for research. The personnel in many small institutions is highly qualified to carry on such research but under the conditions of heavy teaching loads, limited funds and facilities, they simply cannot do it. Additional opportunities for research could do much toward activating the scholarly interests of college faculties and would result in an enhancement of the quality of both under-graduate and graduate teaching. It appears to me that sponsored research support from government and industry could do much to stimulate and broaden interests in basic research in this country and at the same time get important research done to the mutual advantage of both the sponsors and the educational institutions.

As the need for sponsored research developed in this country, it was quite natural for sponsors to turn at first to the larger educational institutions with their research personnel and facilities.

This was most certainly what happened. Almost all of the support of basic research by government and industry was lodged in the larger institutions. Little or no account was taken of the smaller educational institutions as also being repositories of trained scientific personnel. It was only after the larger institutions became more or less saturated with respect to their capacity to absorb sponsored research that sponsors began to give attention to the resources of the smaller institutions. An important exception to this situation should be noted in the program initiated in 1945 by the Research Corporation of New York by which it encouraged research and the development of scientific personnel by distributing research grants for special purposes among the smaller institutions. With the present great need for additional trained scientific personnel and for more basic research, smaller institutions are now being included to a much greater degree in the sponsored research programs of government and industry.

Since my story concerns the development of a sponsored research program at a small university, as background let me describe briefly the nature of my own institution. The University of New Hampshire is a Land-Grant institution of approximately 3200 students. Owing to an established millage tax program the University receives a stable if not bounteous income. The University has the traditional educational and research divisions: the three undergraduate colleges of Agriculture, Liberal Arts, and Technology; a graduate school with approximately 200 students in residence, an extension division, and the Agricultural and Engineering Experiment Stations.

For many years research has been an important activity of the University in the physical and natural sciences, the social studies, the humanities, and engineering, particularly in connection with the graduate program and also in connection with the experiment stations. Up to the present time graduate activity has been limited to work at the master's degree level.

The purposes of the University are, of course, to educate men and women and to advance knowledge through research. Research is regarded as an essential and important part of the University program. It is regarded not only as being important in its own right but for the reason of its contributions to the graduate and undergraduate programs and for its influence in helping to maintain a professionally alert and active faculty. With the limited potential of state support for such activities, it was, of course, natural that the University should seek to promote and develop research

through attracting outside university sponsors. In its program, which will be outlined below, the University has sought to find support for all of its fields, but, of course, the majority of the opportunities have been found in the sciences and in engineering.

In 1949, a Council for Sponsored Research was established and a Coordinator of Research appointed. These agents of the University have as their duties the determination of policies to be followed in the handling of sponsored research projects and to assist faculty members in finding research projects and to assist faculty members in finding research support from outside of the University in the form of research contracts, research grants, and fellowship aid for graduate students.

The Council, appointed by the President, consists of five faculty members representing the fields of biological sciences, physical sciences, humanities and social sciences, agriculture, and engineering, with the President, the Coordinator of Research, and the Treasurer of the University as members *ex officio*.

The Coordinator of Research appointed by the President is charged with the responsibility for carrying out the policies and procedures of the Council.

In considering research proposals the Council has recognized certain criteria that must be satisfied before its approval of them is given. Some of these are: a) the research must be of a type that is closely integrated with the educational objectives of the University. This means that generally the project must be basic in nature. Projects of a strictly applied type are not encouraged. Likewise classified projects are not encouraged. It is recognized, however, that the responsibility of the University to the national welfare and to the people of the State is such that there may be occasions when exceptions to this should be permitted; b) that generally such projects should be initiated by a member of the faculty with a special interest in the research; c) that negotiations concerning the technical phases of the proposed research should be carried on directly between the scientist and the technical personnel of the sponsor, and d) that negotiations concerning the budgetary phases of a contract should be handled by the Coordinator of Research.

The mechanics followed for the preparation of a research proposal are as follows: After the preparation of the technical phases of the proposal, the scientist in collaboration with his department chairman, his college dean and the Coordinator establishes the budgetary and personnel aspects of his proposal, including such

direct charges as salaries and wages of all participants corresponding to the degree of their participation in the project, capital expenditures, supplies, travel, et cetera, and usually an overhead charge, although the inclusion of an overhead charge is actually subject to the classification of the project by the Council and may also be subject to negotiation. With respect to the participation of faculty members in such projects, an unwritten rule is followed that generally the degree of participation shall not exceed one-fourth of the load of the faculty member. This is in line with the view that for the best interests of the University, the faculty member should be involved not only in research but also in undergraduate and graduate teaching. I refer here only to the teaching part of the University and not to the experiment stations where, of course, staff members may be employed exclusively in research.

For the purpose of determining overhead charges, the Council classifies projects as follows: Class I projects which are mainly for the benefit of an outside sponsor and which have little relation to the research programs already established at the University—these are subject to overhead charges; Class II projects which are in harmony with University research objectives but which normally would not be undertaken by the University—these may or may not be subject to overhead charges; Class III projects which are supplemental to established University research programs and which provide funds for unrestricted fellowships and other desirable expenditures—these are generally not subject to overhead charges.

Every contract for sponsored research must include statements regarding: 1) the disposition of any patents or copyrights which may result from the work; 2) the requirement of progress reports. It is understood that all progress reports shall be held as confidential and shall not be published; however, public announcements of progress may be made by mutual agreement between the sponsor and the project director, and 3) the publication of the results of the research. The general policy is for the University to reserve the right to publish the results of the research, but this right may be waived in certain cases.

After the proposal has been prepared as noted above and has received the approval of the University Treasurer and the Coordinator, it is forwarded to the sponsor through the Office of the Coordinator. All negotiations with the sponsor concerning the budgetary aspects of the proposal are handled by the Coordinator. The contracts are signed by the University Treasurer.

A matter closely related to the research activities of the Uni-

versity is that of the handling of patents and copyrights. The University has established a policy concerning patents and copyrights which is administered by a faculty committee of three members. The guiding principle of the policy may be briefly stated as follows: The promotion of research and scholarly writing is an essential function of the University. In order to foster such activities, the University shall maintain a policy in the handling of patents and copyrights which is as favorable as possible to the rights of the individual inventor or author.

For purposes of classification the University recognizes that patents and copyrights fall into three categories: 1) those that result from projects sponsored by agencies from outside the University—an invention or publication that results from such a project shall be the property of the sponsoring agency or the University as determined by the contract agreement; 2) those that result from projects sponsored by the University and for which an individual is employed specifically to devote all or a specified portion of his time—such an invention or publication shall be the property of the University; 3) those that result from activities carried out by an individual on his own initiative and for which he is not explicitly employed by the University—such an invention or publication shall be the property of the individual inventor or author.

For the patenting and exploitation of inventions which are the property of the University, the University shall, in general, make use of its agreement with the Research Corporation of New York.

When an invention or publication is not the property of the University, the individual inventor or author may make any arrangements for its exploitation that he wishes. If requested to do so, however, the University may assist the individual to obtain a patent by making available to the inventor its agreement with the Research Corporation of New York without financial obligation to the University.

Generally speaking, the policies outlined above have appeared to work out satisfactorily. During the past year sponsored projects have been in operation with the Office of Naval Research, the Naval Bureau of Ordnance, the Atomic Energy Commission, the Air Force Cambridge Research Center, the United States Public Health Service, the Research Corporation and with several industrial concerns. The total amount of research of this type in operation at the present time is approximately \$120,000.

Even though our concern here is primarily with research in the

physical sciences, the biological sciences and engineering, I would be remiss if I failed to mention the increasing need by universities for research support in the fields of the social studies and the humanities. With the development of these many research opportunities in the sciences and engineering, I sense a certain wistfulness on the part of faculty members in the social studies and humanities as they see their colleagues expanding their research activities, for a balanced educational institution research activity must be encouraged here as well.

In conclusion I wish to say that the University has sought to avoid certain evils that might accompany the development of a sponsored research program by holding to the criterion that for acceptance the research must be closely integrated with the educational objectives of the University. Our experience, to date, in the field of sponsored research leads us to regard it very highly as a valuable adjunct and supplement to the normal activities of the University. It has contributed much to the scholarly activities of our faculty, it has broadened our graduate opportunities in research and has contributed much in the form of fellowships and research assistantships for graduate students. It has made possible the expansion of our facilities for carrying on research, particularly through its having made available certain specialized and expensive pieces of equipment that otherwise would have been beyond our means. We believe we have developed a stronger University-wide scientific team which has helped greatly to permit the University to fulfill its objectives in the training of scientists and engineers who are now so vital to our national needs.

6: SPONSORING ORGANIZED UNIVERSITY RESEARCH

RALPH G. MEADER

The words "organization" and "administration" do not always have happy and respected connotations in the minds of investigators. Organizing and administering scientific research implies that there is something to be organized and administered. Actually, it implies planning and carrying out the selection of appropriate personnel, the selection and formulation of research to be done by the personnel, the selection of the methods to be used, the provision of physical and technical facilities necessary for the problem and the personnel concerned, the interpretation of the data obtained and the publication of new contributions to knowledge. Obviously, the most important of these ingredients is the selection of the appropriate personnel for if you have good investigators, they will have good ideas for research and know or develop adequate and appropriate methods.

When research is carried out by a single investigator with his own hands, the organizing and administering are relatively simple. Even though he may be harassed by difficulties in the selection of his problem, finding or developing methods adequate to attack it and securing facilities necessary to apply the methods, he is likely to be a relatively happy person.

When research problems become too complex or too extensive for one man to handle alone and other brains, hands, and skills must be called upon, the problems of organization and administration become correspondingly complex, chiefly because of the personalities involved. The productivity of a research team then is likely to be directly proportional to the happiness and sense of personal responsibility and recognition of the individual's participation in the total effort. The achievement of a congenial atmosphere of cooperation in which each member of the team identifies himself as a significant and important contributor to the final, successful completion of the work is, I believe, one of the greatest factors in creating a productive team.

I shall not attempt to tell you how to accomplish this, for, to a great extent, it is a matter of personal attributes of the leader

of the team or group. I am sure some of them are capable of being defined, but many of them are difficult, if not impossible, to describe in other than vague terms. The essence of them can be expressed as an understanding consideration of human nature and of the needs of the individual. There must be included, however, a capacity for broad scientific judgment and knowledge, which will command the respect as well as the loyal cooperation of the members of a team. It is because of shortcomings in some of these qualities of leadership among those charged with organizing and administering research that the very suggestion of a scientific administrator is anathema to many capable investigators. They will have none of organized team research. This ties in with Professor Daggett's comments about the difficulties of crossing the disciplines, the lines of the departments.

And yet the development of special knowledge and techniques in almost every field of science has almost forced specialists to collaborate in order to solve the problems to which they have set themselves. The real scientist is an individualist. He may subordinate his ideas and dreams to those of others for a time. He may be, and often is, willing to forego monetary rewards to do what he wants to do, but he must be able to achieve in the end a sense of self-respect through the expression and acceptance of some of his ideas. This can never be long denied if he is to contribute fruitfully to any cooperative effort.

The word "contractor" as used in research support carries an implication of something being bought. In connection with research supported by the government, it suggests that some part of the government wants research done on a particular problem or in a field, so a search is made to find some competent scientist to do that job. This is what many call "bought" research. If the price is high enough, some laboratory workers will drop the work of their own interest and undertake the new problem. For others this must be spiced with patriotism to make it attractive. In many cases there must be considerable inducement to get a good scientist to give up work on his own ideas and turn to work that he is requested to do. The most ideal circumstance for contract research, of course, is for a scientist to be offered such rewards for carrying out his *own* ideas in his own way.

Turning to the program of support for research which the Public Health Service has been engaged in for a number of years, I should point out that we think of it as "sponsoring" or aiding research, not as "contracting" for it. I would like to call attention

to the article on medical research and medical education which appeared in a recent issue of *Science*.¹ This is a description of the "Education" in *Science*, November 16, 1951, Vol. 114, No. 2968, pp. 517-21.

Public Health Service philosophy and program in the support of research in fields related to medical problems. When you talk about medical problems, of course, there are fuzzy areas of definition, because it is almost impossible to pick out a program of research, fundamental research, which may not have some implications for application to health problems.

I should like to pose some of the problems that face an agency like the Public Health Service when it is charged with the administration of a limited sum of money annually for specific purposes in the utilization of national scientific resources. The question is immediately posed as to the best method of discharging that responsibility. Experience of the past has shown that most methods have their good points and their advocates as well as their inadequacies and their critics or opponents. One method, of course, is to establish institutes, like the Rockefeller Institute, or the National Institutes of Health, which, though local in geography, have a national and international influence in the products of their research staffs and the training of new investigators.

Another method is to distribute all or part of the funds, directly or indirectly, to institutions that will use them for the purpose intended. If allocated directly or indirectly, should they go to all institutions equally or in some definite proportion to aid their research staffs to accomplish more than the limited resources of the institutions themselves will allow? Should such sums be used without specification as to the particular uses of the money within broad purposes, leaving to the wisdom of the individual institution the final decisions as to how the money will be used? Or should these funds be allocated by a central, national, representative group to particular institutions to aid the work of particular investigators on particular projects? If funds are allocated to institutions for local decision of the specific uses of these funds should there be any discrimination as to the institutions eligible to receive such sums? Should all institutions of higher learning and research be eligible or should there be restrictive rules of eligibility? Should such rules favor only the institutions where research is now being actively conducted, that is, those who "have," so to speak, because an active research program almost always denotes those already receiving generous, although probably in-

¹Leonard A. Scheele and W. H. Sebrell, "Medical Research and Medical

sufficient support. Or should they favor the institutions that would like to foster and develop a research program but "have not" one for lack of aid to begin? It is often argued with both sentiment and some logic that one of the greatest unexploited sources of research potential lies in institutions where young minds are being taught but where little or no active research goes on at present.

As an alternative to the granting of funds to an institution by some formula or another with the decision as to uses of those funds left to the institution, there is the method of allocation of funds to particular institutions for particular investigators and for particular projects. If that is done, such allocation must rest largely on subjective evaluation of the significance of the problem, the adequacy of the proposed techniques, the ability of the investigator or the team to carry out the work properly and the relation of the funds requested to the amount actually believed by experienced men to be needed to accomplish the job.

I might point out that the Public Health Service, in discharging the responsibility laid upon it by Congress for support of research in medical fields, has adopted all of these methods of allocation of funds. It has established the National Institutes of Health for research work in its own laboratories by government employees. It has made funds available to institutions in lump sums, not so much for research as for other aspects of medical and scientific training. For example, the National Cancer Institute, the National Heart Institute, and the National Institute of Mental Health make grants to the medical schools primarily and to some other institutions for improvement in the teaching of cancer, cardiovascular disease, or of mental health.

These grants for improved teaching of cancer are given without specification as to how they shall be used. There are many reasons for this. One of the most obvious is that no one knows how best to improve the teaching of cancer. The second is that every institution will have its own problems and it would be impossible to set up any absolute scales which they would have to achieve. Thirdly, money probably would not be accepted and if it were accepted it would probably not be used according to orders given from Washington—there would be a considerable reaction to any attempt to dictate how teaching should be done. The most important consideration is the feeling that each institution can best develop its own teaching methods and improvement.

However, such a policy has not yet been applied in the field of

research grants, although some thought is given to it and some of the grants that are made approach that which leaves with the institution a great deal of responsibility. Some investigators and many administrators object to project-type research grants with applications that specify objective, methods, budget and the usual details requested by the conscientious scientists who review them. It is often stated that these requirements so restrict the freedom of the investigator or the investigator's team that they may stultify, if not destroy, the very purpose for which the funds were intended, that is, to aid and promote better research. These restrictions, they feel, also fail to provide for the exploratory type of study which is sometimes called "wild-catting" or "playing hunches," because sufficient justification of such studies on the usual project basis is difficult, if not impossible, to satisfy critical reviewers.

It is further argued that even when projects can be sufficiently specified to win a grant, the implied obligation to pursue the problem as outlined may prevent the investigator from following other promising leads that develop. Scientific research is said to be at its best when the imaginative investigator is free to follow the search for truth wherever it may lead without obligation to a previously stated project, plan and budget. There seems to be no agreement, however, as to how this freedom can be achieved, while at the same time satisfying the desire to scientists and others, who are taxpayers and donors to the national fund-raising organizations, to be assured that the funds they provide are allocated where they will be most effective and in such manner that they will be available to help unproven investigators as well as those who are better known. The established investigator suggests that he be given what he considers to be sufficient money and a free rein. The institutional administrator suggests that he be the arbiter of what constitutes good research in his institution and how the funds shall be allocated. Unfortunately, neither is free from the criticism of his associates who may not have the same unbounded confidence in his wisdom and ability.

I would like to list just a few of the questions that confront those who are charged with the allocation and administration of funds for research. Then I should like to indicate how the Public Health Service has attempted to meet some of these problems.

How much assurance of continued support is necessary to give stability to the research of an investigator or of a team of investigators? How long should such an investigator or team be given support if funds are insufficient to grant all requests? Unless funds

for expansion are made available, how do new applicants obtain support if previous grantees continue their work at a level where the need is as great as or greater than the original grant and they must have promise of continued support? Should new applicants have to wait for their support until the death of an investigator or some other cataclysmic event brings a supported research program to an end? Or should the new proposals be allowed to compete at regular intervals with those previously approved, in order to determine which should receive future support? How can success in such competition be measured? Are there any objective criteria? Should the productivity of an investigator or a research group be assessed to insure that the money is wisely used? If so, how is it done? What criteria are employed? Should public funds for grants-in-aid of research be used to pay the salaries of professional scientists in view of all the uncertainties that may affect the continuation of such support? If so, is it necessary to safeguard such grants from being used to take over the responsibilities of an institution for the salaries of its regular personnel? Should there be any limitation on the amount and type of equipment allowed as a charge against a grant? Should travel funds be allowed? If so, for what purposes—to attend scientific meetings in this country or abroad, to visit other laboratories, to learn new techniques or exchange ideas, or collaborate on research? Is the purpose of national grant-in-aid funds primarily the short-term approach of securing the greatest amount of the products of research in the shortest period of time? Or is it the long-term approach of developing research potential, especially in geographical regions or in institutions where less research has been done? Should research grant funds be made available for a special problem such as cancer and be allocated according to some strict definition of what is cancer, or should they support research in problems of normal and atypical growth, broadly defined? Should research support be limited to so-called “fundamental studies,” or “basic research,” in contrast to what some call “applied studies”? What sort of division of funds should there be between those two categories, provided you can define them? How much of the indirect cost of research should be charged against the grant as overhead, and how much borne by the recipient institution? Are these grant funds to be thought of as buying research results or as helping an institution to do what its own funds are inadequate to do in providing for the research interests of its staff scientists?

These questions and many variations have led the National In-

stitutes of Health to issue a statement of policy.² The purpose of the Public Health Service research grants is to facilitate progress in research in the fields of health by helping scientists to do work they cannot do otherwise through aid from their own institutions or other sources of support. The aim is to get research done to improve the nation's health, recognizing that this will require emphasis on the immediately solvable problems as well as upon the development of investigators, the techniques, the fundamental knowledge and the facilities necessary for the continuing successful attack on more elusive problems. This implies co-operation and the utilization of all available ready resources and in the encouragement of the development of new resources. Thus far, as I have indicated before, the procedure has been to make grants for project-type research. However, the definition of a project is so elastic that some project grants would fit within some definitions of program grants or institutional grants. The scientists on the advisory councils—there are seven National Advisory Councils to the Surgeon General—have found it difficult to evaluate vague and general, broad institutional or block grants in competition with more specific projects. While the desirability and feasibility of some type of institutional grant is being studied, constant attention is given to eliminating the objectionable features of the project grants.

Most applications are submitted to the National Institutes of Health on the initiative of the investigator. He has a problem in which he is interested. Perhaps he has done some work on it. We always hope he has done something to demonstrate what he can do and that he has sufficient interest to get to work on it. He does have to indicate a budget, and his application should indicate methods that he intends to use. There has to be some justification for the permanent equipment he wants to purchase and it should be clear that he needs as many personnel as he requests.

Eventually, the application, which includes all this information, is carefully reviewed by groups of experts who form our study sections or panels. These are study sections in the fields of biochemistry, endocrinology, metabolism and nutrition, physiology, surgery, and so on. There are twenty study sections made up chiefly of non-Government scientists, who are actively conducting research themselves. They review the applications and make recommendations to the appropriate advisory council. The seven

²*Public Health Service Research Grant Program, Statement of Policy*, January 1, 1952, National Institutes of Health, Bethesda, Maryland. 10 pp.

advisory councils are likewise made up of men and women experienced in the field of their responsibility, for instance, the field of cancer, or in the problems of community health and welfare.

The information provided may be sufficient to lead the advisory council to recommend support in some specific amount for a definite number of years. The award of such a grant with future commitment gives assurance that, if Congress appropriates sufficient money each year to cover all the recommended commitments and unless previous grants have been misused, the investigator may safely count on having for his research the amount specified for each year if it is needed. Sufficient funds to honor these commitments would be put aside out of future appropriations before any grants would be made for new projects or for continuation projects whose future commitments have been fulfilled and for which there is now no future commitment.

If he has underestimated his needs, or if the council has questioned his estimate and reduced the grant, the investigator can submit a request for supplemental funds in the same way as for the initial grant. Such a request will have to compete, of course, with other new applications and with requests for continuation of support for projects whose commitment has already expired. While these provisions do not carry complete assurance of indefinite support, such as many investigators would like and feel they deserve, they do go far to mitigate many of the objectionable features of annual project grants and they do satisfy the demand for periodic review of program and progress and of plans for the future which many scientists and laymen consider essential for the proper stewardship of public funds.

While the investigator is asked to give as specific information as possible about his research plans in order to allow the reviewers to judge the significance of the problem, the soundness of his thinking and his probable capacity to obtain accurate data and draw valid conclusions, he is free to modify those plans completely and follow any new lead once the grant has been made. This is intended to provide that freedom of research which is considered so necessary to reap the harvest of unexpected results which occasionally lead the alert student to new discoveries. It would be a perversion of the intent of the grant if the researcher were to feel obligated to pursue the original plan described and to ignore the new paths that have come into his view. It may be obvious, however, and certainly not unexpected, that he should be able to show when continuation of support is requested, that he has used

good judgment in altering his course rather than chasing every will-o'-the-wisp that has crossed his vision.

Considerable latitude is allowed in budgetary adjustments, but administrative approval is required before an investigator can shift money into the purchase of permanent equipment, additional travel, or other items of that type, but he may shift funds within limits into personnel or consumable supplies. These restrictions are admittedly a compromise between those who have such faith in all grantees and their institutional administrators that they believe there should be absolute freedom in the use of grants and, on the other hand, those whose experience makes them believe some control is necessary to prevent abuse. So far as I am aware, most of those that are concerned with the program in one way or another consider this a happy compromise.

There is no arbitrary limit to the number of years that support may be provided to a project, to the amount of funds for a project, or to the total number of projects or amount of money which may be awarded to any one investigator or institution. Each instance is examined on the basis of all information made available and in relation to all other requests. In order to insure that new projects or new investigators will have an opportunity to compete for available funds, there is a general tendency to limit commitment for future support to not more than three years, although in exceptional cases it is made for five years or longer.

When the period of commitment for a grant is about to expire and further support is requested, the new application may provide for additional support of anywhere from three to five years and the decision is made by the Surgeon General on the advice of the advisory councils.

There is much conflicting opinion about the propriety and desirability of paying the salary of a mature investigator from a research grant. Many feel that it engenders or abets an unstable situation that has a bad effect upon the morale and research, not only of the professional staff but on the whole team, his technicians and his animal man, who may be paid from that grant, because if the investigator should be cut off from his grant, it might be difficult for his institution to assume the full salary burden. The purpose of grants is not to become a permanent endowment but rather to aid the institution with the hope that it will eventually assume the financial burden. In the present financial plight of some institutions whose income from endowment does not permit

the assumption of those responsibilities, this situation becomes acute and no easy solution is evident.

From another point of view this responsibility is that of organizations which may desire to expand research beyond the existing capacity of a university or research institute to provide for the research men from their own funds. For such grant-giving organizations, too, this is a difficult problem because unless their resources expand concomitantly, assumption of these responsibilities permanently would soon cause a large proportion of their funds to be obligated and their opportunities for encouraging new investigators and for aiding in the exploitation of new discoveries would be correspondingly limited. Moreover, most organizations feel that they must remain flexible to meet these new developments and to permit those who later take over direction of their future to guide them in the directions that conditions at that time indicate are desirable. Some people feel that the problem is becoming so great that only the national government has sufficient resources to provide that sort of future which will attract first-class minds into the fields of research. They predict loss in the recruitment of such minds if there are many more examples of men who give their lives to research without appropriate recompense either in salary or security and finally reach the end of their apparent usefulness to society only to be discarded with insufficient provision for their needs. Whatever the cause, these are responsibilities which no group seems willing to accept. The problem remains unsolved.

The matter of financing the indirect cost of research is one on which Professor Daggett has commented. It is a matter on which vehement opinions are expressed and which the Public Health Service is still exploring. For institutions with a large staff doing research, much of which is financed from external funds, the indirect cost may be considerable and may impose a heavy and unwarranted drain on resources intended to finance educational and other important and necessary functions. Such institutions, faced with reduced income from investments and dwindling unrestricted gifts and with expenses increased by inflation, argue that they cannot longer meet the burden of indirect cost imposed by research, which they are urged to sponsor, unless some source of additional finances is provided. They, therefore, plead that the agencies encouraging research expansion accept a greater share of this burden.

While granting the seriousness of this situation, another point

of view argues that the granting agencies are not buying research in the sense of contracting with the institution to perform certain functions they would not otherwise be doing. Proponents of this view say that grants for research, such as the Public Health Service makes, are intended only to help the institution to enable its highly trained staff to do the research they wish to do and which they could not do otherwise. They point out that a great many tangible and intangible benefits accrue to the institution through these grants, such as the acquisition of new equipment and of adjunct staff members who may contribute to the training of undergraduate and graduate students, as well as in the retention of desirable personnel who might otherwise move to another institution where better research opportunities would offer greater inducement. They also emphasize the direct and indirect benefits that often result from the prestige of a larger research program than could otherwise be financed. It is not infrequently reported that the receipt of external project grants has led to private gifts of money or land because of the recognition of competence which such grants have helped to provide. Whatever the solution that is finally reached, it is evident that an ideal solution is not immediately at hand.

I will mention one more of the many problems that plague the leaders of universities. This is the reported observation that the offering of research support through project grants sometime leads to an imbalance between the research and teaching functions of an educational institution. Staff members who are successful in securing research grants make so much of responsibilities of this type that they may neglect their teaching responsibilities. One remedy suggested by administrators of these institutions has been that money to hire teachers should also be supplied with research grants. Although Public Health Service policy permits the granting of funds to employ a substitute to carry some of the teaching and other duties of the grantee investigator under certain conditions, it is quickly evident that this is an unsatisfactory method of meeting the general problem posed. Obviously, the universities, colleges and medical schools are in bad financial plight, but their condition is so serious that grasping at the straws in the research grants will do them little good, whereas it would quickly deplete support for research. A more general and a vaster program of aid for educational institutions from voluntary gifts or from tax funds or both, is required to meet the problem. In specific cases of imbalance between research and teaching functions, the responsi-

bility would seem to rest not on the granting agency but squarely on the shoulders of the institutional administrator. It is one of his functions to see that the research and teaching functions are kept in balance within the needs of his institution. It is not only within his power, but it is his responsibility to see that the staff members do not accept grants that entail responsibilities interfering with their other duties. A wise and capable administrator can accomplish this.

PART TWO

PERSONNEL FACTORS IN TEAMWORK

7: SELECTING THE RESEARCH TEAM

THORNTON PAGE

The title "Selecting the Research Team" implies that somebody does the selecting, and raises questions as to who that somebody is and on what basis the selection is made. In a university the practical answer to the first of these questions is that the dean of the appropriate school or division usually makes the selection. There may also be a complex process of recommendation by various departments. Of course I am thinking of the faculty, or a department within the faculty, as a research team. The dean's function in selection is a thankless one and does not often win him the high regard of everybody on the faculty. In the University of Chicago, where I have been until recently, the dean was too busy with committee meetings and other things to keep up with this function of appointing new personnel, and hired an assistant dean to do it for him. This was widely cited about the campus as an example of "a mouse learning to be a rat."

The type of problem we are faced with here, the problem of selecting personnel for specific purposes, is one of a class treated by the new discipline called *operations research*. At the Operations Research Office we are engaged in studying general problems of decision—the type of work which is necessary before an action decision can be made. You may be interested to hear that we are also engaged in setting up a program of study for students to take advanced degrees in Operations Research at The Johns Hopkins University in Baltimore.

I will attempt to apply the few principles we have arrived at in operations research to this particular problem of selecting personnel for a research team. It is clear that the first step is to establish the basis for selection and the desired properties of a research team. There are many ideas on just what this pair of words "research team" may mean; in fact there is very little agreement on just what research is. Of course, I could adopt the point of view here, as Humpty-Dumpty did in "Through the Looking-Glass and What Alice Found There" that "when I use a word it means just what I choose it to mean—neither more nor less," but to improve communication between us, I took the trouble of

checking definitions in the dictionary. First I looked up "team," and found the definition "(a) Two or more beasts of burden harnessed together"—not exactly what I had in mind! A second definition was "a set of workers or players," and there were two more which don't seem to have much bearing. None of these has quite the meaning I assume for the word "team" in the linked pair "research team"; my meaning involves unity of direction which, it seems to me, is essential for a group of men working together on a research problem. In order to draw this definition somewhat finer the word "crew" came into my mind, and the distinction between a crew and a team. Webster defines "crew" as "a company of seamen under a commander," or "a rowing or racing group." You will agree here that the unity of direction is perfect in a crew of that type. Perhaps it is too perfect. (When I rowed in my college crew I wondered at times whether the good Lord intended a man to get his exercise sitting down, facing backwards and taking his orders from a runt!) In any case this points up the distinction I wish to make between a crew and a team, and my meaning of "team" in this talk. It is possible to over-coordinate the efforts of a group of men so that there is a reduction in their productivity.

About research there is a very basic lack of agreement. In Webster it is defined as "systematic investigation." (Investigation is not clarified further in the dictionary; it is defined as "the act of investigating"!) At some place along the line I think "facts" have to come in, and "research" for my purpose is the act of seeking out relevant facts and relationships. Of course, this begs the question slightly since, as with all definitions, when you get them too general, they also become meaningless.

The question then becomes "What are relevant facts?" *It is the selection of relevant facts and relationships (with emphasis on that word "relevant") that I believe is the important factor in team research because it is the agreement on this selection which makes an investigation systematic. It is the agreement on an answer to the question "What is relevant?" which provides the coordination and unity of direction—and is the basis of teamwork in the field of research.*

It is important at this point also to distinguish research from mere application. In some problems all the research as I define it has been done, and it is merely necessary to apply known formulae to specific situations. This might be called engineering, in contrast to research (although there is also research engineering, a legitimate form of research which I do not want to slight), and should

be distinguished from research in speaking of a research team. This approach puts a heavy emphasis, you will notice, on newly developing subjects which need research.

You have probably all noticed the stress which is laid at any one time on specialties newly developed for military purposes. You will remember that the first World War was sometimes called the "Chemists' War." Chemistry was in a very active state of development at that time and a great many new things came of it which were of use in military situations. The last, World War II, has been called by some a "Physicists' War," because of the contributions made by the rapidly expanding field of physics. There is a good deal of reason to believe that World War III may be the "Psychologists' War," because of the rapid development in that particular field. Just when the astronomers (my profession) will come in on this, I don't care to predict!

Now, the question of just what research is—just what activity a research team engages in—has been examined by a large number of people. I will introduce here two rather diametrically opposed points of view. One is epitomized by P. W. Bridgeman in his book, *Reflections of a Physicist*,¹ which appeared last year. His definition of research is that it is really a *private affair*. For him research can be only individualistic. His statement that research is essentially private probably means that one can attach reality only to what we ourselves experience. So his conclusion is that research is only done by individuals, and this means that the activity of the research team can only be determined by the judgment of an individual. I happen to know Bridgeman, and in the presence of such a monolithic individualist as he is, I can assure you there is nothing more you can do but agree with him—but I have my reservations.

Another book I would recommend to you strongly in this connection is *Art and Scientific Thought*,² by Martin Johnson, an English physicist. It comes to exactly the opposite conclusion, that scientific research is surely a *public matter* and is distinguished from an art entirely by the fact that scientific knowledge, by its very nature, can be communicated to any rational individual whereas an artistic creation must be recreated in the mind of the

¹Percy W. Bridgeman, *Reflections of a Physicist* (Toronto: Geo. J. McLeod, Ltd., 1950), 392 pp.

²Martin C. Johnson, *Art and Scientific Thought: Historical Studies Towards A Modern Revision of Their Antagonism* (New York: Columbia University Press, 1949), 200 pp. Also published by Faber & Faber, Ltd., in London in 1944 and by Ryerson Press in Toronto.

one who appreciates it. I might say that Johnson is able to go on from this distinction to develop surprisingly specific conclusions in the field of physics. For example, the transformation equations of the special relativity theory arise merely from the assumption that the laws of physics must be communicable between one rational individual and another.

Well, this latter view that research is essentially a public affair changes the picture considerably. It means that group research can be more than just the control of a crew by a leader who tells the individual members of the crew exactly what to do. It fits in very much better with my understanding of the "scientific method," and with such statements as one attributed to Sir Isaac Newton, "If I have seen further than most, it is because I stood on the shoulders of giants." I think Newton meant to imply that research is not done by individuals but is the coordinated effort of all the people engaged in research to achieve their goal. This view also fits the views of most philosophers who have examined epistemology and the structure of scientific knowledge.

The point I wish to make, then, is that scientific research is a cooperative effort to put together a logically connected body of facts and relationships, to construct what I would like to call a theory. Perhaps I am again being like Humpty-Dumpty here, since many people think of a theory as something which is quite inapplicable, or quite outside the practical realm. I certainly mean by theory quite the opposite. As an example I draw your attention to the theory of motion, which was developed in the 16th and 17th centuries ending with Newton's equations of motion (which by my definition form a theory—a summary of our understanding of how things move). Newton's equations find highly practical application in engineering.

Another example is radiation theory which has led to practical application in radio and radar. A further example is the theory of nuclear structure, presently being developed, which will undoubtedly have more practical applications in the atomic field.

I think, then, that for the purposes of group research, the answers to these questions of how the group is to be unified, what its activities are to be, and what provides the coordination—all these would be settled by reference to theory. The effort of group research, as of any research, should be to produce a consistent logical theory of whatever phenomena are being studied. I suppose this is redundant. Most of you must have formed this opinion in your own research experience. You will recognize the need on a research

team for men and women who understand research in this sense: as fitting together facts and relationships into a consistent theory, rather than just collecting a lot of disconnected facts, or speculating without any reference to observed facts.

Unfortunately, team research by its very nature (and perhaps like any new gimmick) has opened the flood gates for a lot of activity that I wouldn't call research. In some of this supposed research perhaps the facts were not relevant—perhaps facts weren't referred to—perhaps no consistent “putting together” of the facts was ever achieved. I don't need to recount all such projects I have heard of to make this point. One comes to mind: Recently an astronomer in one of the smaller colleges wanted a grant to support study of the geographical locations of all telescopes less than one inch in aperture during the 17th century, and I don't think that this particular project had the aspect of research in the sense I am using the word.

There is also the danger of research being confused with application—with utility—as I mentioned earlier. It is a difficulty we have in governmental research, at least of the type which I am doing, in that governmental agencies would like to see practical results as soon as possible and are not too anxious to wait around for more basic understanding of the subject. There was an excellent article in the *American Scientist* recently by James Miller, entitled “How Newton Discovered the Law of Gravitation.” He develops the fantasy that Newton might have been supported by governmental research grants somewhat as follows: In between all the committee meetings and filling out of forms usually required for these grants, Newton had noticed an apple fall. He mentioned this to the dean of research in Cambridge, who immediately applied for a government grant on this particular project. The government assigned it to the Agriculture Department and their emphasis was quite naturally on developing apples that wouldn't fall quite so fast! Anyway, Newton was assigned to setting up research teams of unemployed milkmaids, who were organized to observe apples of different breeds, and other fruits as well. They came up with the conclusion that all fruits fall when they are ripe, and the only trouble that occurred was when one team of milkmaids got off on a sideline developing new recipes for apple-jack!

Well, I don't want to cast aspersions on collecting facts, or on projects which may seem disorganized before a good theory is established. All of these theories must start with facts, and the

first step of seeking out from a body of facts those things which are recognized as connecting them is a difficult step indeed.

Now, the question must have arisen in your minds as to how this applies to selection of personnel for a research team. On the basis of this brief discussion, I would like to make the point that *it is essential that the research team have a common point of view*. In fact, this appreciation of what the team is doing—of the theoretical aspects of its activity—must be available to all members of the team. This has a very practical result in that, unless the point of view held by members of the team has this common basis, *communication* between the various members of the research team will not take place as easily as otherwise. It provides, in other words, a common basis within which the physicist can talk to the psychologist, or to the economist, or to the sociologist, and so on. I view this as the most important single characteristic of a research team. Of course, there are several other necessary requirements. It is necessary to have good leadership, and in the terms I have just been describing, it seems to me that the leader especially must have an appreciation of theoretical constructs. His goal must be the theoretical development of the field in which the research team is devoting its labor.

Then, there must be a *variety of skills*. Our work at the Operations Research Office has pointed this up very clearly. Many of our problems are not confined to one field, and we have found that a research team is far more effective when there are differences in training among the different members of the team rather than too great similarities. As an example, there is a field of human engineering which has progressed very rapidly with the cooperative efforts of psychologists, electronics specialists, physiologists, and mechanical engineers.

Then, too, I think that we all agree that a prerequisite for establishing a research team would be to *specify the task*, the task which the team is supposed to accomplish.

Finally, selection involves the *size of the team*. Our experiences indicate that a team somewhere between four and ten in number is most desirable. It has been found that with fewer than four, something we call "self-ignition" does not take place. With fewer than four people there is not enough variety of points of view to lead to good teamwork and, of course, by this word "teamwork" I now mean something which can be distinguished from the efforts of individuals separately—the difference between having five people in five separate rooms working separately, and having

them all together in one room discussing their problem. On the other hand, with too many—a number greater than ten—the difficulty is with too much cross-talk, too much “noise” in the circuit. Probably ten is roughly an upper limit to the number that can work effectively together. This does not take account of the possibility of grouping teams so that you have four or five teams contributing to some common cause through a committee of their leaders.

Another way of organizing my observations on this topic of selecting the research team is to put them in terms of the steps we have found it necessary to take when we seek to build up a research team for operations research. It is decided in advance that our staff is to be organized in teams of four to ten people, each team assigned a certain problem.

The first step is to *specify the area of research*; when a new project is set up, a careful definition of the project, its area, scope and program is put down. This must be done without rigid constraints that will later limit the originality inherent in research.

The second step seems to be a *preliminary study of the theoretical status* of the project. In certain fields, such as human engineering, a great deal of work has already been done. Many of the facts have been grouped together in meaningful relationships and it is not necessary to start over again.

This preliminary study usually leads to the *skills required of the team* that should be hired to engage in this particular research. I can't tell you in detail here about any one of our projects but I can apply this second step to a problem I was interested in at the University of Chicago, namely, the origin of the earth. It is a problem which is not entirely in one of the recognized disciplines, and preliminary study indicates right away that the skills pertinent to the solution of this problem—the very distant past of the earth—are the skills of the geologist, the celestial-mechanics specialist in astronomy or mathematics, the solar physicist, and the chemist. One might not have rung in the chemist just on the face of things. It took a little study to recognize that chemistry was an essential part. This example also illustrates the point that the kind of team you have changes as you work on the problem. As the problem is pursued, you find that the nuclear physicist is also extremely important in the problem of the origin of the earth. So, in this rather artificial case, which certainly doesn't apply to governmental research, the problem branched, so to speak, after it got

started and required modification of the team six months after its beginning.

The *choice of a leader* comes presumably at the same time that this preliminary study is being made. I frankly have not thought through clearly all the requirements for the leader of a research team. I have the feeling that it is probably the most critical step in the list. Whether one should choose a man as a recognized expert in the field, or for his interest in the field, or for his activity, his get-up-and-go, or whatever you call it, is something I do not feel competent to say. Certainly a leader must be skillful in handling his men and must be able to gain and hold their respect.

The next step in gathering a team seems to be a *paper survey of candidates* or applicants, looking at their training and experience. I say "paper," because one should presumably go over a large number in order to obtain the best by selection. I notice that in your 1949 Institute proceedings it was noted that some kind of roster would serve well here, and I heartily concur with that idea. A survey of some sort which could be used by people trying to build up research teams would be very helpful. The question of just what to go on at this point is difficult, and my own experience is that you can't do much more than look at the man's age and his field, perhaps a little bit about his experience. One can't lay down a definite rule that you need Ph.D.'s, M.A.'s, B.A.'s, or people with practical experience—at least I have not been able to establish such a rule. The only advantage of a Ph.D. might be that it may insure some experience in research and therefore some understanding of theory that I described earlier, but one certainly can't guarantee that work for a Ph.D. would always produce this. So, as far as I have been able to determine, one cannot utilize very readily the fact that the prospective recruit has a degree.

I think the most important step is the next one of *interviewing selected candidates* whose records look good. It is *absolutely essential* that the leader of a group should make the interviews, determine whether each man individually will fit in, in the sense that his attitude, his point of view or approach to research is amenable to the leader specifically, and to the whole group, and to the problem. It is at this point you establish, it seems to me, the basis for good communications at a later time, and if you pick a "lemon," this is where it is done. This is where a great deal of care should be taken in interviewing to determine a man's communicativeness, his attitude toward research, his originality and ability to follow up. In the Operations Research Office we found this step to be one

of the most difficult requirements for team research. As the organization grows larger, we find people left out of the main stream of thought. Unless steps are taken to maintain good communications both within the group and between the group and the outside world, their efforts are seriously hampered.

Finally, allowance must be made for the *recognition of new requirements*. That is, as in the case of the problem of the origin of the earth, it was not until study had been pursued for a period of time that it was noted that nuclear physics, initially omitted from the skills required, was very important. The administrative outlook must be sufficiently flexible to recognize the need for new types of personnel.

In conclusion, I would like to refer briefly to the question of the proper disposition of American scientific manpower in the face of the very serious shortage of scientific manpower that we are facing at the moment. There are so many research projects being set up that we are in great danger of using up all our scientific manpower before we have finished all the important research problems. The question is whether in the selection of personnel for research teams it isn't important to emphasize the need for getting along with the *minimum* that will fill the requirement, rather than overstating the requirement by saying we have to have all Ph.D.'s or we have to have all men with at least five years' experience in research. Perhaps we should emphasize training on the job; research teams do provide an excellent opportunity to train research personnel. This, I think, has been recognized for a long time in university work where research in scientific problems is carried out by a professor, and perhaps another member of the faculty, plus four or five graduate students. This group does not operate quite as the team that I have been describing and undoubtedly does not produce results as rapidly or effectively, since there is a big difference in status between the leader and members of the team. The kind of team I have been describing earlier was one in which the difference in status between the leader and the members of the team was a minimum. However, it would be unfair to give the impression that all teams should be organized in that manner when the scientific manpower shortage may force us to conserve manpower by utilizing marginal research workers in these research teams.

To recapitulate, the bases, I believe, for selection of personnel are: (1) the area of research; (2) the common philosophy, or "approach," or appreciation of theoretical knowledge for purposes of easing communications; (3) a diversity of skills and background

and interest, necessary to get the maximum amount out of a team; and (4) a certain amount of flexibility to take account of how the problem may develop. In time sequence we have specification of the area, the preliminary study, the choice of a leader, the decision of what skills are to be required, survey of candidates through rosters, application forms and interviews, breakdown of tasks, the establishment of good communications, and, then, the provision of new skills if new requirements arise.

8: HUMAN FACTORS IN RESEARCH TEAMWORK

DAVID B. HERTZ

With the more complex interpersonal relationships of team research, the problem of organizing research becomes much more complicated. Why do we put a research team together? The answer is that in some specific sense we wish to enhance the ability of the individuals in that team. And the ability we wish to enhance is usually what we like to call creative. What do we mean by creative ability? Novelty, or what is sometimes called new knowledge, is created when two or more pieces of information are put together for the first time to form perhaps a new idea, a new hypothesis, or a solution to some problem. The more improbable or unexpected this new combination is the more novel or creative we might choose to call it. We are familiar with this concept as one of the tests of patentability of research results. Routine or repetitive solutions to problems, while they are useful, cannot be considered highly creative.

Routine work of a non-creative variety must form the background of creativeness in any laboratory. The reason for this is obvious. In order to put together new combinations of information, the information itself must be available. Perhaps this information is data from a long series of routine experiments. It may be the result of extensive studies of the literature or the accumulated experience of many years in a specific field. Whatever it is, this kind of information is the raw material of the research worker and whatever the best source for the particular type of problems to be solved, laboratory operations have to be geared to provide information efficiently.

The major interest of this discussion is with the creative aspects of team research. Perhaps we can agree that the truly creative mentality is: (1) receptive to new information, (2) flexible, (3) intellectually curious, (4) able to formulate problems, (5) able to put this information together in many ways as a means to getting to an acceptable solution to a specific problem.¹ These factors

¹David B. Hertz, "The Creative Mentality and Research Problems" in *Selection, Training, and Use of Personnel in Industrial Research*. (New York: King's Crown Press, 1951), 274 pp.

may not be sufficient or even the most important, although they may be essential. Others which count heavily are experience, or a store of previously obtained information and the ability to work with others in team activity.

Personnel possessing some or all of these qualities or attributes must form the core of all research organizations and any increase in the efficiency of these people should lead to an increase in the efficiency of a collective research activity. Research has come more and more to depend on teamwork. The ability of our individual worker to operate as a member of a creative group assumes great importance in our modern laboratories. The reason for this emphasis on team research should be quite clear. The team can create, it can solve problems where an individual may not be able to do so. If the individual could solve these problems alone, then the team would probably be an inefficient means of getting solutions.² The contribution in terms of information of, let us say, two members of a working group may be put together by a third member to provide the solution to a particularly difficult problem. A common experience in group research occurs somewhat as follows: member A volunteers some information, member B an additional fact or two, and then member C says, "That's it. I have it. Here is the solution to the problem we have been working on."

In a trivial sense this is the way the team works. The more difficult the problem the longer this process takes, but essentially it must be resolvable into group creativity terms. If this is true—and we probably can assume that it is—then team research can pay off. It can provide solutions to problems where an individual would not. But the team itself must be actively created and maintained. It is obviously not just a matter of choosing a group of top-notch scientists and putting them in a room somewhere and tossing them a problem and waiting for the answers to be turned out. People have to get to know each other, to be able to communicate with each other, and to be able to work together. This is particularly true where diverse disciplines are necessary to solve particular problems. A common language has to be developed and an atmosphere of intellectual security has to be maintained.

This kind of security can only exist when the individual is relatively certain of the type of responses he will get from the various members of the group when he advances an idea. Both language

²Walter H Kohl, "The Human Element in Research and Industry," *Proceedings of the I. R. E.* 39 (1951), pp. 228-229.

and security take time to develop. In other words, the team has to work together for a while before we can expect it to produce results. In terms of the administrator this means that he should not impose too great task pressures on newly created research groups in their initial stages of operation. Given time to learn each others' ways of thinking and behavior, such teams probably have a great deal to contribute. If we expect them to furnish answers to the most difficult problems immediately, we may be putting them in a sufficiently frustrating situation that the team process will break down.

For this reason where team research is desirable, we must choose our research workers not only for these traits of individual creativity but also for their ability to cooperate in the group problem-solving process. On the other hand, except in isolated instances, it is likely that direction and management attitudes toward the research workers are more important in encouraging teamwork than the personalities of the research workers themselves. In general, given the proper spirit and suitable aids to group activity, the great majority of research workers will be able to participate constructively. Freedom from petty annoyances, open channels of communication, fair personnel policies, frank explanations of problems, generous salary scales, all contribute to the strengthening of team play.

It is quite essential that the members of a team communicate with each other, each seeing his own work in relation to the whole, and each understanding enough of the surrounding fields to suggest experiments to those who have the specialized skill to carry them out. Each individual will come to a particular group with his own set of attitudes toward the problem at hand and his own particular method of approaching solutions. What is required in administering team research is to put together these attitudes and attain some collective solution. However, if problems are analyzed on some authoritarian basis by a director or group leader and transmitted without modification or change to the group, one of the main advantages of group activity is already lost. In this case, except for the quantity of the work involved, the research might as well be considered individual. Under exceptional leaders of research, such a procedure may be, and indeed has proved to be, quite efficient, and can lead to satisfactory solutions to very difficult problems. But if we are trying to build research teams and not research individuals, then the conflict that is inherent in this kind of operation may destroy a laboratory organization. Skillful leadership and

administration and an understanding of the group process will enable such teams to operate at reasonably high levels of efficiency. I believe that additional training of team leaders and research administrators in group processes, and in the leading of group activity, can yield very fruitful results in most research laboratories today.

Quite often the influence of personality can be utilized advantageously by proper handling on the part of a team leader. This is an important concept to recognize in the organization and administration of research teams. Hierarchical structures, for example, in research teams must be based on real ability differences for optimum results. If the hierarchy is established without apparent and clear ability differentials, there may exist a serious conflict situation. Eaton³ has noted that as long as members of research teams feel secure in their personal relations, if they are able to tolerate criticism by the other members of the team (and such criticism is obviously of great importance in arriving at good solutions to problems), they do not need the defense of prestige. When the interpersonal relationships within a team are poor, members of the team put great emphasis on their unique professional roles and backgrounds. These, as a rule, can be more easily defended against threat, real or imagined, than can their total personalities. So you find that a physicist may say, in effect, to a psychologist, "The whole background and weight of tradition in physics is behind me, and you don't have any defined methodology, ..." The psychologist will use such defenses as he can bring from his professional field to protect himself. In such cases, proposed methods and solutions to problems become ego extensions of the persons who hold them. Personal motivations for plans and activities of accomplishing the research will become dominant to a greater or less degree. The more the real or imagined threat the more the ego is involved in specific solutions.

This problem has to be faced quite frankly if communications within research groups are to be maintained. The ability to communicate is a key factor in maintaining a team. Eaton points out that he believes the multi-professional team involves an experience in group therapy, and suggests that the multi-professional group study itself systematically in the process of making its decisions, attempting to see how much of its work is defense against threat and how much of it is directed towards the problem.

³Joseph W. Eaton, "Social Processes of Professional Teamwork," *American Sociological Review*, 16 (October 1951), pp. 707-712.

With respect to the problem of individual security, at the Columbia University Center for Studies of Research Administration, under a grant from the Manpower Branch, Office of Naval Research, we are undertaking a rather broad-scale study of research teams in their native environment. This is somewhat similar to one completed by Professor Shepard at Massachusetts Institute of Technology sometime ago.⁴ Shepard studied a group in a laboratory. He determined that this group had to solve for itself such problems as the following before it could accomplish anything with respect to the solution of the problems that were assigned to it. First, they had to overcome the restrictions of procedures and evaluation criteria set by their supporting groups, which were the university and the specific sponsors. This was the framework in which their personal problems had to be solved. Secondly, they had the situational requirements of cooperative research and its implications for the individual. In Shepard's terms this required devising of a communication system to continuously introduce necessary corrections into each team member's conceptual model of the relevant aspects of the physical system that was under study. In other words, each team member brings his own attitudes towards the problem and these have to be, in some way, put together into a collective attitude. The third problem was meeting social and personal requirements for satisfactions within the restrictions imposed by the first two; these requirements include salary schedules, status hierarchies, etc., within the framework of the research group. Shepard points out that in this particular group the solution for these three problems was provided by the group's looking on the whole process as education. In other words, the team member said: "We are in a university. We are educating and being educated," and this was sufficient to solve most of the problems raised in each of these areas. For example, if salaries weren't high enough at a particular level, they could say, "We are obtaining an education and one of these days it will pay off." The relationships between members of the team were: "You teach me and I will teach you," and as such it worked out well and resolved their particular problems.

This type of solution is not always available, but it is one solution for a set of problems which we are anxious to study. We hope to extend this type of study, within the framework of our own model, to a number of industrial and government laboratories.

⁴Herbert A. Shepard, "Communication and Cooperation in a Physical Science Laboratory," unpublished manuscript.

The schematic model of the research team being used for the study at Columbia is shown in Figure A. The center comprises—and this is the focus of our attention rather than the entire administrative hierarchy of research administration—the research workers. There are also higher authority, technicians and assistants of various kinds, extra-group contacts within the organization, and outside organizational contacts.

Our intention is to look at the communication channels and to determine in various kinds of research teams those communication

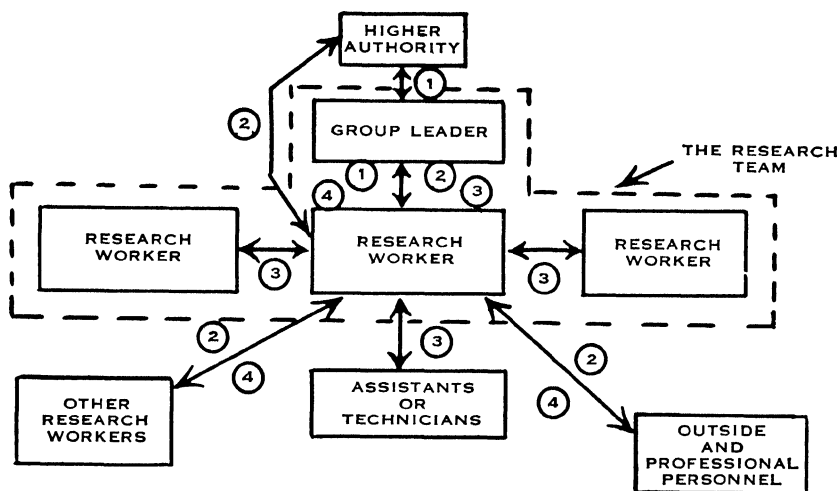


FIGURE A.

- ① POLICY ORIENTED COMMUNICATION
- ② MORALE ORIENTED COMMUNICATION
- ③ POLICY ORIENTED COMMUNICATION
- ④ GROWTH ORIENTED COMMUNICATION

channels that are used largely for “problem orientation,” and “information transfer,” those that are used for “morale,” those that are used for “policy,” and those that are used for what may be called “growth,” etc. We have some hypotheses about the major use of each of these channels for these purposes. For example, I think we can probably designate the channel from higher authority to research worker as “morale.” “Policy” goes largely through the

channel from higher authority to group leader and communication with the research worker from higher authority is not seriously "problem-oriented." "Growth" is especially important via this channel. So we can hypothesize that we will find that "morale" is the reason for this particular set of communication events. The channel from group leader to research worker is possibly the most important link and probably includes communication directed towards all four categories.

In our initial studies it appears feasible to determine these channels to develop the existing patterns, and perhaps eventually to say a great deal about how to bring about higher morale and better administration within research groups. The study also includes an inventory of existing research teams, and a study of methodological problems involved in assaying productivity of research groups.

In addition to being able to communicate, the members of a research group have to learn to wonder together *what* would happen if they did thus and so, and *why* something does happen the way it does. This is a fairly conscious process and one which can be cultivated by both the individual and the group.⁵ Research directors and group leaders can stimulate this process by providing, for one thing, provocative suggestions.

Also the amount of intellectual activity or creative activity within a group is probably related to the pressure exerted to get the job done. If there is too much pressure on a research team, the results will suffer, but, by the same token, if there is too little, operations may proceed at a considerably slower rate than desirable. How to achieve this "pressure" is a matter which will bear considerable investigation. In any event administrators can experiment with the results of task pressure applied in various ways and find some range of amounts which will get work done at an optimum rate. Requirement of weekly or monthly project reports from the research worker can be an important and useful kind of task pressure. Such a report should be specific with reference to problems, but general with reference to progress as well as easy to maintain. I believe, above all, that directors, administrators, and group leaders have to listen sympathetically to the tales of false starts and screwball ideas and other manifestations of the fact the group is thinking in terms of "why" and "what would happen if." If you discourage this kind of thinking merely because it doesn't seem to apply to the problems at hand, then you have probably cut an important channel of creative productivity inadvertently. In this

⁵Hertz, *op. cit.*

connection, it may be hypothesized that the relationship of the group leader should probably be much closer to his group than to his own superiors. The "policy" channel between higher authority and the group leader may be cut for a long time without serious effect. Systematic studies of patterns of organization through which ideas can be integrated and communicated both within the group and through entire organizations will be extremely useful. We still have a long way to go, but from observations in research laboratories, the use of research teams and the growth of knowledge concerning their proper administration are very encouraging portents for the future.

9: THE INDIVIDUALIST AND THE RESEARCH TEAM

HOWARD R. TOLLEY

It has been my observation that much the same problems arise, whether the research activity is in social science or in non-social science. Hence, I presume that the relationships of the individualist to the research team in social science would be found to a considerable extent the same in other fields.

An individualist, we note first of all, is inquisitive. To him the world is full of unknown things toward which he wants to reach out. That is the reason he is a researcher. He may also want to do something that will influence events, which may be related to his ambition or to his desire for recognition in his profession. The individualist tends to be resentful both of supervision and restraint and, hence, at first rebels against the "direction and supervision" in teamwork. Directed teamwork seems to be at odds with his individualism.

At times it is quite necessary to utilize the abilities, the genius, the contributions of even the most obdurate individualist. His contribution might well be *the* contribution toward the success of a particular research team. Admittedly, some of us have these individualistic characteristics more than others, and, of course, it is true that some people are so individualistic that they could not be good members of a team. They are so individualistic, so brilliant, that it would be a mistake to harness them into a team. They must proceed in their own unfettered way. The director of the team or the administrator of team research must meet such problems realistically. He must not jeopardize the team as such by placing upon it a person who cannot work with others. On the other hand, he may devise a mechanism for individual consultation, criticism, and synthesis.

The researcher who is characteristically individualistic tends to resent interferences. He resents security investigations, regardless of how impeccable he himself may be. He thus bars himself from many research teams, upon which he might offer a significant contribution. He may even shrink from doing what is plainly his duty as a citizen. The administrator of research, by a candid ex-

planation of all the circumstances, is sometimes able to surmount the initial objections of such an individualist so that in one way or another he can work with and make contributions to a team.

In any team the members have varying degrees of individuality, but as in an athletic team, the players submerge their own stellar characteristics for the common good, the team's over-all good. Sometimes this requires the coordinating action of the team captain, but each researcher has to bury his personality within the team-concept to a considerable extent in order that he and his teammates may pursue a common goal. It is as true in the laboratory as on the playing field. In fact, the players work as equals, each has his part to play. Lest we misunderstand the framework of the team, it should be mentioned that it is comprised of all the players. The team as such has no hierarchy. *Within* the playing team are the captain, the principal players and the substitutes. Within the research team are the team-leader, the stellar researchers, the lesser lights, the research assistants, the glass washers, the instrument men, the computers—all who contribute to team achievement. On the team we may find researchers who are old and senior along with those who are young and junior. There is frequently a tendency for the seniors to take a condescending attitude toward their juniors, especially the youngsters. Such individualistic attitudes do not make for good teamwork.

Even when the research team has been constituted for some time, individualism may crop out to mar the joint effort. One or another member of the team may get tired and become frustrated. He manifests this in various ways. He fails to show up. He does not come over to see you or talk to you. He withdraws within himself. He sits and looks out the window. He makes no contribution to the team. Quite frequently this can be attributed to the fact that at heart he is an individualist working in a group where everyone is trying to tell him what to do, tending to shove him into a narrow groove of application. The situation is amenable to cure on the part of the team, particularly the team-leader. The latter can assert his leadership, perhaps talking to this individualist, asking him to lunch, feeling out by counseling that which is at the root of the trouble. But the approach must be real and it must be friendly, never condescending, never rough, never tough, because Mr. Individualist by his very nature would be repelled, with a resultant loss of a team member. This is a problem which requires the initiative of the team-leader, one which challenges his

leadership, one which draws upon his coordinative powers in strengthening the ever-tenuous bonds of the team-concept.

In programming the work of a team, the individualist should not be lost sight of. Of course, general subject projects come down to the team in terms which have already been laid out. Then begins the job of further specialization. It is in this process that the team-leader should recognize the individualist. He might be well-advised to tell the team the total goal and then permit the several team-members to propose their respective courses of action. One man, the leader, cannot sit in his room and lay out particular pieces of research work for each member of the team and then hand it out to them. It is team-work around the table, discussion by the individuals, which will discover each man's particular slant on the project and his own proposed segment of the total solution. Hence, the team-solution is usually better than leader-solution at this stage of the problem.

Majority rule within a team seems to work well on the most rugged individualist. While his nature resents being bossed around by another individual, he seems to accept the consensus of his peers. This democratic reaction, even to the point of a vote, is sometimes used to good effect on research teams. It operates something like a "huddle" on a football gridiron—a proposal—a consensus—a concerted action—a submerging of the individualist toward the team's objective. It enhances the concept that each team member has a job to do. It heightens his feeling that he himself can contribute and lastly it solidifies the team feeling that Mr. Individualist is the particular man to perform that job best in the team's over-all interest.

Group-thinking or team-thinking can evolve from individual thinkers. The goal in putting a team together is to gradually bend or mold the individualist so that, while retaining a degree of his individualism, he nevertheless more and more inclines toward group approach, group-thinking, team-thinking. Then it no longer is satisfying to an individualist to contribute as a *prima donna*. His satisfactions result from the total product of the team. His single contribution may have been important when standing by itself, but ever so much more important when developed and modified in concert with his teammates, so that it becomes an integral part of the total contribution of the entire team.

10: SUPERVISING AND TRAINING FOR TEAMWORK

ADDISON M. ROTHROCK

Research can be divided into two categories—research for acquisition of knowledge and research directed towards the improvement of a specific end object. In the former, the purpose for which the results will be used is of secondary interest and the value of the results in one field are not necessarily compromised by those obtained in another. Consequently, although the groups working in a given field may be large, it is not in general necessary to coordinate the work other than to insure that each group knows what the other groups are doing. In research leading to the improvement of an end product, that is, in applied research, two things are necessary: (1) that the rate of progress in all fields be balanced by means of shifting emphasis so that the end product is improved at the greatest rate; and (2) that the continued compromises required by findings in the different fields be appreciated. These two facts make it necessary that in this second category the effort be organized for teamwork. This teamwork can be on an individual group basis, it can be on a laboratory scale, or it can be on a national scale.

This concept of teamwork is itself somewhat opposed to the attributes that make a good research worker—a desire to have freedom for independent action. For this reason, it is important that the need for teamwork be realized and appreciated from the start of an applied research career. With the research money (which in turn means man-hours and materials) that is being spent in the interest of the defense of the country, it is increasingly important that this concept of teamwork permeate through our research establishments and between our research establishments.

In research for the acquisition of knowledge, the scientist is generally interested in increasing his knowledge and therefore the knowledge of other people in the field of particular interest to him, and the paths he follows can be those of most interest to him without regard to the over-all balance in the field. In research leading toward the improvement of an end object, the scientist uses the knowledge he is acquiring or the knowledge other people have

acquired to improve this end product. It means that he does not have a free choice in the paths he follows but must shift his lines of emphasis as demanded by the over-all objective. For instance, if he is an aerodynamicist working on the improvement of compressors for turbojet engines, fifteen years ago his objective would have been to increase the efficiency of the compressor to such a point that the jet engine could fly. As the efficiency is improved, the stage is reached where further improvement in efficiency will result in little gain in aircraft performance although the improvement may present problems of great scientific interest. The emphasis now shifts to other specific goals. As supersonic speeds are achieved, it becomes increasingly important to decrease the diameter of the compressor for a given air flow through the compressor. As production demands are increased, it becomes important to decrease the number of blades in the compressor so that manufacturing costs will be lowered, and the research must be redirected to meet these needs. Research on fuels for the engine may be dictated by the desire for more energy per pound of fuel for greater range, by the need to burn the fuel at higher altitudes, by the availability of fuels of different types in case of an all-out war. This redirection of scientific and engineering effort can only result from the concept of many people working as a team.

Technical progress is dependent to a large extent on our ability to operate successfully devices of increasing complication and devices the results of which depend on many scientific knowledges. As the end object becomes more complicated, it becomes increasingly necessary that the laboratories not be a loosely knit confederation of experts each working on problems in his particular field of accomplishment. The problems faced become individually so difficult and so complex and so intermingled with other equally difficult and complex problems that an entirely new order of team activity is required.

Although men in scientific and engineering laboratories are trained to think clearly and logically, scientists and engineers do not always extend this process to their personal reactions. Thus teamwork will not result of itself. It will only result through continued effort on the part of the research management. It is desirable in laboratories and between organizations working towards the same general end that a competitive spirit exist. But this spirit must lead to over-all benefit of the end product rather than to the advancement of an individual or of an organization at the expense of the progress of the product.

The larger the effort expended towards a given objective the more important it becomes that this need of teamwork be appreciated from the top management through the whole organization. It is becoming increasingly important that the research director be qualified to organize his laboratory on this basis. It means that the director must have a thorough knowledge of the over-all objective of the group, his judgment must be sound, he must have the personality that results in men liking to work under his direction, and he must have the organizational ability to see to it that the laboratory works efficiently and in a well-balanced manner towards its goal. These attributes are not easy to find.

With the effort that is going into applied research and with the importance of the results of this research towards the security of our country, it is just as foolish to conduct applied research in an unorganized manner as it would be to let each fighting unit in case of war fight the war according to its own desires and beliefs. Unfortunately the success of the applied research effort is never fully known until the end product is placed in its inevitable competition with that of another producer, whether this competitor be an industry or a nation, and it may then be too late to correct past mistakes.

If the top supervision has the abilities and the desire to develop this spirit of teamwork, it can and will be developed through the organization as a whole; it will be found in general that men will enjoy working under this environment. The number who insist on being lone operators is small. The less an individual desires to work as part of a team the higher must be his brilliance to justify his continued effort in the applied field.

The achievement of teamwork will be assisted if each person throughout the organization feels that his efforts are being appreciated, and that the assignment of jobs and the credit for the work accomplished either through authorship or reports or through salaries paid is based on a fair and logical procedure. The men in a group know just as well as do the supervisors who the best men in the organization are. Every promotion in an organization either in salary or in position is judged by the manner in which the man getting the promotion stacks up with his co-workers. Promotions based on seniority as the most compelling factor will result in a general disintegration in spirit through the organization. Promotions based for any reason other than merit—merit that is recognized by the people involved—will result in deterioration of team effort. It means that the person or persons making promotions

must be willing to move men over others, must recognize managerial ability in research workers when such positions are open and must be willing to take forthright action when such action is required. These things are not easily done, particularly when a position has to be filled and there is more than one person of nearly equal competence for the job. I use the word "managerial" ability rather than supervisory or directorial ability advisedly, because in research, supervision as generally conceived or direction of work as generally conceived must be used with great care. For in research we are generally working in advance of precise knowledge, and we seldom know definitely what is right.

One member of a group will seldom have all the knowledge that is required in coming to a decision. The people who are in supervisory positions must realize that their worth depends on their ability to bring forth the best group thinking, to bring out the best opinions, for finally on this ability to judge opinions depends much of the success of the work. Whereas in basic research, time is not necessarily a factor, in applied research time weighs heavily. Decisions must be made as of a given time, and they will be made on the facts that are then available—incomplete as those facts may be—and the factor of judgment becomes increasingly important.

Supervising the scientists or engineers of different specialties but of considerable knowledge in their specialties is not easy, because the men must be asked to submerge the emphasis on their own groups for the good of the objective as a whole. If the number of jet engines produced is dependent on decreasing the amount of certain alloying metals in the turbine, then turbine research in the field of alloys or of cooling the blades must be emphasized at the cost of research, say, in the fields of fluid mechanics. The heads of the divisions in the different fields must be made to feel a part of the over-all effort and realize that their own appreciation of the need for de-emphasis at a given time in their own field is also an expression of their worth to the organization. Shidle¹ has stated that the only true security is the ability to meet changing conditions, and certainly this statement applies to the success of an organization in applied research. And by security I refer to the secure position of successful accomplishment. It means men must be taught to appreciate the need for dropping work at an interesting phase from a scientific standpoint. Some men try to build to great precision; sometimes this precision is warranted; other times, because of speeds at which the development is moving, it is not.

¹Norman G. Shidle, Editor, S. A. E. Journal.

At the next level—say, the level at which a group of chemists or physicists are working together on a problem—the cooperation is possibly easier to attain and it becomes more a question of personalities involved rather than a conflict between different fields.

In supervisory positions the technical competence of the group leader is of great importance. Records will show that a lack of respect for one's boss is the greatest cause of worker dissatisfaction. In technical work this competence is even more important, I think, than in other jobs, and if the leader does not have this technical ability, work in the group as a team is practically impossible. A lack of respect for a leader will pretty well prevent any unified general effort in a group. Such a situation, if it exists, must be corrected. The longer it is permitted to exist, the more difficult the situation is to correct and the more damage will be done in the eventual correcting.

Once a feeling has grown up within a group that each man must jealously guard his contributions and that promotions will be based only on specific ideas that are credited to him or reports that are written by him, a situation will soon exist in which, instead of a group effort, there is a series of unconnected paths being pursued with each man jealously guarding his results and ideas from his co-workers. This spirit once it has grown in a group is extremely difficult to overcome. In fact, it generally takes quite drastic action to remove it. Supervisors should be informed that there should be on the whole a complete interchange of ideas not only within the group but between groups. Any knowledge acquired should be available as soon as acquired, to any other person who has a legitimate need for or an interest in the information and it should not be retained for the personal advancement of the group or individual.

By this statement I do not mean that we should rush into print or into discussion with ideas that have not been sufficiently digested or with data that may be inaccurate. Any person has a right and should withhold data or information that has not been adequately checked, the dissemination of which may result in damage to the over-all objective. Each man should be made to realize that the number of reports of which he is an author or the number of ideas directly attributed to him are not the sole criteria that determine his advance, but that his advancement also results from other intangibles—the general worth of the man to the objective.

The young engineer or scientist must have developed in him a keen desire to merge his own interests with that of the objective which his organization is trying to attain. Principles that lead to

teamwork in research are essentially those that lead to teamwork in any other endeavor. The individual must realize that his work is part of a group effort and that his own personal advancement will, over the years, be more satisfactory if it results in the greatest advancement of the group objective. He must also realize that the scientific endeavor of the group as a whole is always involved in the actions of any individual member of the group and that once a worker is identified with the group he cannot in his writings or in his speaking completely divorce himself from his team. He must feel his responsibility toward the integrity of the group as a whole.

Bringing teamwork into a group is the responsibility of research management. The management will set the pace for the development of teamwork. A leader of any research group should have within him an inherent sense of fair play. If a man does not have this characteristic, I doubt that he should under any circumstances be made a group leader. Certainly as the number of people under his direction is enlarged, this characteristic becomes more and more important. It is the responsibility of the group leader to show by example that he is interested in the success of the group as a whole rather than of himself as an individual. Starting with the individual worker it means that he must have inculcated in him the fact that it is only what is right that is important and not who is right, and in his conversations with his group—in conversations between the men themselves—that principle should continually be followed and no discussion should be allowed to get to the point where it becomes largely an issue of who is correct. The leader must be extremely careful in the matter of seeing to it that credit is correctly given. He should realize that his position means that he must lean over backward to see that the men in his group rather than himself are credited for work accomplished. In the preparation of reports, he must see to it that other work in the field is well referenced. It is better to give credit that is not called for than to omit credit reference that is deserved.

The supervisor must learn to distinguish between personality differences and technical ability differences and he must consider both in making assignments. A man who is a precise worker should be assigned as far as possible to jobs in which the time element is minor. A man who has difficulty expressing himself should be assisted in putting his ideas across. Few of us realize these traits in ourselves and it takes considerable tact to use a man most effectively for the benefit of the team effort. It is up to the group leader to place his men in positions that accentuate their good points rather

than their weaknesses. If a man is advanced beyond his abilities or placed in a job outside his abilities, his debits rather than his credits come to the fore and again the efforts of the group as well as those of the man suffer.

The men must be trained to realize that the specific advantages apparently resulting from any one piece of work may be offset or modified by the demands of other fields that apply to the over-all objective. This means that the group must understand the extent of its responsibility and must not try to enforce advice upon another group. It should not go into fields of work that are being covered by another group but which bear corollary interest to its own field. The group must be willing to carry an idea to a given stage and then turn it over to another group for completion. Again, the group must realize that its objective is to improve the end item and that this precludes the pursuit of a particular project past the point of profitable return.

You will find that men in a laboratory have a possessive feeling for their equipment. It becomes their "own" equipment. This feeling of possession is a natural feeling of pride in workmanship and in accomplishment. It should be fostered but guarded to the point where the worker realizes that, although he is charged with the use of the equipment, he nevertheless has the responsibility to use it for the general good for which it is intended. Moreover, he must be willing to sacrifice his own wishes not only in carrying out his own ideas but in the use of the equipment effectively to carry out ideas of other people when these other solutions are at the moment the most important.

Much of the success of teamwork in a laboratory depends on the organization of the laboratory. In general the organization that would be most beneficial cannot be realized because of the lack of individuals to fill certain positions. In this case it is generally preferable not to establish the position rather than to fill it incompetently. This fact is not always realized and its lack of realization has done much to damage teamwork. The organization must be modified to fit the abilities of the men available. For this reason, although two laboratories may be organized for work in quite similar fields, the organizational structure may be different because of the individuals involved.

Management has the responsibility for the continuation of sound management. For this reason, in research, men should be allowed to develop a sense of responsibility as rapidly as practicable. By so doing two things are accomplished: the continued success of the

organization in having personnel trained for various positions is assured; and secondly, through being assigned greater responsibilities, a man will feel that he is more a part of the organization and thus increase his sense of responsibility in the over-all work of the organization. This is the keynote of successful teamwork.

Considering various specific means that can be used to develop teamwork, conferences may be used wherever there is a need for the exchange of ideas. In many cases conferences are beneficial in arriving at a successful recommendation. Conferences cannot take the place of managerial decisions. Whether we like it or not, experience has shown that in order for a group to be most effective it must have one individual in charge. Teamwork can be improved through correct use of conference procedures but it can be damaged if conferences are used in an attempt to come to those decisions which directors or heads should themselves make.

As far as possible each person in the organization should know what is expected of him, what his prerogatives are, and when he must go to higher authority for a decision. In research organizations I do not think these things can be written out. I think they can best be decided by conversation and by example. Any man in a research group should be free to talk to his immediate supervisor, or any supervisor up the line. Courtesy requires that the immediate supervisor be told of the discussion that takes place, but teamwork is effectively destroyed if the supervisor insists that no action ever be taken by his men except through him, and that his men not talk with higher authorities in the organization except in his presence. A research supervisor who enforces such tight unity of command is probably conscious of his own shortcomings for his job. He does not realize that the course he is taking is emphasizing his weaknesses.

Scientific integrity must be developed if effective teamwork is to be developed. By "scientific integrity" I mean the ability at all times to think logically on a scientific basis and without bias on any problem submitted. It is the ability to consider another man's work as favorably as you would your own or another group's needs as favorably as you would those of your own group.

Asking a supervisor to make a decision that affects his own group adversely should be avoided whenever possible, because pure objectivity is a rare trait. Again, this is a question of management managing rather than shirking its responsibility. The establishment of a top-heavy staff in relation to the line positions should be avoided. Where staff positions are used, the staff members

should be taught to realize that their job is that of bringing together the best thoughts of the organization and not the furtherance of their own ideas. I think a lack of appreciation of this fact is the cause of the lack of respect that is at times held by the line groups for the headquarters group.

Correct example is the best trainer, I believe. If top management is thoroughly imbued with the basic principles of sound management, these concepts will permeate the organization, except where stopped by some person who does not have the inherent ability to instill this spirit of teamwork within a group. In this case no amount of instruction will accomplish the desired end. If an organization grows rapidly, it is almost too much to hope that all supervisory appointments will be good, and yet we seem very loath to make a change even when it becomes obvious that a change is required. We seem to forget that in the same manner that men grow beyond the scope of their assignments, assignments can grow beyond the scope of their men. Such a situation virtually prevents effective teamwork in the group involved and no amount of training or explanation will correct the situation.

In writing on a subject such as training for teamwork in research, it is difficult to avoid the platitudes and clichés that so often come into a discussion on supervision. I am tempted to say you cannot train for research supervision, you can only develop through example and opportunity the inherently required abilities if they are already there. In supervisory group heads we should look for technical ability, scientific integrity, understanding of human character, a basic liking for people, and ability to come to clear decisions—in other words, the general qualities of leadership, plus technical ability. The degree to which the supervisors have these abilities, the opportunities they are given to develop these abilities, and the example set them, determine how far the organization will go in developing teamwork within it.

PART THREE
AIDS TO TEAMWORK

11: COMMUNICATIONS AND TEAMWORK

EUGENE W. SCOTT

First of all, I should point out that the title for this discussion is somewhat redundant in that teamwork is impossible without good communications. The essence of a team is communications between the members of the team and once you have a team established, communications flow more smoothly.

Nature of Communications. In today's talk I shall mean by "communications" all the types of devices for the exchange of information that pass through a research organization. Some of them are formal, some informal; some oral, some written. Their content may be technical or administrative, and they may be transmitted "horizontally" or "vertically" within an organization. I will not discuss the actual mechanisms of communication, such as telephones and tape recorders. I do intend to discuss the importance of communications for teamwork and to follow that with a general analysis of communications within a research organization as I understand them. This is perhaps putting the cart before the horse but I feel that once you obtain my understanding of the significance of communications to teamwork, perhaps you will see the significance of the general analysis to the work of a team.

First, the team itself is a communication medium. It is established to bring to bear a multiplicity of experience and training on the study of a particular problem, which is to be solved using scientific methods. It is a mechanism whereby men with different training and ideas and different methods of approach to problems, are put together in a common cell in order to provide communication between disciplines and between trainings. The team may consist of five to ten members, perhaps only three members, but it should not have more than ten, in my opinion. The team members as individuals have informal relations throughout the organization which provide them with resources of information which can be brought to the team, and of course these individuals are put into the team because of the fact that you thereby bind together a number of information resources.

I have been referring to the transmission of technical material. Next we turn to "official" information: information that it is a part

of the job of the team to provide, or a part of the obligation of the organization to furnish the team, particularly administrative information but also technical information in the nature of formal reports and progress reports. That information must travel through vertical channels. It should go from the team leader to the supervisor, to the research director. If you permit official communications to travel horizontally through the organization, you soon have a chaotic condition in which individuals do not know what authority is supervising their work. The communications must, therefore, go through the team leader who is the official communication channel. He is the first step in the vertical channel of communication. The team members have the responsibility of reporting to the team leader and he, in turn, of reporting up this special line of command, but they also have this other problem of obtaining "technical" information informally or in some instances, formally, through horizontal mechanisms: through people that they know and from other teams and from other parts of the organization; from production, from certain groups in management, from administrative services, from research, if they are in research, from development, from the pilot plant, etc. It is their responsibility to get that technical information from these other sources, and it is perfectly permissible for them to transmit technical information horizontally.

Those who have experience in military organizations realize this perhaps more readily than individuals trained entirely in research. The transmission of information through official channels to the top, to the head man, to another head man and down through another channel is a very slow and tedious process. If it is official information, if it has to do with the establishment of a policy, that is the way it has to go, and that is the way it should go, but if it is technical information, you may go from private to private. You don't want to go through the corporal, lieutenant, sergeant, corporal to private. These two alternative channels should be kept in mind and used properly.

The team leader should usually represent the team at conferences. This is not invariably true, but depends to some extent upon the type of conference. If it happens to be a conference on engineering problems and the team includes an engineer who is a good mathematician, it is probably better for the engineer to be present at the conference. It is obvious that the whole team cannot be present, so he has the responsibility of reporting to the team what happens

in the conference, regardless of whether it is a technical conference or it has to do with administrative matters.

I turn now to a discussion of different types of communications. I have just mentioned the staff conference, which can be of several types, depending upon the echelon of authority at which it occurs. At the lower levels, it is usually a purely technical conference. As you move up the line to the research supervisors and finally to the assistant directors, it becomes more and more a management conference until you arrive at the meeting of the board of directors, where it is a purely management conference.

Among formal communication mediums are official reports, technical reports, technical memoranda, and a few devices that are not generally thought of as communications, e.g., seminars, abstract bulletins and accessions lists, house organs. There are, however, very important informal media which are often overlooked, although most of us who have been in research, and particularly in coordination of research, realize they are very important. These are the section meetings of the professional societies in the area of the organization. They are the parties that individuals give in their own homes and that are occasionally given at Christmas and New Year's in the office. And a very important informal medium of communication is the intramural sports activities which are usually fostered by the management of the organization. Participation in these activities is on a purely social basis but the friendships formed in this way furnish informal points of contact throughout the organization.

The Staff Conferences. Staff conferences can be burdensome, very burdensome, particularly if they occur too often and if they are too long. People in the government, I believe, feel that there are entirely too many conferences. A man in my position of coordinating and attempting to get a group of people to agree upon some policy is constantly in a conference or committee meeting of one kind or another. I can count on having at least one committee meeting or a conference with five or more people every day. This is not so true of the research man at the bench level, a man who is actually an investigator, and every care should be taken to insure that his time is not misspent by attending too many conferences. Actually, one of the duties, as you gain authority and responsibility in a research organization, is to meet with other people and, therefore, as you move up the line, conferences occur oftener and oftener.

The worst thing about conferences is the fact that they are usually too long. Sometimes it is best just to place an arbitrary

limit on them, even at the expense of decreasing the amount of communication you have. The present committee for which I work has set an arbitrary limit of two hours. If we met at 2 o'clock, at 4 o'clock the chairman will say "We have met long enough. If there is any further business we will take it up at the next meeting or leave it to the Executive Secretary to settle." Consequently, I have little difficulty in getting the members—the actual members, not the alternates—to attend these meetings.

I want to emphasize that a conference requires planning, leadership and reporting. If it is worth having, it is worth having an agenda and it is worth having minutes. The minutes need not be long or very detailed, but they should report the discussions that went on, and the actions that were taken. They are for the benefit both of those who attended, and of those who are not permitted or cannot attend. I might say also that the minutes should be issued promptly if the conferences are to be efficient in their aims.

It is frequently overlooked that a good conference requires leadership. It must be led by a man who can keep it on the agenda, limit the speakers, and see to it that things are accomplished other than idle talk. A well-run staff conference is delightful to attend and most individuals are pleased to go. The poorly-run staff conference, unfortunately more frequent, is the reason so many people object to committee meetings.

Reports. Reports are also formal methods of communication and I reiterate what I have said about staff conferences. Reports need careful preparation. They need standards; they need editing. They need good writing. One author wrote recently about a report: "One of the prime requisites of lucidity in a technical report is a basic structure consisting of introduction, development, application and conclusion. If the ideas are presented in logical sequence and if the literary technique is simple and direct, the goal of clarity will be achieved. One criterion of the intrinsic worth of any piece of technical writing is the manner in which it is constructed because its completeness of information and creativeness of thought will be of little value to the reader if he cannot readily understand the written word." All too often important information is lost simply because the individual who wrote the report does not know how to write clearly. It is really simple, I think, to learn to write clearly. Although I do not entirely agree with Rudolph Flesch in his statements about readability, he has a good many remarks

that are quite to the point. It would benefit all of us to read or reread "*The Art of Plain Talk*" by Rudolph Flesch.¹

Memorandums are little reports which often accomplish more than a big report. They also must be written from the standpoint of the man who is to receive them. You can write one kind of a report on organic synthesis for your professor of organic chemistry or your technical supervisor, but you have to write a different kind of report if it is going higher up the management line. So you should always bear in mind to whom the report is to go and, except in the case where you are absolutely sure who is going to read it, I would write it a little bit below what I would consider the man's comprehension. In other words, write simply, erring on the side of simplicity rather than on the side of complexity. It is invariable that simplicity communicates and verbosity confuses. For example I quote the following diagnosis: "He had conjunctival erythema and edema accompanied by a malfunctioning of the gastrointestinal system which were strongly indicative of intemperate post-prandial assimilation of spiritus frumenti." or in ordinary language he drank too much and had a hangover. If you look over your own writing, you will frequently find that you err in the direction of using too many words and of using confusing technical words when a simpler word would do.

Seminars. A seminar differs from a staff conference in that a seminar is something in which the participation is voluntary from the standpoint of the listeners, and features a talk given by one person on a special topic of interest to the organization. Industrial organizations and certain government organizations frequently overlook the opportunity of having technical discussions on material which may be only slightly related to the work of the company. Those talks give the younger men in the organization an opportunity to meet some of the experts and it gives some of the busy men in the organization an opportunity to learn a little bit about what is going on, either outside the company or inside. You can, of course, bring outsiders in to lecture, but you also have in a technical organization of any size, a number of very experienced individuals who have something to say and who should be given an opportunity to say it. This helps the young people continue their education and gives others in the organization, including some of the administrative men, a chance to hear what is going on, even if they do not understand all of it. There is a constant need

¹Rudolph Flesch, *The Art of Plain Talk* (New York: Harper and Brothers, 1949), 342 pp.

for continuing education in any technical organization, whether it be government, university, or industry.

In my own case I still feel and I hope that I shall continue to feel when I reach retirement age, that there is always something more that I can learn. I have stopped learning much in the field of organic chemistry, although I still read a few papers in it, but I have many other subjects to study now. I have much to learn about communications, for instance, and I am constantly trying to learn more about it, even some of the mechanisms of communication, some of the theories of communication. I was discussing the other day something that I had not heard of before, but something I am going to try to learn more about—how much redundancy do you need in communications? You can actually communicate a number of words, leaving all the vowels out and still the communication is clear. Putting in the vowels constitutes, therefore, a redundancy in communication by the printed word. Yet those vowels aid your comprehension. They enable you to read better. As I say, I don't know much about this but I want to learn more about it.

The seminar is also valuable in that it lifts the individual out of the insidious path of specialization. There is no greater opportunity for a man to get stuck in a rut than to follow some very special field and to become an expert on, let us say, the type of paint you put on optical instruments. Unfortunately, it is true in government, it is true in industry and to some extent true in a university. The individual does tend to come to know more and more about less and less. A seminar gives him a chance to hear what else is going on in the world.

Reference Aids. Abstract bulletins and accessions lists are necessary in any large organization because the general abstracting services and indices that are distributed are too general for special use. Chemical Abstracts will never be replaced, but there still need to be speedy announcement services for technical information that arises both within the company and outside. If the organization is small, an accessions list that announces the receipt of these publications is appropriate.

In a team you can save a good deal of time if you have one individual who likes to do literature searching. That job can best be given to one man if he is willing to accept it. If he does a good job on it, he can bear the responsibility for the whole team in this one respect. One thing further about such abstract bulletins is that they only expose the technical man to the body of knowledge

available. The fact that it reaches his desk is no sign that he uses it, so that in a good many cases we suspect that the work of preparing abstracts and making catalogs and reports is largely wasted because the individuals who could use the abstracts and the reports never hear of either. We intend to find out about that by means of a study which is rather fundamental to some of the work that is going on.

An Informal Method of Communication. There is an informal method of communication within an organization which was used in the first office organization with which I was connected. I left a research laboratory at the University of Cincinnati and came here to work in the Office of Civilian Defense, working on war gas defense. The Medical Division of this organization had a reading file. Everyone who wrote a letter or memorandum-to-files put a copy of it in the reading file. This circulated around the office. It was one means of finding out what the other fellow was doing and I would say that every individual on reading that file found at least three items which led him to go to the men who had written them for more details and perhaps to work out some deals between them. You cannot, however, use a reading file in a big group. Even in a small organization you have to set up two or three or four copies of the reading file. You have to set up some special rules, too, e.g., that the reading file has to go out of the office the day it comes in. Otherwise you get a reading file containing material that is six months old.

Communication Patterns. In the small organization there is less difficulty with communications. Five people certainly should be able to get together most of the time. However, even in a group of three people, frequently one man—not the same man all the time—will do something of concern to the others and forget to tell them about it. The reading file can take care of that to a large extent. It saves time of all the men concerned, since the time to read something is a lot shorter than the time to say it, especially if some of the reading is reduced to scanning.

The communications and the communications pattern become much more important as the organization grows in size. As you go up the chain of authority, too, communications become more and more important. The research supervisor, assistant director, research director, as you go up the line, have greater responsibility.

The communication pattern is always a two-way flow. The command up the line is responsible for communicating downward although this is frequently inadequately done. The vertical channel

up the line, as I mentioned before, must be used for official information. I would like to take the case of a single report and briefly trace it down through an organization. If you took the single report and passed it to the research director—let us assume that it is a technical report of considerable interest to the organization—he would want to read it and then he would want his staff men to read it, so he routes it to several assistants. It goes around the circle, which takes time. Then it is passed down to the research supervisors. They all want to see it, so it goes around again making a circle. This pattern of circumlocution occurs at each level of command, and it finally gets down to the research man working at the bench. The complete process can take months and it does.

If you permit a single report to go that way, very serious situations may develop. In every organization the distribution system should be studied to make sure that the communications flow rapidly. There are ways of assuring this if you just use a few precautions.

Let us think of communication up the vertical channel. Suppose that each team writes a report and all these reports come along at the same time. The individual supervisor has three or four teams working under him, so he gets three or four reports. The assistant director has a few supervisors working under him, so he has ten, twelve, or fourteen reports and the research director finally ends up with a hundred reports. That is not a good way of doing business. Actually, this extreme does not occur often. What we are concerned with most of the time are the intermediate cases and how to get these closer to a good, well-functioning system of communication, be it written or oral.

To take care of the case of the technical information coming in to the top level, you can establish a rule that technical reports go to a central office and that the central office put out an announcement of some kind, perhaps an abstract bulletin, or a simple accessions list. This can be used by each of the teams and by an individual member of the team. It is a hard—a very hard thing to do. In the Office of Scientific Research and Development I was in charge of an office that handled exchange of information between our allies and this country. The hardest thing we had to do was to insure that the arrangements for the circulation of reports between groups in England and this country actually came through our office. That wasn't because we wanted to exercise authority. The reason was that we wanted to know that the report was here

and to know its availability. We eventually worked out a system whereby if a report came in addressed to a specific individual we photostated it and in twenty-four hours it was on its way to that man, but we had a copy of it for anyone else interested. It is such devices that can be used to insure that the individual is satisfied, that he gets his information, and also that the needs of the organization are satisfied.

Administrative information, including policy information, in many cases can be supplied in multiple copies so as to avoid a long delay at each level. At each level an individual can be designated to determine the number of copies needed. Once the first distribution is made and he has the initial copy, he simply calls the central office and requests the number of copies needed of this piece of information. It is well to separate as much as possible your routine administrative information from the technical information and from important policy memoranda. If not, you find that technical information of extreme importance is frequently buried or in one way or another accidentally attached to something which announces that there will be a party at the Wardman-Park next week. It will cost you \$1.50 if you are a member and \$2 if you are not a member of the Recreation Club. You can laugh at it, but it does happen that these things get mixed up. In handling reports originating within the organization, it is important to recognize the fact that the research director cannot read adequately all the reports that come out of that organization if it is at all large. He can read abstracts of the reports, but there are a great many of them. So it is important that you recognize that the communications be so established that at each level as you move up the line, there are summaries of groups of reports.

The emphasis changes as you go up the line. A man becomes more and more interested in the number of dollars spent and the over-all progress of a program rather than the details of individual research problems. For this reason, summaries become increasingly important and become for his purposes original reports. They have to be written from the material which is gathered at each level. The need for these summaries must be recognized and man hours assigned to compile them. Thus you have a great number of technical reports being summarized as you move along until, at the final stage, you arrive at the point where the report is hardly technical at all. It has a few technical words in it, but that is all. It is a *management report*. It is the report of the research director to the board of directors or to the vice president in charge of research,

which, of course, is an extremely important report. In a measure, its value depends upon how well the *first* report was written because if the first reports are not well written, the management report may be either confusing or wrong. The summary might state that something cannot be done or that something was unsuccessful which, if the initial report had been written properly, was actually successful, or at least successful enough to be worth another trial.

Bell Telephone Laboratories, for instance, circulates technical memoranda with a specially designed cover sheet on which the individual scientist lists the names of the individuals he believes would be interested in or should know about the subject matter of the report. The cover sheet includes a brief abstract. Certain precautions are taken to protect patentable matter by submitting the memorandum to the Patent Department prior to circulation of the document.

Rules for Communication. *Good communications are really the soul of good teamwork*, either teamwork between individuals in a team, or teamwork between groups in an organization, between management and research and between research and the engineering group. They determine how well the whole organization functions. So the first rule of communications is to *recognize that communications are important*. The second rule is that *there are ways of getting better communications*, both formal and informal. Third, *you need staff men at appropriate places within the organization*. These are men who are outside the authority chain. They do not have any authority because their job is a liaison job. They report to a research director or a research supervisor. These men can be made responsible for the planning of conferences and for writing of minutes for conferences. They can be responsible for the preparation of summary reports. They can also—since they must read reports in order to prepare summary reports—be responsible for reporting progress to their immediate superior. Above all they should be *experts at communications*. In other words, they should be good reporters. They should know how to summarize, how to cite and how to write. They should be aided in their task by editorial assistants who insure that reports conform to established standards. There are a number of helpful references on how to write reports.²

²Dwight E. Gray, *Writing the Technical Report, Technical Report Writing. Good Technical Bulletins, How to Conduct Conferences. The Essentials of a Good Report, Research Reports—Their Form and Usefulness*.

See also Chapter XIV of C. E. Kenneth Mees and Joseph A. Leermakers, *The Organization of Industrial Scientific Research* (New York: McGraw-Hill Book Co., Inc., 1950), 383 pp.

A fourth rule or principle is to *look out for the bottlenecks in your communications systems* and for bottleneckers, and devise schemes for getting rid of these if you can. Some examples are the poor writer and poor speaker. You get rid of that deficiency by making sure that the man is not called upon to speak or that he takes a course in speaking, and you get rid of the writing problem to a considerable extent by providing editorial assistance to poor writers.

Let me summarize by saying that I consider that in communications *every man, whether he is a member of the team or an individual investigator, is a link in the communications system*. The responsibility in regard to communications increases as you progress upward through the chain of authority. Above all things you should remember that the channels go two ways. They go up and they go down. They go backwards and they go forward and don't forget it, because it is extremely important that the people below you have a good deal of the information that exists at the top. And I believe the obligation to the individuals that you are supervising is greater than the obligation to the individuals who are above, because supervisors can ask you for information more readily than subordinates.

12: AUXILIARY SERVICES AS AIDS TO LABORATORY RESEARCH

ALBERT F. SIEPERT

Research is like the search for oil. In 1859, E. L. Drake found the way to obtain oil in quantity by drilling only 69 feet through the sand and rocks of Pennsylvania. This first oil-producing well in the world resulted from Drake's ingenuity in combining an old and a new idea into a practicable method of drilling and casing the well hole. To prove his idea, he required only \$3,000, an improvised drill rig, and a two-man crew. Today, the average drilling attempt probes nearly a mile in the search for oil and some go as deep as 16,000 feet. To explore that deep, the petroleum industry has been willing to invest as much as \$500,000 in a single effort, and normally expects to spend \$100,000 on each well it drills. But the returns from the wells which do produce oil abundantly justify the substantial investment of men, money, and materials which the oil industry now devotes to the search.

A similar development has been true of scientific research. Because the search for important new knowledge requires deep drilling, much of today's research is of a nature requiring increasingly large-scale undertakings.

The basic tool for research is the mind of the individual scientist. When a scientist needs few, if any, tools other than his mind, he can do good work alone. This kind of research is indispensable. But there are relatively few laboratory scientists today who do all their work alone or rely on only one or two assistants to supply their total needs. The complexity of a wide range of research problems requires that the bench scientist have access to the knowledge of various scientific disciplines, to extensive physical facilities, or to complicated apparatus which he cannot obtain or maintain through his own personal efforts. Because of these basic needs, much research has become a teamwork enterprise. The scientist increasingly relies on the support of a wide variety of auxiliary services to do for him what he cannot, or has not the time to, provide for himself.

Auxiliary services in a research program embrace all the technical and administrative activities which deal with furnishing men, money, and materials *except* those under the personal direction of

the bench scientist or his immediate staff. The competence of the research staff is the biggest single factor in achieving high calibre research. But the effectiveness of supporting services can often make, or break, the physical and intellectual environment which competent investigators seek for good research.

The maintenance of an environment which stimulates good research is a primary goal for any research administration. The factors which largely determine the character of the research environment are:

1. The competence and intellectual vigor of the scientific staff itself;
2. The work relationships of the scientists to their colleagues in and outside the organization and to the other employees who assist their work;
3. The adequacy of resources for research; and
4. The effectiveness of technical and administrative services in furnishing these resources to the scientist as he needs them.

The auxiliary services affect all of these factors, but particularly the last two. Under present day requirements for research, what are "adequate" resources and what are "effective" supporting services?

During the past five years, the National Institutes of Health at Bethesda, Maryland, has been trying to develop some answers to these questions. The NIH, a bureau in the Public Health Service, Federal Security Agency, operates the largest federal program of grants and direct research devoted primarily to basic medical research problems. Since the end of World War II, medical research has expanded greatly throughout the country. As is true of many research centers, the National Institutes of Health has been having its share of the "growing pains". It has doubled in size within the last five years and now has 2400 employees, 2000 of these at Bethesda. The Bethesda staff may grow to 4500 or 5000 employees over the next few years primarily to staff a new Clinical Center that will begin operations in 1953. The Clinical Center is an integrated hospital-laboratory facility. It is designed to bring together into a common association or team the basic laboratory scientist and the clinician—the scientist who studies body processes and diseases in test tubes and animals and the clinical investigator who studies the same in man.

Inventory of Auxiliary Service Requirements

1. *Types of Auxiliary Service.* Even a small research laboratory has to provide some auxiliary services. Larger organizations usually find that many of these supporting services have sufficient volume or require so much technical competence that they are best set up as full-time specialized services available to the entire staff. In the National Institutes of Health, the following services—centralized in whole or part—are provided in support of research:

Table I
Auxiliary Services
in a Large Medical Research Organization

<i>Top Program Direction</i>	<i>Technical Aids</i>	<i>Scientific Information</i>
Intramural research coordination	Laboratory Aids, including Precision Instrumentation	Research library
Extramural relations	Animal Production	Photography
Liaison with headquarters & other constituent units	Glassware cleaning & issue of sterile glassware	Medical Arts
<i>Administrative Aids</i>	Glass Blowing	Translating
General Administration	Media Preparation	Scientific editing
Financial Management	Buildings Management, including	Science writing
Personnel Management	Fabrication & Repair Shops (carpentry, metal, electric, plumbing, refrigeration, paint, air conditioning)	Visitor arrangements
Records Management	Laboratory design & maintenance	Public relations
Management Analysis	Safety & sanitary engineering	Statistical advice
Procurement & Supply	Utilities, (heat, water, steam, light)	<i>Other Aids</i>
Property Management		Transportation
Communications		Vehicle repair
Mail, Files, Messengers		Grounds maintenance
Duplicating		
Telephone & wire service		
Machine tabulation		

2. *Distribution of Research and Service Personnel.* In any research organization, there are usually many more people in supporting roles than there are scientists. At the Bethesda headquarters of the National Institutes of Health only 30 per cent of the total staff are professional personnel (i.e. trained for research in science, medicine, engineering, etc.). A little over half of these are experienced, senior investigators. The others are junior professionals who work under the supervision of a senior investigator. An additional 30 per cent also work in the laboratories under immediate scientific supervision; they serve as laboratory technicians, animal attendants, laborers and clerks. The remaining 40 per cent of the total staff are not physically a part of an active research team. They are behind the lines in various auxiliary service posi-

tions, ranging from top program directors to truck drivers and building cleaners. In the Bethesda headquarters staff of 2000 employees, there are 1700 engaged in the NIH intramural research programs;¹ 60 per cent work in the research laboratories under "bench scientist" supervision; 40 per cent are in some auxiliary capacity, located either in one of the institutes or in a central NIH facility. The detailed comparisons by category are as follows:

Table II

Percentage Comparison of NIH Personnel Engaged in Direct¹ Research and those in Auxiliary Services to Research—January 1952.

	<i>NIH Research at Bethesda only</i>	
	%	
Active Research Teams:		
Senior Professional Personnel	16	
Junior Professional Personnel	14	30%
	—	
Lab. Technicians	20	
Animal Caretakers and Laborers	4	
Clerks and Stenographers	6	30%
	—	
Sub-total: Active Research Teams		60%
Auxiliary Services:		
Professional, Technical, or Trade skills	8	
Animal Caretakers and Maintenance personnel	13	
Central administrative personnel	2	
Clerks, Stenographers, Misc.	10	
Scientific information skills	2	
Institute administrative staffs		
(Admin. Officers, Clerks,		
Stenographers, Misc.)	3	38%
	—	
Top Program Directors (NIH and in Individual Institutes)		2%
	—	
Sub-total: Auxiliary Staff		40%
		—
Total Staff		100%

¹The remaining 300 are concerned with research, training, and control grant functions.

In the NIH experience to date, each senior investigator requires the support of $4\frac{1}{2}$ people— $2\frac{1}{2}$ direct staff assistants and 2 others attached to auxiliary service functions. These ratios have only a short-range planning value because they change with the character of research, expansion of physical plant, and the amount of funds available.

3. *Growth of Auxiliary Service in Relation to Expansion of Research.* It is sometimes asserted that, as a research laboratory expands, administrative costs and other indirect research expenses will take an increasingly higher proportion of each addition to the

total research budget. Many regard this an inevitable development on the assumption large scale organization requires that an increasing proportion of the total effort go toward resolving problems of direction, coordination, and communication. This can easily happen, but it is not inevitable.

The experience of the NIH, for instance, does not bear out such assumptions. The organization has doubled in size since 1947. However, the cost of all auxiliary services has increased at practically the same rate as the cost of laboratory research operations. In each of the past five years (1948-52), about 25 per cent of the total funds available for research in NIH laboratories has been devoted to auxiliary services.

Table III

Per cent of NIH Total Research Dollars Invested in Auxiliary Services					
Fiscal Year	1948	1949	1950	1951	1952
Auxiliary services:					
Technical & Lab. Services	17.1	17.1	16.0	19.1	18.4
Administrative Services	7.5	6.9	6.2	5.7	5.6
Sub-total Aux. Services	24.6	24.0	22.2	24.8	24.0
Direct Research	75.4	76.0	77.8	75.2	76.0
Total Research Operations	100.0	100.0	100.0	100.0	100.0

The figures in Table III show that direct laboratory research operations have consistently received about 75 per cent of all research funds even in a period of rapid growth. Within the 25 per cent for auxiliary services, there has been an increasing emphasis on the supporting technical and laboratory services (animal, instruments, media, shops services) and a steady decline in the percentage of funds for administrative services (such as budget, personnel, procurement, etc.). In fact, administration required 7.5 per cent of the 1948 funds and only 5.6 per cent in fiscal 1952, a decrease in itself of 25 per cent.

The personnel needed for the auxiliary service at the NIH has not increased as rapidly as the research staff. During the period 1948-52, the laboratories increased their staff by 90 per cent, but the auxiliary areas increased by only 60 per cent. The reasons for this difference are partly obvious and partly conjectural. More service has been obtained from the same personnel by better or simpler methods or by expanding their facilities. When additional research people are employed to work in laboratories which are

already equipped, more of the direct research dollar can go initially into personal services. This in time, however, may create pressures on central services to convert more of their dollars into materials rather than personnel in order to supply the larger research staff with increased utilities, fabricated apparatus, and other non-personal service items.

The consistency of these figures over a period of years is rather remarkable, since the budget for auxiliary services has not been determined by a mathematical relationship to the amount of direct research dollars requested. Rather, it has been fixed by a process of estimating fund requirements against the known limitations of available facilities and the revealed inadequacies in the present volume of service. For this reason, the same proportions will not necessarily be constant in a future period when the character of research and the type and extent of facilities change substantially.

Top Program Direction

Of all auxiliary services, the most critical to the organization is the type of program direction which comes from the top. The top research administrator and his immediate staff are usually the most effective if they regard their roles more as auxiliary aids to research than as actual directors of the research process.

The decisions they should make primarily relate to the main goals and policies of their organization, to the provision of facilities, funds, and staff for the job. Substantive decisions on changes in direction or content of a particular research study can usually be made best at the research level itself—generally by the project head or his immediate research chief.

This creates few problems when the organization is small. The bench scientist and the administrator can have easy access to each other. In larger research organizations, this face-to-face relationship between the top administrator and the bench scientist usually gives way to an impersonal chain of communication in which the intermediate links are other levels of scientific supervision. The chain can work satisfactorily, provided each link communicates, rather than blocks, what the scientist at one end or the research administrator at the other needs to know.

At the NIH, for example, there are now seven research divisions called Institutes, each headed by a professionally-trained Director.

The Institutes are organized along categorical lines corresponding to major areas of disease: cancer, heart, dental, mental health, microbiology, arthritis and metabolic diseases, and neurology and blindness. Each of these Institutes sets its own research program within a very broad charter. Each supports a substantial amount of fundamental research which may have just as much application to other fields as it does to the categorical program of the sponsoring Institute. Decisions on individual studies are with rare exceptions made at the working laboratory or branch level. In some of the Institutes, an Associate Director is in immediate charge of the research program with the laboratory chiefs reporting to him. The top program directors, consisting of the individual Institute Directors, the Director of the National Institutes of Health, and their immediate staffs, are concerned with broad areas of programs, major fund commitments, administrative servicing, key personnel selections, and external relations. Those closer to the bench are responsible for the planning and conduct of the research studies.

Under this philosophy, it is possible even though the organization is large, to give the experienced investigator a wide degree of freedom to select and plan his own line of study, to revamp the work as his own research leads indicate, and to publish his findings where he chooses. This, of course, is a right which is earned gradually rather than extended automatically. The independence of any given investigator is expanded as he proves that he has the judgment and competence to exercise freedom wisely.

Factors in Organizing and Operating Auxiliary Services

Whether or not a research organization permits the bench scientist free choices in his line of work, the auxiliary services in that organization ought to be geared to what the scientists say they need and not to what someone removed from the bench thinks will meet their need. Actually, there are always limiting factors to be considered, particularly the available money and facilities for auxiliary services. Both the nature and volume of auxiliary services always become a compromise between what the scientific staff would like to have and what they and their chiefs are willing to spend to get it.

Let us assume for the purposes of discussion that the research organization has, or can obtain, reasonably adequate resources for

auxiliary services. In such a situation, what factors need be kept in mind?

1. *Self-sufficiency.* Services for research can be supplied: a) by the research team itself, b) by outside contractors or suppliers, c) by a parent non-research organization of which the research unit is a part, or d) by a central auxiliary service within the research organization. To what extent and for what functions should a research organization be self-contained? Self-sufficiency is a real convenience and, in times of shortage, is often essential. World War II demonstrated this to many research institutions which found otherwise dependable commercial shops and services closing up when manpower and materials became scarce. It is a great help to have administrative and shop services immediately at hand to procure, fabricate, or install and service the incredible variety of specialized apparatus which scientists use today. Even relatively small research units can save time and dollars by equipping and employing several craftsmen and technicians to keep apparatus in working order or to adapt it to other uses.

These jacks-of-all-trades become more specialized in the larger research organization. In 1938, the NIH had twelve skilled craftsmen out of a total staff of 420, but in 1941 increased this group to forty who serviced about 720 employees. This increase was barely sufficient to keep up an expanded defense research program throughout the war. Today, the same ratio is needed—about 100 craftsmen and engineers in ten kinds of shop services to service 2000 employees. This provides no “peak-load” staffing, so that unusual demands must be accommodated by rearranging existing work and placing on outside contract that work which is less urgent or can be secured as quickly or cheaply as if NIH did the work itself.

There may be difficulties in having a parent non-research organization provide administrative and maintenance services. This is particularly true if the servicing points are geographically removed from the research site. Research creates special problems, special requirements, and special urgencies which often cannot be accommodated when the parent servicing staff must also wrestle with the distractions of non-research operations. The NIH medical research program requires some 140 kinds of occupations, 75 of which are occupations not found in the usual office-type operation of the Federal government. With the aid of a special NIH Board of Civil Service Examiners as a recruiting source, our own Personnel Office at the NIH makes all appointments except for employees at

or above a \$9600 salary which require headquarters concurrence. Similarly, maintenance of a laboratory building is a vastly more specialized function than maintenance of an office building. Through special legislation and arrangements with the government's landlord, the General Services Administration, the NIH maintains its physical facilities with staff under its own supervision.

The extent to which self-sufficiency is desirable will depend on the size of the plant to be served, and its geographical proximity to other dependable services. One of our main field stations, the Rocky Mountain Laboratory, has only about 120 employees, but is located in Hamilton, Montana. It has virtually complete shops and maintenance services because of its isolation from outside sources of supply.

2. *Coordination of Services.* The top research administrator cannot personally supervise and coordinate the wide diversity of technical and administrative skills involved in providing auxiliary services. It appears more practicable to organize them under one or two assistants who are directly responsible to the research administrator. This assistant (or assistants) may come from any academic background, provided he has had considerable administrative and supervisory experience. When the NIH was expanded in 1947, the administrative and technical laboratory services were re-grouped under an Executive Officer with a public administration background, and the scientific information services were placed under a science writer with experience in various public health operations. The exact division of functions between the general assistants would not be critical, since there should be a technical specialist heading each of the various services, e.g., a veterinarian in charge of Laboratory Aids, an engineer in charge of Buildings Management, a trained librarian in the Research Library. The specialists can be their own bosses on technical matters; they look to the Executive Officer or Scientific Reports Chief largely for administrative coordination of their work with other units and with over-all policy.

3. *Centralization versus decentralization.* Whether a particular auxiliary service operates on a centralized or decentralized basis is best decided after considering a number of conflicting factors and pressures in each case. The most important factors in supplying a service are usually its volume, economy, quality or convenience to the scientist. There is little point in centralizing a service which

is needed by only one segment of the research staff, which involves few specialized skills or equipment, or which does not have enough volume to warrant a full-time service staff. On the other hand, consideration should be given to centralization if a uniform quality of service is needed by several research groups and if specialized skills and equipment are required to produce it. The highly-skilled craftsman is always in short supply; relatively fewer are needed in a centralized shop where the maximum advantages can come from diversity of work, flexibility of equipment, and steady work-load.

Usually the conflicting factors can be logically reconciled to the satisfaction of most of the scientific staff. The solution may involve a combination of centralized or decentralized service. For instance, the NIH has a central animal production unit which raises 600,000 mice and 100,000 animals of other species each year. But separate animal colonies are maintained when the growing or breeding process is an integral part of a genetic research study. We have a central glassware unit. But some scientists have their staff wash their own glassware, when the same calibrated glassware is reused on the same experiment or when their requirements of chemical purity for an experiment are different than the central unit's standards of sterility.

One of the NIH's most appreciated services is a Precision Instrument Shop which designs, fabricates, modifies, or repairs practically any type of scientific apparatus. Yet there are a few small instrument shops where, for example, a biophysicist himself can work on whatever devices he needs in his research. Each is a specific case to be decided in relation to the factors previously mentioned, plus the availability of necessary and suitable space.

4. *Administrative Links between Researchers and Services.* If the organization becomes large and if a number of the auxiliary services are centralized, the services and the laboratories must often be located in separate buildings and organized under separate leadership. Then scientists and the supporting services easily lose touch with each other's problems. It may no longer be easy for the research staff to know the servicing employees personally. Arrangement for service becomes a matter of paper work rather than personal, friendly negotiation. Where size and physical separation do create this barrier, some new communication link must be added. Unless this is done, the research staff member will find it necessary to devote excessive time to administrative dealings in or-

der to obtain what he needs from auxiliary service units, or he will undertake to perform certain of the routine service functions himself.

One link in the communication between researchers and servicers can be established by the proper location of someone who has a developed skill in the field of administrative management. Insofar as possible, he should be a generalist, or jack-of-all trades, in administration. At the NIH, we locate an administrative officer with the director of each Research Institute. The persons who usually fill this type of post well are those with a liberal arts background or other type of broad college training plus various experiences in public administration and business methods. The administrative officer acquires, or is expected to acquire, his understanding of research by on-the-job personal experience in servicing scientists and laboratory assistants. The reverse technique, i.e., "re-treading" a scientifically-trained employee by on-the-job experience with administrative problems is less practical in view of the continuing shortage of research manpower. This latter approach can work, however, if the scientist has a definite preference for administration rather than research, and a real aptitude for the inter-personal dealings on which successful administration depends.

The administrative generalist described above is expected to carry out a number of functions. He participates as adviser on administration to the Institute Director and his key scientific staff. The extent to which he participates in top policy formulation and programming of research operations depends largely on the competence of the generalist and the degree of confidence the Institute head has that the generalist can act with or for him where scientific judgment is not essential. Under basic guide lines established by the central organization, the administrative generalist obtains necessary auxiliary services for the bench scientists, particularly in budget, personnel, and procurement matters, by (a) helping them requisition services with a minimum of effort, delay and inaccuracy; (b) keeping track of fund and personnel commitments to the various research units; (c) acting as liaison representative with central services to obtain a fair share of the available services, to resolve any questions concerning requisitions for service, or to expedite the furnishing of such services; and (d) supervising and/or training clerical assistants in necessary administrative procedures. The administrative generalist also advises the scientific staff on those essential administrative tasks which supervisors gen-

erally should know about and perform themselves in order to maintain effective working relationships with their own staff.

The administrative generalist can be a member of the central servicing staff detailed physically to work near the research laboratories. The difficulty with this plan is that he is likely to give his prime loyalties to the servicing structure instead of the research program. The NIH believes the better way is for the chief of the research division (or Institute) to take personal responsibility for selection and supervision so that the generalist is identified primarily with an operating research program. Obviously, some administrative personnel find it harder than others to be loyal to the research program of their supervisor, without sometimes overlooking the interests of the total research organization. This makes it difficult for central services to work out mutually agreed and equitable plans for servicing all the research areas.

On the other hand, the generalist sometimes feels helpless because he can only "request" rather than "order" some auxiliary service to be performed. And yet no auxiliary service machine could run effectively if each of a variety of administrative generalists were to insert his own personal crank in the machine in an attempt to grind out the service his research staff wants.

Even though this arrangement of administrative "generalists" does not work easily or perfectly, the NIH still feels after four years' experience, that the arrangement holds the best promise of bridging the communication gap between scientists and their auxiliary services. Someone has aptly said that *ease of administration* can often be mistaken for *effective administration*. This can be just as true in research organization as in any other activity.

5. *Financing Auxiliary Services.* How the operating units pay for services provided by a central organization may have some effect on the adequacy of the service. There are at least four ways to finance supporting services. First, a single appropriation or general fund can finance all services without specific charges to the research laboratory budgets. Second, each research program can carry on its payroll a share of the central service staff and other expense. Third, each research program can be charged an *a la carte* fee for each service it receives. Fourth, each research program can pay into a central fund a pre-determined share of the total central service costs.

The single appropriation for auxiliary services is simple and adequate so long as the amount of the general fund has some relatively constant relationship to the amounts which are appropriated separately for the various research programs. The NIH had to discard this method when its general appropriation could not keep pace with the increases in research funds provided through special appropriations. For a time, services were expanded to meet these increased research demands by the second method of adding auxiliary staff which were carried on the laboratory payrolls. This, at best, is only a temporary expedient that results in complicated payrolling and bookkeeping. The third method—a reimbursement for each service—involves extensive cost accounting to be equitable and considerable clerical time to operate it. It can be a precise method for allocating costs to each project and it can make the research staff more cost-minded. Whether these are advantages which are worth the expense of such a system is a matter each research organization must determine in relation to its own needs.

The National Institutes of Health has adopted the fourth method—a joint sharing of the total service costs. In 1948, it established a reimbursement formula in which each of its five research appropriations bears a predetermined share of the total cost. This share is determined each year in proportion to the number of people to be served, the dollar size of the research program, and other easily available factors. Although volume of service has not been used as a factor, we have been checking selected work indexes and find that the actual distribution of service to each of the research areas comes surprisingly close to their reimbursement shares.

Under the system the National Institutes of Health is now using, all central service personnel can be carried on one payroll with funds transferred as a contractual service into the central appropriation for expenditure. It is recognized, of course, that this approach would be of less value in developmental or contract research where specific costs per project may need to be determined.

6. *Distribution of Services.* In a recent address, the Director of the National Institutes of Health remarked: "Realistically, freedom of research rests not upon freedom to requisition unlimited resources, but upon freedom to follow leads and hunches." Since the service resources are limited, how can they be distributed most effectively when the demand exceeds the facilities? Under normal circumstances, the scientist or his supervisor can be free to determine and requisition his own needs. If he needs personnel, or

equipment to be paid from his own research allotment, the funds are of course a self limitation. When the services are available centrally and without direct cost to the laboratory, the research worker is expected to keep in mind that these services operate "family style". At a "family style" table, those with inordinate and inconsiderate appetites are conspicuous. In cooperation with the supervisor of such individuals, corrective treatment can be arranged. It is usually possible to control the few without issuing ration books to everyone.

There is, however, a constant problem of keeping services adequate for a growing research program. When funds are limited, a space expansion with moderate or no personnel increase can sometimes help greatly. The NIH animal colony, for instance, has doubled production since 1947, by increasing space 110 per cent, and staff only 50 per cent. Less often a personnel increase in existing facilities (such as a night shift) may be an answer. The NIH Instrument Shop was put on double-shift for six months to reduce a serious backlog. Later experience showed that re-arrangement of facilities to accommodate the increased staff on one shift was a more satisfactory solution.

When expansion is planned, it is important to keep in mind that research requirements change unpredictably. Three years ago, our staff needed more guinea pigs and rabbits, so we secured the use of a farm and in six months doubled production. Then, the demand abruptly slackened in favor of suckling mice, because scientists found these have unusual value in virus research. The problem is complicated by the fact that it involves not only delivering the suckling mice to the laboratory, but also losing the mother from the breeding stock. A year ago, the demand was only 100-150 litters a week; the level now is 500; the needs are 600; and we would like to plan for 1,000 litters a week if we had space and personnel. Research changes like this place a premium on the design and use of service facilities for maximum flexibility.

If auxiliary services cannot expand or change their service to meet new demands, then rationing or allocation becomes inevitable. Occasionally, the only step needed is to ask the laboratories to re-appraise their backlogged requests, cancel those least essential, and assign priorities to the rest. Rather than cancel work, laboratories sometimes may want to advance funds from their own allotments in order to solve a temporary need for services. This solves only an

immediate problem, for it is merely temporary financing of what usually becomes a permanent expansion of demand.

If such steps are not adequate, actual quotas may be necessary. In our Instrument Shop, we have had to establish annual quotas of man-hours available for each Institute. No one is happy with rationing, so particular efforts must be made to explain to the scientist what is possible in quantity or quality of production.

The auxiliary staff should try to establish for itself specific goals of performance and let the research staff know what the standards are. It does not follow that each scientist will accept these as adequate standards in meeting his day-to-day needs. Research men are quick to express appreciation for excellent quality of service, but are just as apt to note that the delivery was behind their expectations. This is understandable and, not infrequently, it is a justifiable criticism of the auxiliary service. It is no satisfaction to a scientist to know that the "average processing time" for a purchase order has been out from 20 to 30 days if he needs a particular item delivered tomorrow. Most of us judge the speed of the waitress who serves us food in terms of how hungry we are and how fast we think we could do it ourselves. As in any good restaurant, the service staff must be sensitive to the expectations of the customer. For the same reason, the auxiliary staff in a research environment should be continuously motivated to "service the research" rather than to "service the service branches".

Aspects Peculiar to Certain Supporting Services

1. *The Budget Process.* Obtaining funds and managing the expenditure of funds for research is an auxiliary service in itself. If bench scientists are to do any research, the budget work must be done for them by others who devote most or all of their time to it. In the federal service, the appropriation process seems to take fourteen months out of every twelve. At one time, a government agency is operating in one year, presenting its program to the Congress for next year, and justifying before the Bureau of the Budget its plans for two years ahead.

Under the circumstances, it is advisable to distract the bench scientist as little as possible on budget matters. Usually, it is

necessary to ask him only once a year to estimate his program needs. From this, auxiliary personnel can figure the costs of the personnel, equipment and supplies he needs. Obviously, his plans for research are seldom crystallized for an operating period 18 to 30 months away. Except perhaps on developmental engineering projects, it would be a mistake to try holding him to a planned timetable. If a scientist develops a really good idea, he usually starts on it immediately if he possibly can adjust his time and resources. Hot leads are seldom deferred to wait for appropriations.

The active research investigator does not concern himself much with budget estimates as a device for planning his own work. Between inception and completion of an appropriation, there are many changes in the budget figures and many changes in research ideas. It seems better for program directors to wait for definite assurance as to the amount of available funds before involving the bench scientist in plans to expand, curtail, or convert his research studies.

In the federal service, the task of preparing a budget request and defending it before those who frame the executive budget and before the Congress is a particularly important part of research administration.

Budget preparation and defense involves three parallel lines of effort. The first is to determine how the research program is to be shaped, so far as this is controlled by the volume of funds. The second is to translate these broad decisions into the multitude of figures which show the detailed financial requirements of each program. Additional and extensive data that are not required for the budget document itself must be assembled to provide answers to a wide array of questions about the research program. The third task is to explain the budget and the program behind it to the Bureau of the Budget and to the Congress. This requires both written and oral justifications.

The first task is one of top management, and requires pooling the judgments of those who have the major responsibility for the operation of the organization. The second task is a highly technical one which must be handled by people trained in the intricacies of the Federal budgetary format.

The third area of effort involves careful, precise and persuasive writing. A good written budget justification is a difficult thing to

prepare, because the purpose, the accomplishments and the aims of the organization—as well as the bare recounting of what the money will be spent for—must stand out clearly if the job is to be effective. This work requires both scientific and administrative talent, preferably of those who are in close contact with the research program they are describing. Of equal or more importance than the written justification is the oral testimony of those who present the budget to appropriating groups. Men with a laboratory research background sometimes have difficulty in the role of a budget witness. One reason is the fact that the vocabulary of the scientist is not the vocabulary of the administrator or legislator. The burden of responsibility nevertheless rests with the scientists to use lay terms which will explain his program.

Another difficulty is that training and experience in medicine or the physical sciences is not ideally designed to produce an understanding of the administrative and political process. Often research people must exert a conscious effort in order to understand why the Congress has a legitimate interest in research, and how the content and objectives of research can be communicated to people whose experience and training is outside scientific fields.

Flexibility of research funds is also very important because research can be quite unpredictable. If research projects become specified and fixed in the appropriation structure, the earmarked funds often outlive their scientific importance. Lump sum appropriations, on the other hand, permit desirable flexibility. With a lump sum appropriation, the NIH in 1950 was able immediately upon the Mayo Clinic announcement of the startling effects of cortisone on arthritis, to realign its funds and initiate a substantial program of research on the new compound and its effects on many diseases.

2. *Personnel Operations in a Research Environment.* The management of the personnel function is particularly challenging in a research institution. In the government, an alert personnel staff can do a great deal to adapt civil service procedures to fulfill rather than frustrate research needs. The staff can also take leadership in promoting the human relations factors which build teamwork between scientist and laboratory assistant, between scientist and supporting services. This paper does not go into the critical questions of selecting and evaluating research personnel, since others at this conference have discussed these points.

The NIH has recently installed a personnel generalist system, so that a research supervisor can deal with one technician on all personnel matters instead of with various specialists in recruitment, classification, training, and employee relations. In the first nine months under the generalist plan, the personnel office handled the same load of personnel actions with a 10 per cent decrease in staff. Better yet, the number of unfinished actions at the close of this period was 44 per cent less than the number pending just prior to starting the personnel generalist system. Careful training of the would-be generalists is essential to the success of such plans. In the NIH experiment, 60 hours of formal instruction were given before the group began work as personnel generalists.

3. *Public Information on Research Progress.* The current interest of the general public in scientific research has created great demands for preparation and release of information by the research organization. The scientist is prepared to publish his own scientific findings in a professional journal of his choice, but he properly shrinks from any participation in the "Gee Whiz!" type of scientific prognostication which finds increasing space in some mass circulation magazines. What is needed is for scientists to accept a greater part of the responsibility for getting the accurate information before the reading public. He can do this by cooperating with trained science writers. Such writers, either as employees or "free-lancers", can be a most valuable auxiliary service if the organization sees to it that all releases are in keeping with the dignity and purpose of research and within provable scientific findings.

4. *Allocation of Space.* So far as practicable, the detailed control of research space should rest near the operating level where the substantive research decisions are also made. At the highest levels of program direction, space allocations are determined according to the relative emphasis to be given major program areas. The NIH assigns space en bloc to the research Institute and requires reporting, rather than approval, of any internal space adjustments. We have developed a punch card analysis of space utilization. It supplies data which are indicative, but seldom conclusive, when space adjustments become necessary. Space requirements for laboratory work differ greatly according to the field of research. As a general average, we are finding that 37 per cent of total net space devoted to research purposes is actually available for the laboratory work itself; in such space, an average 150 feet

per laboratory worker seems to produce an effective work area. Because of varying needs and temporary space limitations until the Clinical Center opens, the average today is as low as 110 square feet per worker in a few of our research laboratories.

5. *Procurement.* Of the total research dollar at NIH, approximately 70 per cent goes into personal services and 1.2 per cent for travel. The balance of funds (28.8%) goes into procurement: 10 per cent for equipment, 13 per cent for supplies, and 5.8 per cent for such miscellaneous items as communications, rents, and contractual services.

Purchasing by a government agency requires compliance with many technical conditions designed to protect government funds and provide open, competitive bidding. It is usually economical and practicable to centralize all purchase and supply functions in a single staff which can specialize in procurement of scientific apparatus and supplies. For small isolated field laboratories, special delegations of direct purchase authority may need to be given the official in charge. This saves time and money, particularly when local supply is available.

The emphasis in research procurement must be on accuracy of specification, speed of delivery, and minimum cost. In the larger research organizations, there are a number of opportunities for a central purchasing staff to improve the accuracy, speed, and economy of its service.

(a) Step-by-step analysis can locate and remove bottlenecks in the processing of a requisition into a purchase order. Within the central NIH purchase office, the average processing time has been reduced from 20 working days in 1947 to 5 in 1951. Half of all purchase requisitions are now processed within three days.

(b) Consolidating requisitions into single purchase orders, and using open accounts with frequent suppliers, can increase production without corresponding increases in the number of purchase clerks. Compared with three years ago, the NIH purchase personnel is handling a 26 per cent increase in the number of "line items" ordered with an 18 per cent decrease in the number of purchase orders written. In the same period, the staff has increased by 13 per cent.

(c) Large-scale research offers opportunities for obtaining substantial discounts by quantity purchases of specialized ap-

paratus and supplies. Central purchase and storage has made it possible for the NIH to save in discounted prices on one commodity alone an annual cost of \$90,000. When bought in lots rather than one at a time, stock purchases of expensive but standardized pieces of equipment eliminate long delivery delays and cost less per unit.

(d) Adequate stocks of commonly used items should be maintained in centrally located supply rooms available either through one-day mail order requisitions from a stock catalogue, or over-the-counter emergency service. The number of "out-of-stock" items should be kept to an absolute minimum in order to reduce excessive ordering by research workers who otherwise feel they must hedge against an uncertain supply in the future.

(e) Emergency purchases of items not carried in stock (such as 40 cents worth of liver) can be handled by creating petty cash or agent cashier funds to facilitate cash purchases. Emergency orders can also be arranged entirely by telephone. The research worker phones central purchasing which places the order by phone and arranges prompt delivery with the local supplier.

(f) Establishing an equipment loan service can make apparatus immediately available to a scientist instead of making him wait for delivery of a permanent purchase. For short-term research projects, a loan may obviate the need for purchasing an additional piece of expensive equipment.

(g) Overhead expense and processing time can both be reduced by organizing training courses to show the requisitioning personnel from the laboratories how the central purchasing service processes requisitions. Such on-the-job training can eliminate much of the delay and confusion which arises from inadequately prepared requisitions.

(h) Shortening the time-lag in paying invoices will earn greater cooperation of manufacturers in giving good service and prompt delivery. Those in charge of auxiliary services should give particular attention to the relationships between the requisitioner, purchase and supply, and the accounting and auditing staffs, each of whom can become a bottleneck in the flow of paper which must document and precede the payment of any bill.

6. *Development of Shop Specifications.* Auxiliary shops can do work of exceptional calibre if adequately equipped, competently staffed, and operated in close collaboration with the scientist. In

fact, the problem of quality frequently may be that the skilled craftsman wants to put more quality into a job than it needs. The scientist is expected to develop the performance requirements he needs for a piece of equipment, but the responsibility for design specifications should be shared between the scientist and the fabricator. Shop heads should have freedom to reject custom-designed jobs when the same performance characteristics can be obtained from commercially available products. Delivery time and comparative costs are, of course, factors which often dictate exceptions. Precautions should be taken not to rely entirely on commercial specifications for work which must be specially adapted to research needs. A trained engineering and drafting service specializing in research design can be most useful in planning major construction and installation projects.

CONCLUSION:

A Way to Work Towards Teamwork

A combination of scientific competence, technical skills, and administrative abilities is required to create and maintain a good research environment. The work of an operating research unit is built around the abilities of its scientific and technical talent, but its leaders cannot be effective unless they understand something about managing resources and supervising people. This is also true for the top program leaders. The work of the other supporting services lies in the fields of technical production and business management, and yet its leaders cannot be effective without appreciation and respect for the scientific method. The development of these insights by both scientific and administrative personnel depends upon each learning from the other through the practice of working together as a team.

Teamwork can assure that auxiliary services will really serve research. The basis for teamwork is adequate communication, and it is not easy to achieve adequate communication in a large organization. Auxiliary services can easily be out of touch with the scientists' real needs and not know it. Much of the adjustment in their operations is based on the complaints or the helpful tips of an articulate few. Some method of communication should be devised to determine whether the rest of the research staff—who say nothing—are satisfied with, or resigned to, the service they receive.

The research environment, as we have mentioned before, is really the composite attitude of the research staff towards their work, their human relationships, their material resources, and their supporting services. Normal supervisory channels of communication cannot collect and interpret the real attitude which staff members have toward these factors. As a partial answer to this problem at the NIH, there is now a representative committee of bench scientists and administrative staff advising us on how to study the impact of administrative chores on utilization of scientists' time for research.

We have also been interested in the techniques of research into social organization, such as those used by Dr. Rensis Likert and the Institute for Social Research at the University of Michigan. The interview and questionnaire tools being developed today offer a promising way of appraising the attitudinal factors which help determine the effectiveness of workers in a research environment. To date, such studies have been confined largely to industrial situations of a non-research character. Data secured from research organizations through such techniques might well have valuable application for research administration generally.

Continuing study of attitudinal factors toward supporting research services would need to be linked with a willingness on the part of the auxiliary staff to adjust its performance standards to the revealed expectations of the scientists. In case the resources to do this cannot be obtained, then it is essential to adjust the expectations of the research staff down to the realities of the situation. Either way calls for close communication between both groups, as well as careful study and informed action by the research administration. From such study, real progress should be possible in evaluating how effectively auxiliary services are aiding research teamwork.

13: ADMINISTRATIVE SUPPORT OF "SECTION T" RESEARCH AND DEVELOPMENT PROGRAM

R. B. CURRY

A review of the origin and operations of research and development under the "Section T" pattern of organization of the military and government civilian agencies, and industrial and university laboratories discloses a richness in heritage of notable records of accomplishment and technical success in a task force type of approach to an undertaking involving a wide cross section of the physical sciences. This report is to develop the story of the administrative support for this unique framework of technical organization.

From the previous discussions, it is readily seen that the Section T relationships between the Technical Director and the operating organizations were designed to be as divorced from the need of administrative support as any framework could be; that administrative support, while essential, was incidental; and that while administrative support was utilized, the exigencies of the time required all emphasis toward meeting pressures of the moment regardless of administrative consequences.

By judicious notice and a little analysis of later discussions of the origin and the current operations of the Section T program, it can also be seen that today the boundary conditions are changed from those due to wartime pressures. However, to the greatest extent possible, decisions today are still reserved to the technical staff; their panels, boards and committees function and have reserved for them the complete right of decision regarding technical objectives and the methods for achieving them. They need only know today's broad boundary conditions within which they operate and an understanding of the degree of operational freedom within those parameters.

Briefly stated the present Section T Associate Contract relationship is composed of a group of direct prime contracts between the military contracting agency and a number of industrial and university contractors for the conducting of research on a broad task in accordance with technical direction by the Director of the

Central Laboratory. These associated contractors function under administrative control of individual prime contracts made with the Department of the Navy or other military service or federal agency sponsoring the work.

These contracts were an outgrowth of the concept of research and development contracts adopted during the war which in themselves were quite a transition from the stereotyped ideas on procurement contracting and which have led to the more flexible research contracts of today.

The Section T contracts with industrial and academic institutions set forth that research and development work will be undertaken on tasks assigned by the Chief of the Bureau. These supplementary task statements stipulate that research and development in specific areas will be performed in accordance with the technical direction of the Applied Physics Laboratory of The Johns Hopkins University.

Consequently, there are two lines of control to the contractor: first, the administrative contractual control *not* from the Applied Physics Laboratory but from the Navy, the contracting agency itself, and, secondly, the technical control exercised by the Laboratory. Thus, there is not and can not be functional administrative support in the Section T operation deriving from the Central Laboratory. The University has no fiscal, accounting, payroll, disbursing or audit functions with respect to the associate contractors; no personnel recruitment or personnel relations responsibilities; no direct security responsibilities; and, similarly, no building, transportation, or service type functions. The central technical direction of the program is as divorced from administrative support requirements as is possible.

This elimination of administrative control is a tremendous help to the technical effort. Unencumbered emphasis can and is placed on the technical direction of the program. It is not always possible to avoid involvement due to the fundamental nature of some problems and in other cases due to existing boundary conditions. However, assumption of responsibilities by the Central Laboratory is almost entirely in the nature of lending of assistance and not exercising direct control. Two areas in which administrative support developed on technical decisions were personnel and facilities.

For example, it is apparent from Dr. Tuve's presentation that wartime pressures made it expedient that some control be exercised over the assignment of personnel or the assignment of problems or even contractors within Section T in order to utilize the highest

qualifications and talents of participating personnel in the component and technical problems of the broad tasks undertaken. In the justification of facilities also, the requirement for plant expansion and specialized facilities most frequently grew out of a program-wide requirement, not necessarily peculiar to one contractor. However, these areas of administrative support were so interrelated to technical direction itself that a separate existence may not be considered recognizable.

After relief from the pressures of actual war and combatant time scales, the need for greater utilization of administrative support grew until the peace-time operations and economy considerations dictated a completely different set of boundary conditions for technical and administrative operations. The transition from the war-time concept of operations to continuing research and development in a peace-time economy created many administrative problems. New interests were introduced by the change of sponsors from emergency organization (OSRD) to the Navy. Realignment of the administrative organization to better understand, write, agree upon, and carry out the contractual obligations was dictated by a completely new philosophy of contract operations in peace time. A modified administrative organization and changes in University policy were required to meet the new problems. The war is over. Unlimited overtime, materials at any price and many other operating practices which tend to increase costs are no longer acceptable by the contracting officer as necessary to performance of the contract. Today expenditures must be justified on the basis of good business practices, not alone the saving of time. Nowhere now can one say "Don't you know there is a war on?"

The war-time employment of personnel on a 'no gain—no loss' principle cannot be applied today. A little reflection on personnel recruiting and personnel turnover will show how far removed we are today from any concept except salary competition. Employment today is motivated by need for personal gain induced by a rising economy. We are in an area of keen competition for qualified personnel and the war-time feeling of participation, achievement and contribution is understandably subordinated to personal accomplishment and an improved individual standard of living.

The Laboratory has, of course, its own administrative support team for its internal operation, but our discussion here is the administrative support for the Section T program. Consequently, we have been noting in the report on administrative support as much what it is not as what it is.

There is, however, some administrative support to the Section T program peculiar to the operation of the Central Laboratory that should be described, even though the over-generalization or over-simplification of the functional organization is made. This support embodies several areas, all of which involve communication as the term "communication" is used in administrative circles today, that is, communication in the broadest sense. This support falls naturally into four major groups, but it should be emphasized that from an administrative point of view they are essentially problems of communication, internal and external, with information and understanding flowing in both directions.

The four areas of administrative support or communication are:

1. Technical Planning
2. Fiscal Planning
3. Technical Reporting
4. General and Miscellaneous Planning

First, technical planning embodies the task boards, technical panels and committees that generally parallel the breakdown of the broad task into component technical effort areas that Dr. Gibson enumerates, such as combustion, guidance, engineering, analysis, propulsion, aerodynamics, etc. This technical planning, includes facilities requirements. Administrative support of this character begins very early in the formulation of plans for technical applications. Another aspect of technical planning is carried out by a group of liaison representatives, usually engineers who bridge the gap between the research laboratory, the technical panels, boards and committees, and the operating personnel of the industrial contractors. The responsibility throughout the field of technical planning is to promote and achieve a meeting of the minds on technical problems through direct two-way communication with both groups.

Secondly, in order to implement the technical plans, some method for planning financial implementation had to be devised. There is, of course, no legal or administrative mechanism between the associate contractor and the Central Laboratory for the funding of contracts. This is a contractual matter between the individual contractor and the Navy. Fiscal planning is accomplished by direct communication between the contractors and the Central Laboratory through the media of task board meetings, liaison officers, problem statements, budget estimates and fiscal data and other informative memoranda as the communicative means of translating technical planning into financial developments.

The third area—technical reporting—is a direct communication problem. It follows quite obviously that the elaborate contractor task and problem assignment in many technical fields would require close technical coordination which could be achieved only by effective technical reporting. Since the end product of this research and development task force is technical progress rather than the “hardware,” the Section T contract organization with each handling a small segment of the broad task and operating in many technical fields would necessarily require an extensive and elaborate system of reporting scientific and engineering progress. By a system of review and cross checks with ultimate responsibility assigned to the Central Laboratory, the technical integrity of reports is under constant scrutiny and verified before its release as the authoritative report on progress.

The fourth class of support deals in other areas relating to general policy and operating decisions between the Navy, The Johns Hopkins University, industrial contractors and university contractors. The policy decisions establish the boundaries of operation and participation in the research, development and prototype production areas of effort. Such decisions, of course, must be made at the general management, director or chief executive officer level of the participating organizations. Operating decisions include miscellaneous support to organizations, mostly the smaller organizations, in the matters of legal liaison, patent counseling, public relations, personnel planning. Miscellaneous items or functions of administrative organization are handled on an informal cooperative basis.

In summary, it may be said that the objectives of administrative support have not changed since the origin of Section T, but the boundary conditions have shifted. Dr. Tuve's running orders are history and although picked up and actually published by the Navy they cannot serve today's rules of how to get things done. When one reads them and remembers the year of 1942, one will appreciate why Dr. Hattery made them available. One must also appreciate that “there is a place for everything, and everything a place,” and that today's half-war, half-peace is not the place for war time orders. But within that qualification, the objective of administrative support in the present period of stressed international relations and limited conflict in Korea is to further foster and observe the spirit of endeavor that characterized the successful exploitation of the task force approach to a research and development program, as conceived and applied in the Section T Research and Development

Program. Within the parameters of today's operations, the goal of administrative support is still that the technical man makes the decision. Our job is to completely eliminate, to minimize or to alleviate those parameters so as to compromise or influence a technical decision as little as possible.

PART FOUR

CASE EXAMPLES OF TEAMWORK

EDITORIAL NOTE: One of the most remarkable scientific achievements of World War II was the development of the proximity fuse. The work was carried on under an urgent time schedule and in the face of major problems of mobilization of scientific talent, secrecy of operations and the established paraphernalia of legal and other procedures associated with any extensive research operation and perhaps with government-sponsored research operations in particular.

Much of the story has been told in Irwin Stewart's *Organizing Scientific Research for War*.¹ A more detailed account of the mode of research organization and administration developed in connection with work on the proximity fuse which came to be known as the "Section T" system is found in a Master's thesis submitted to The American University².

In the two ensuing chapters by M. A. Tuve and R. E. Gibson and the preceding one by R. B. Curry, the spirit and the operation of the Section T system during World War II and in the post war period are related by the responsible leaders of the system. Dr. Tuve, for whom the system was named, was in charge of the war-time development of the proximity fuse. He thinks of his contribution more in terms of a "spirit" of organization and administration than a "mode." Dr. Gibson who inherited the personnel and goals of the wartime Section T, has further developed the mode which includes a system of subcontractors associated with a central laboratory. The system however, has been placed by Dr. Gibson on a philosophic base of scientific investigation. Mr. Curry, assistant to Dr. Gibson for business operations, has developed in a systematic way the administrative support for the Section T system.

In these three papers one sees the development of a mode of operation, supported by a spirit and a philosophy, adjusted to changing conditions and changing demands. Throughout is the concept of concerted effort, teamwork and support toward a group goal.

¹Irwin Stewart, *Organizing Scientific Research for War; The Administrative History of the Office of Scientific Research and Development*. (Boston: Little Brown and Co., 1948), 358 pp.

²Norman T. Rasmussen, *The Section T System*. Thesis, American University, Washington, D. C. 1951. 213 pp. multilithed. ("Running Orders" are on pp. 12-13.)

14: DEVELOPMENT OF THE SECTION T PATTERN OF RESEARCH ORGANIZATION

M. A. TUVE

I am sure it is difficult for all of us to go back to the summer of 1940 and get our minds in the framework of the pre-war situation, but I believe a quick sketch of the history of Section T might be of some interest.

In the late autumn of 1939, we reached a conclusion that if the world was going to be inherited by people like the Nazis, there wasn't any point in doing a great deal of basic research. We had better get ready for the defense of freedom. We actually stopped work in our Carnegie Laboratory in the early spring of 1940 in order to see how we could prepare ourselves to take part in the fracas. This bore fruit in a series of discussions with Dr. Vannevar Bush and others which resulted in the establishment of the National Defense Research Committee in June 1940. Then I chewed nails in Minnesota while my clearance was being settled, but as soon as that came through I received the assignment from Dr. Richard C. Tolman and from the Navy Department, to work on influence fuses and on preliminary investigations of other ordnance problems. This led us into work on all kinds of influence fuses for bombs, rockets and artillery shells. The organization grew from the four men in our Carnegie Laboratory¹ to about 1100 at the end of the war.

The recruiting policy is of some interest. If you simply pick out at random people in a crowd the chances that you will pick a traitor are one in a million or less. That is safe enough in a war, so we said "Don't take anybody that applies, but ask your friends who might serve." This is the way Section T was recruited. Each man was asked to nominate new people who might come.

The history of development of the proximity fuse has been adequately covered in newspapers and other places since the war. It was not easy. But I want to point out that it was engineering development, not basic research. "Team work" is always develop-

¹Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C.

ment, research is an individual activity. There was very little research done during the war. We were concerned with running engineering development, goal-focused activities, and this is quite different from the aims of natural philosophy, which at least according to my early training represented the goals of research, disinterested knowledge for its own sake.

With that much of an introduction, let me say that we had quite a lot of experience on how to run engineering development. I suppose that *it was the spirit of the thing* that was of greatest importance, and, in fact, one of the principles under which we operated was to make sure we didn't get in the way of the spirit of things. There were a few basic points that came up—probably came up out of the way in which the Office of Scientific Research and Development and the National Defense Research Council were set up. They were set up by scientific and research people, men who had a fair amount of experience in developing practical things and these men were the final authority, not the banks, not the budget office, but the technical people.

"Is it feasible and can it be done quickly?" These were important questions, as indication of some of the boundary conditions. They were conditions highly specialized and appropriate only to the war time. The penalties were different from civilian research and activity. The penalties were extreme for failure—men that we cared for were shot. The penalties for fiscal failure were negligible. This was a special boundary condition.

We ran by a succession of slogans, matching the particular difficulties as I saw them. One of those slogans was—and it lasted quite a long time—"I don't want any man in this outfit to save money. I only want him to save time," and we put some vigorous penalties on people who were trying to save money. I coupled that also, however, with the fact "*You fellows have lost your sense of what a million dollars means. A million dollars is six men in slavery for a life-time. Don't you forget it.*" This was our human measure of finances. These were constantly driven home.

One of the very important conditions was that everywhere through the organization it was recognized that *the technical people really had the authority to make decisions.*

Another important condition was what I believe to have been a vivid expression of the principles of democratic behavior. Nearly every man was invited to participate. My job was to point the goal, to keep that clear, and invite every person to participate toward the ultimate goal to the limit of his capacities. I think this

is as good an expression as any of the central idea of the democratic system, "You don't boss people, you tell them what needs to be done, and ask them to help." Sure, we boss each other in terms of setting objectives. I had jobs to carry out and every boss does, and I saw to it that my bosses let me know in no uncertain terms what my next obligation to them was and I let them know if I failed—acknowledged it, but tried my best to carry it out. Thanks to Van Bush and a few others it was relatively easy.

The invitations to participate extended to every technician. They all knew that if they could make a contribution it would be appreciated from top to bottom. They all felt free to go ahead with the presentation of ideas in answer to this invitation to participate.

We dealt with very understanding people in the Navy. Captain Shumaker¹ who died in the Pacific theatre in the middle of the war, was one of them. It was this type of "matched impedance"² that made it possible to go ahead. When I talked to these people downtown in the Navy I was understood and they respected the sharpness with which we kept our goals clearly in mind.

You may remember some of the difficulties of recruiting people. We got started a little late because it wasn't clear that you could manufacture miniature vacuum tubes and shoot them in a gun. Fortunately the oil fields weren't denuded of technical people, so I sent two or three men on a flying trip to Texas and as a result we had a very lively time because we had a lot of these oil field fellows who were quite frank and brutal in some of their judgments. They were the mainstay of our team. It was very refreshing. They were excellent people especially for the kind of a task we had. The technicians were appreciated. The goals were always kept clear, as were the functions of a supervisor. One of our slogans was: "Foresight and initiative, this is the primary function of a supervisor." The goal, however, wasn't limited to research. It wasn't limited to the ordinary scientist's contribution to a problem. It carried all the way through to the enemy airplane burning on its way to the ground.

Our principal assignment was anti-aircraft. By far the largest use of the proximity fuse, of course, was antipersonnel in artillery shells for airburst, against which foxholes were no protection. The end use was always kept in mind and we stayed with the job be-

¹Samuel R. Shumaker, Captain, U. S. Navy, then in charge of research for the Bureau of Ordnance.

²Matched impedance means that a given source of power can deliver most power into a load impedance that is equal to the output impedance of the power source.

cause we weren't able to find a good point at which we could shear off our responsibilities and hand them on to others. So we carried right on through from the earliest kind of development phases to all-out production. There was some basic research at the beginning while there were only six of us. So it isn't true that there was no research in our program, but it is almost true. Most of our activities were goal directed. We saw no way to shear off the more industrial responsibilities and pass them to others without losing time. The net result was we went right ahead from the earliest research prototypes, so-called, through engineering development prototypes into the problems of production and quality control before we had the first working prototypes in the air. We had the manufacturers in with us. I was a great believer in at least trying to "match impedances" into the industrial system because we couldn't do those things ourselves in quantity, so the industrialists were in very early. Then, we found no way of extricating ourselves because the testing laboratory was necessary for quality control. So we accepted the responsibility of setting up necessary statistical standards for adequate performance in the field, which brought us right into the field problems. The result was we had over 100 ordnance teams at the battle front during the last year and a half, actually supervising and reporting back to us the use of the equipment and reporting back to us for further development on quality problems which, incidentally, were rather desperate in electronics. Persons who have had experience with electronics in the tropics will know some of our problems.

The special boundary conditions of a war situation made it possible to have such a very satisfying team experience. I believe this was true to a large extent for everyone in the outfit, all the way from technicians to Vannevar Bush. There was a sense of worthy participation under very special circumstances. One was also subject to the special circumstance of severe penalties from one's own conscience, when you felt that serious mistakes were made. We ran into some big errors. I made some of the biggest and I think I am aware of many of them. We also ran into the situation that it looked several times as though the things we were attempting to do simply were not going to be done, at least not in this war.

There was a time, for example, when the battery problem had us completely whipped. We could not get rid of the prematures, (unwanted explosions of the shells before reaching their targets). We knew they were due to the batteries. We had to get, let us say, reserve batteries. This is simply a power source with a glass ampule that would break because our dry cells were dying in the tropics in

less than two months. But we couldn't get rid of the prematures with the glass-ampule batteries. We spent five months and ran through hundreds of engineering tests and we got down to just two remaining ideas as to the source of the trouble. Beyond that we just didn't know what to do except to give up. This was May 20, 1943. We had built a million and a half fuses which were sitting around waiting for batteries, because it wouldn't do to put the old dry cells in them. The next to the last test was successful, and by May 28 we were producing useful batteries. We had driven our men to what seemed to be the "last test" several times but this time we had been simply through making changes, without starting all over.

So, I just remind you that there were some "impossible" situations encountered. Throughout it all, however, the sense of essentially personal failure was a strong incentive—it wasn't that the finance department would cut off your section and stop the Laboratory because you were running in the hole. We didn't face the ordinary industrial standards for performance which exist in most of the industrial activities in the United States, because the normal buyers' market doesn't exist. It was necessary to emphasize the realization throughout the group that the men who were operating rather large things, and spending—let's say had control over—the larger expenditures, didn't get the idea they were running, let us say, a \$10,000,000 business. Sure, in a sense they were, but it was without the usual penalties. Let me just quickly say we spent 31 million dollars in Section T covering all the research and development, quality control, field operations and so on, but not production. The total spent for proximity fuses for guns, under our general supervision, was over 800 million dollars. This is in addition to the fuse work elsewhere that was done for rockets and bombs, which unfortunately did not reach use in quantity by the end of the war.

It was the spirit of the thing that really counted the most. As far as the formal organization of Section T is concerned, it was changed repeatedly by agreement and by shock. It was always done after many conferences with the people affected. It wasn't just little changes in organization. First we would slice the cake horizontally and we would run for a while that way. When little empires developed and other symptoms had begun to show, I would step in and slice the cake vertically. The result was that after a couple of these operations, people realized it didn't pay to build empires. There was a certain amount of grumbling, but there was far more agreement in the situation than there was grumbling. I just took grumbling with this attitude: "Bill, the rest of the boys are getting shot. All I'm doing now is shifting you. Putting you down in the service department for the time being."

We didn't worry very much about pride. Mine was bumped around quite a lot. The result was there was a pretty universal sense of common participation, so that they were after the problem which was constantly in front of them rather than making sure their particular outfit was running, because next week they might be in another one. This happened about six or eight months. Toward the end of the war it got rather complex and it took about a year to make these changes. This is quite different from the ordinary small shift but in keeping with the temporary nature of the situations we met during the war.

It was the spirit of the thing which ran Section T, and not the financial organization, the letters and directives on which we were allowed to do certain things, and the way in which the official relations were set up. I have many times during the war and ever since, used the figure of speech that I was a short-legged donkey running ahead of a bunch of race horses, and this is exactly the way it felt. The group kept right on going because everybody knew where he was going and the challenge was ample. You worked in a situation devoid internally of fears. The removal of fear and the absence of normal penalties are important and highly specialized features of organization, appropriate only to a war situation.

We did one thing of a technical nature—a legal procedure—which was a demonstration, with the help of the Legal Department of the Bureau of Ordnance, that research contracts acceptable to University groups could be handled on regular funds—to everyone's astonishment. The problem concerned the detailed clauses in the writing of research contracts. The ordinary procurement rules were found to be bureaucratic regulations and not organic law. With the help of Rear Admiral Lewis Strauss, who was then in the office of the Secretary of the Navy, and one or two men in the Legal Division, Bureau of Ordnance, we were able to write up a new set of procurement regulations for research contracts and see that they were promulgated by the Secretary of the Navy. This form of contract has since been widely copied. It was used before the end of the war by a whole series of government agencies. It is the essential basis on which the government today underwrites contractual obligations for research work with regular funds. There was no difficulty about prototypes on emergency funds. The rules for spending money under an emergency are entirely different from those when you are spending through a regular department. Oscar Cox set up these things for the research contracts in NDRC before we ever got started.

However, the problem of getting suitably free contracts to underwrite under regular government executive department budgets was something else again. The important thing was simply to drive

entrenched legal and clerical advisors out of the position they had taken, that you cannot do this or that because the Bureau of Supplies and Accounts or the General Accounting Office won't allow it and so and so and so. It all turned out to be a very large fabric of bureaucratic regulation. The thing we did was to work with Admiral Strauss and the lawyers at the top in setting up a new set of special rules for the purchase of research and development and for the operation of those contracts. When those special rules went into effect in late 1944, we were thereby prepared for the transition, which Dr. Bush foresaw early in the war, of moving research and development over into the regular Army, Navy and Air Force Departments (then the War and Navy Departments). That is one unexpected technical accomplishment in which Section T participated.

I would say that the thing which has been emphasized to me by the men who participated in this experience with us has been rather *the spirit under which the thing* operated, and the directness with which we followed a rather sharply defined line toward the particular goal. Both features arose from the special circumstances of the war.

One of my favorite slogans was "O.K., boys, *with a gay spirit* here we go again." We would just face one problem after another as they came along. When it comes to time and effort *I am kind of a cheerful gambler. I think anybody who is in research has to have that kind of a spirit.* If it looked feasible, interesting, and worth doing, we would say, "O.K., boys, here we go again." The text of that was this, "*With a gay spirit.*" You take your chances. This was a very important part of the whole thing. If there is any one quotation which I think was in keeping with the philosophy of the times, it was "O.K., but with a gay spirit." You may get shot down but you are going to enjoy the flight while you are doing it.

Another slogan was "*Paper work is a marvelous tool. Don't despise it.*" You can imagine the amount of negative response to the Army-Navy-government paper work which was engendered in quite a few high-speed technical people, trying to get an industrial job done. I am one of the most vigorous despisers of excessive paper work. I have done enough of it, but also I know its usefulness. So when I determined in my own office to accept and utilize a modest amount of paper work as a specialized tool, the idea spread throughout the organization. Through this kind of exchange they discovered that there was a function even for government paper work.

Correlated to that was, of course, *the importance of delay.* This is the simplest technique in the world. We practiced the technique of "subversive" delay when there were things we didn't want to have interfered with. This is well developed downtown in Washington and the easiest thing in the world to copy. It worked rather well.

I suppose the key idea was that our *responsibility for technical matters on these fuses goes all the way to the crippled airplane*. This, in different expressions because our goals were different at different times during the war, was the essential idea as far as the technical organization was considered. The other essential idea as far as human beings were concerned was the *invitation to participate*. This went so far that when we didn't find qualified people we always made it known that three men working at $\frac{1}{3}$ of the needed effectiveness add up to one man. We didn't hesitate to pay the three men respectable salaries and said, "By golly, we're glad to have you," because, one, two, three, we've got men at work on jobs that we could not get done otherwise. So people were, I think, given self-respect throughout the whole thing, even in jobs for which they clearly had no special fitness.

If there is anything characteristic of the way we ran Section T, it is the idea of recognizing problems of the spirit. Very often what we ran into was not a technical difficulty, it was a spiritual difficulty. We recognized this constantly. You encounter it—the problems between people. The word "spiritual" is ordinarily very frightening to scientific men. It brings them up short. It wasn't primarily a religious dedication, but it brought attention to the bifurcation of the world. You can handle the physical world in terms of the laws of nature and the rules of technology, but as an intelligent person you must recognize constantly the fact that human awareness and motivation and the satisfaction of the spirit is truly another type of fabric; these things are not governed by the laws of the physical world.

15: THE TECHNICAL TEAM: SECTION T IN CURRENT RESEARCH OPERATIONS

R. E. GIBSON

In following Dr. M. A. Tuve on this program, I am glad to acknowledge the debt we owe to him for the foundation of the organization which has become the Applied Physics Laboratory of the Johns Hopkins University. He also started the system of associate contractor cooperation which is now known as the Section T pattern of contractor research and development. I would also endorse his remarks about the spirit of research teams. In the terms of the market place, the commodity which a research laboratory has to sell is not a material one; it consists of ideas and the application of ideas and, unless the spirit of the individual worker and of the institution as a whole is properly oriented and inspired, the chances are great that the product will soon sink to a level of mediocrity.

The transition of Section T from the wartime state that Dr. Tuve has described to you to a peacetime state has been a process that you can easily visualize.¹ The change has been mainly a cooling off from the fever heat of war activity, where time was worth more than money, to an active effort in which the time scales are somewhat longer and where economic considerations again are important. The same spirit, however, still inspires the organization. The scale of operation remains high and, compared with pre-war figures, our budget is large; but the complex problems of modern warfare require up-to-date and complex solutions. The cost is dictated primarily by the saving of manpower that can be made when men are supplied with the powerful and intelligent machines now within the reach of research, development and engineering.

Pure Research, Applied Research, and the Arts

In introducing a discussion of the present and future operation of Section T, I should like to make a few general observations concerning pure research, applied research, the useful arts, and their interrelations.

If we look back into history, we see that man's needs and desires have been supplied by the "useful arts", a purely empirical activity.

¹See preceding chapter.

We may define "art" as *the reduction of a complex of ideas to a form which appeals directly to the emotions of man*, a definition which covers the arts of the painter, the musician, the actor, the poet, the weaver or designer, the silversmith, the engineer, or the physician. The incentives of the "useful arts" lay in the realization of the needs or wants of society, of possible markets, of military or economic problems. The methods used by artists and artisans were purely empirical, based on individual training, ingenuity, skill or experience. Ability to perceive, weigh and integrate intuitively the many elements of a complex phenomenon and to express the results of this intuition in tangible form are essential traits of the successful artist. By these traits, artists through the centuries have been able to reduce complexes of ideas which they did not understand explicitly to readily apprehended or useful forms by using rules or practices learned by cut-and-try methods of purely local or specific application. In such company, conservatism flourished, authority was supreme, subjective opinion was a criterion of excellence, the expert dominated, and age was superior to youth. Prior to 100 years ago all our industries and other agencies contributing to the physical comfort and safety of man were based on the "useful arts".

A much younger activity than the "useful arts" is the scientific approach to the problems of nature, which dates back only some 300 years. I like to use the term "natural philosophy" to describe this activity, because it connotes the "understanding" or fundamental and consistent description of the natural or physical world—the end and aim of what we call basic or pure scientific research. Although the by-products of basic research may be such important things as the development of new instruments and techniques, the compilation of data, the discovery of new substances or materials, or the creation of a new branch of science such as radio engineering or the development of new gadgets, few will disagree with the thesis that a *unique objective* of basic research is to solve problems by expressing the new or unfamiliar in terms of the known or familiar and ultimately to develop a system in which a few simple fundamental entities and laws with a recognized consistent logic will not only express quantitatively-known facts but will predict new ones. By this process we seek an "understanding" of specific phenomena and processes and ultimately an "understanding" of the universe itself.

I would emphasize that this quest for understanding and the methods and criteria that have been developed in this quest constitute an outstanding characteristic of scientific research or natural

philosophy. The spirit engendered by this discipline may be used to guide all research, whether its objective is the understanding of some phenomenon encountered in nature or the solution of problems arising in an operation or in the development of a military weapon. Indeed, it is the combination of this discipline and its capacity for intelligent prediction with the empirical approach and practical outlook of the useful arts that has made possible the accelerated growth of technology noted in recent years.

Recognizing that the terms pure, basic, fundamental, etc., as applied to research, mean many things to many people, I have given the quest for "understanding" covered by this definition the symbol R_1 .

RELATIONSHIP BETWEEN PURE AND APPLIED SCIENCE AND THE ARTS

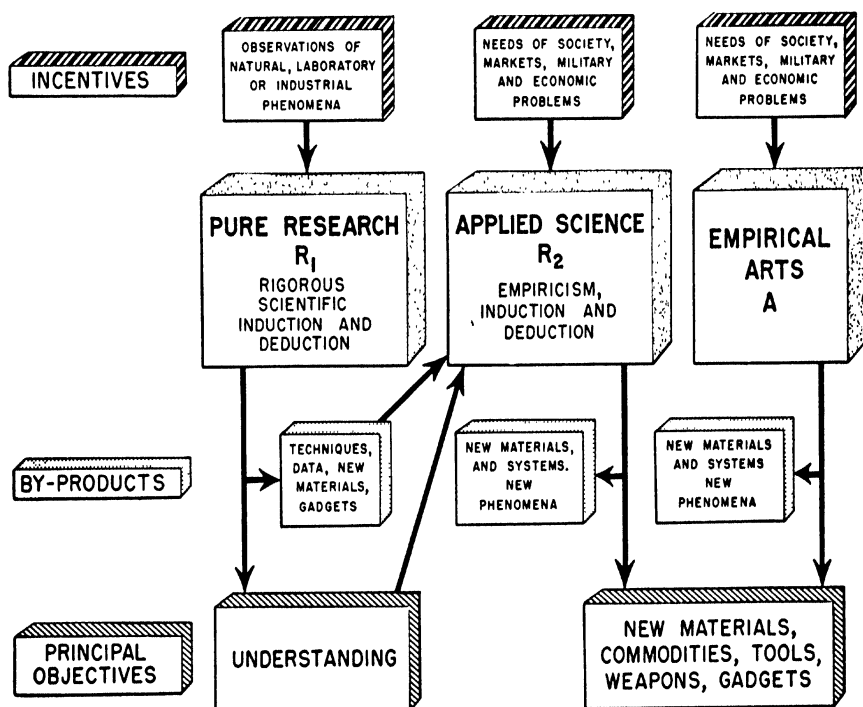


Fig. 1.

In a very simplified way, I have depicted in Figure 1 some of the interrelations of the arts and the pure and applied sciences. On one side we indicate the empirical arts A , whose inspiration is derived

from the anticipation of a need or market, whose objective is to fill this need, usually in a way that brings profit, and whose products are things that people may use and enjoy. On the other side of the figure, we indicate pure research R_1 (natural philosophy) with its inspiration coming from problems and arising in the observation of natural, laboratory, or industrial phenomena. Its chief product is "understanding" in terms of fundamental principles, and its by-products are new techniques, new substances, structure or the like.

In the middle we introduce a third activity which has become of overwhelming importance during the last half century and is rapidly replacing A in modern technology, namely, applied science or applied research and development, which I shall call R_2 . Like A , it receives its chief inspiration for action from the realization of a need or potential need (market for industrial products or military requirements for weapons or equipment) for a commodity, but instead of using purely empirical methods to develop the items to fill this need it makes use of *all that is available from R_1 and, when the necessary principles or data are lacking, seeks to supply timely but limited solutions to research problems by scientific methods or by combining empirical methods with whatever scientific knowledge exists*. In this type of research, the prime objective is not "understanding" in the R_1 sense, but rather the development of a working prototype whose behavior is sufficiently well understood to permit it being engineered for production as an item which will perform reliably within specified limits. However, "understanding" is an essential ingredient in the optimum performance of the functions of R_2 , and the more "understanding" that is available to R_2 , the swifter and surer will be its progress. Practically all industrial and military research carried out today falls under R_2 , the proportion of scientific to empirical work in any one organization being determined largely by the state of the art they are cultivating. R_2 differs primarily from A in that it makes a great use of personnel trained in science and relies less and less on the long-experienced expert.

The outstanding contributions of the nations of the West to civilization stem from the application of natural philosophy to the acceleration and extension of the progress of the useful arts. The increase in the productive capacity of the individual worker which these nations have achieved through scientific technology has made possible for their populations a standard of national welfare unequalled in the history of man.

The middle column, Applied Science R_2 , describes the sphere in which the Section T pattern is designed to operate. Its incentives are the realizations of important military problems coupled with ideas for technical solutions, its objectives are weapons to help solve the military problems; its methods involve the use of the best combination of understanding and art available at the time. Thus, for instance, the defense of ships against air attack is a problem of general military significance; technical means for aiding in the solution of this problem are proximity fuzes for enhancing the effectiveness of antiaircraft guns, or guided missiles which combine the desirable properties of guns and of interceptors. The job of Section T is to explore the technology of these devices and, with a combination of art and understanding, to develop a prototype device which embodies as many of the desirable performance properties as the state of the art allows.

This type of problem has many technical ramifications which overlap such conventional technical fields as physics, chemistry, and engineering, and the Section T pattern is designed to bring together into a task force men of varied training and skills so that their efforts may be focussed on the problem at hand.

In Figure 2, I have attempted to depict the over-all objectives of the Applied Physics Laboratory and Section T in terms of a three-dimensional model in which the length represents the number of fields of technical activity to be explored, the breadth represents the advance of new knowledge and understanding in this field, and the height represents transition from basic knowledge through development and engineering to the final output of a production line. To complete the final building, satisfactory progress must be made in all three directions. The structure shown in Figure 2 consists of four floors, each supported by the one below it. The ground floor depicts basic knowledge and understanding in all the scientific fields concerned; it must be continually extended to support the superstructure.

The transition from the first floor to the second is through "development", and the second floor represents development prototypes, breadboards or working models. Through engineering, we reach the third floor, the engineering prototype, which is a model built for durability, ease of maintenance and testing and also embodies components and structures which are producible in quantity by known methods. It is a model which can be specified completely. Finally, there is the product of the production line in which all the

characteristics of the engineering prototype are combined with factors that permit ease of production, maintenance, storage, and use. At each level, I have indicated that research in the broad sense of the word is needed; problems arise at the levels of the develop-

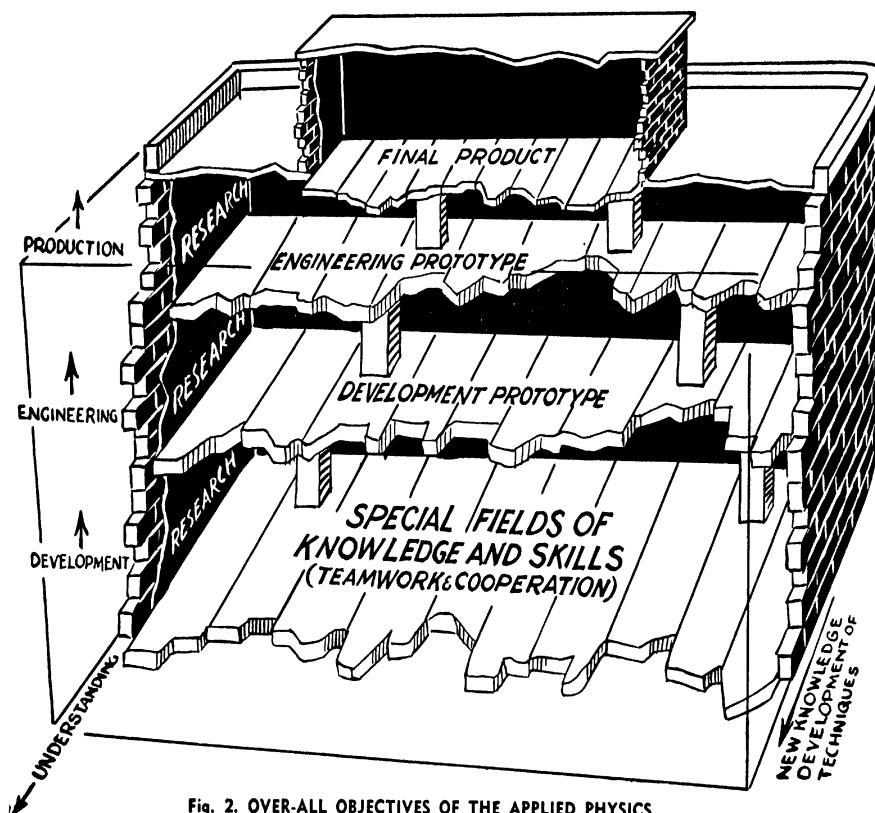


Fig. 2. OVER-ALL OBJECTIVES OF THE APPLIED PHYSICS LABORATORY AND SECTION T.

ment prototype, the engineering prototype, and the engineering of the final product which require ingenious applications of science and art.

Figure 2 as a whole indicates another aspect of the *raison d'être* of Section T. The building itself is an integrated structure to which many varied units make their appropriate contributions. No matter how many contractors take part in constructing this building, it must be under the general direction of one firm of architects, who see that all efforts are coordinated and focused on the execution of a single plan. In Section T, the central laboratory acts as the firm

of architects who undertake to produce a structure meeting the general requirements of the sponsor. The varied contributions are made partly by the central laboratory, especially those pertaining to the lower floors, and partly by associate contractors who have special skills and facilities with which to develop specific parts of the building.

Principles Underlying Section T Operations

I will now turn to some more specific aspects of the Section T operation. Dr. Tuve has already indicated that Section T was originally set up to provide a new pattern for the procurement of research and development by the government. In accordance with the objective, two new features are introduced into all the contracts now known in the Navy as the Section T type of contract. The first is the description of the work to be done in terms of a broad task which does not seek to specify in detail the requirements of the end product but which calls for research and development leading towards the solution of a problem, specifying a broad objective such as a fuze or a missile as the type of solution to be sought. Within this task, the Navy delegates to the Laboratory the responsibility of breaking down the broad objective into specific technical objectives and in deciding what fields must be investigated to attain these technical objectives. By study and consultation, the work under the task is crystallized by technical men to problems which are recognized by the Navy as the itemized description of the work to be done under the contract. This broad task type of contract is no less efficient than one which calls for very specific items, and it has the advantage that it places responsibility for the initial technical decisions on technical men who are to carry them out. All contractors associated with Section T work under contracts in which the task is set forth in this general way. The second feature to be mentioned is that the technical direction of the work of all the contractors in Section T is delegated to the central laboratory, the Applied Physics Laboratory. Not only does the laboratory have the responsibility of formulating the problems defining the work to be done under the general tasks undertaken by itself and its associate contractors, but it also has the job of following and reporting progress, of promoting close liaison, and of bringing the results together into prototypes of proven and documented performance. This feature of delegating the over-all direction of a program to a group of practising scientists and engineers is a very important

experiment in scientific administration that was initiated by the Navy in Section T. It has worked out reasonably well, and it does give a man in charge of a segment of the program the opportunity of trying out ideas for himself and testing their feasibility before assigning problems to contractors.

The Section T pattern, with its central laboratory and group of associate contractors, was set up for the purpose of undertaking integrated tasks of considerable magnitude and complexity; it is not intended to be a mechanism for "job shop" research and development. With this in mind, I should like to mention three general principles in the actual operation of Section T, namely: (1) The focussing of a variety of talent, training, or skills on a complex problem, (2) the utilization of these talents or skills and the special facilities required where they occur, and (3) the promotion of independent centers of initiative by decentralization.

The first principle is obvious when one considers the types of task that are undertaken, which might require a synthesis from such fields of technical endeavor as aerodynamics, aeroelasticity, thermodynamics, theory of structure, electronics, servomechanisms, the theory of communications, and high speed computers, chemistry, metallurgy, physics, combustion, etc. The second principle, namely the utilization of talent, training and special facilities where they occur, arises from a variety of considerations. The job of staffing and equipping a central laboratory large enough to deal adequately with detailed investigations in a large number of fields is almost prohibitive, especially when exceptional facilities like supersonic wind tunnels or large test chambers are required. It has been a policy of the Laboratory to keep its staff and facilities to a minimum. Hence, it has sought to enlist the help of those who have special facilities or staff already available, or to build up staffs and facilities in university or industrial organizations where nuclei of interest and experience already exist. Such a principle also avoids the disadvantages attendant on the relocating of people. Scientists and engineers, like many other people, have preferences about the place in which they live that arise from many sources outside their daily work. Something of a man's personality is lost if he has to move from congenial surroundings to those which please him less.

As an example of the second principle, I may cite the development of a project which the Laboratory has carried on for the past six years. Fields of work included in this development were subsonic and supersonic aerodynamics, design of diffusers and combustors,

both from the aerodynamic and structural point of view, design of fuel metering systems, study of fuels, and the study of high speed combustion including physics and chemistry of flames. An aerodynamic test facility was built around an air supply existing at Daingerfield, Texas, and is now operated for the Navy by Convair as the Ordnance Aerophysics Laboratory. At this facility, engines were tested at all stages of their development. In other cases, the experience of Bendix Aviation Corporation in fuel metering permitted this contractor to make a valuable contribution to the program; the Standard Oil Development Company's Laboratories contributed to the solution of practical combustion problems; Convair built full scale models; Experiment Incorporated in Richmond added to the requisite knowledge of fuels; the University of Virginia contributed basic ideas on engine design; and research at the University of Wisconsin produced a badly needed fundamental basis for a theory of flame phenomena. The Applied Physics Laboratory directed and integrated the program; produced, itself, theories which bridged the gap between the fundamental physics and chemistry of flames and practical performance; and effected liaison among all those contributing to different phases of the program. This development is an example of the general scheme I have depicted in Figure 2.

The third principle, namely the promotion of independent centers of initiative, all of which, however, are focussed on a tangible objective, is a most important one, particularly in a rapidly growing technology. It is a problem which faces every major military development and derives its importance from the fact that potentially fruitful developments are not always recognizable in this early stage; and the easiest thing for a centralized authority to do is to stop them on grounds of economy or conservation of effort. Yet the disconcerting fact is that the more radical and far-reaching a development is, the harder it is to discern its potentialities before feasibility has been demonstrated. Through an associate contractor operation, this can be achieved, whereas it is extremely difficult in a centralized operation where the veto power of a single director can be exercised only too easily. It is, however, a principle which is extremely difficult to carry out in practice, since it requires great skill and judgment to steer the thinking of independent centers of initiative into channels which contribute to an integrated over-all objective and avoid dispersal or duplication of effort. The timing for the incorporation of the products of different centers of initia-

tive into a program is as essential as the timing of the transplanting of plants in a well-kept garden. When difficulties arise in advanced stages of a development, the ability to focus the attention of different centers of initiative on its solution has proved to be a powerful asset.

In the Section T family as it is constituted at present, there are sixteen associate contractors, including eight industrial concerns and eight universities², in addition to the Applied Physics Laboratory and the Ordnance Aerophysics Laboratory. Together, these organizations cover the skills and facilities required to carry on an operation such as is typified in Figure 2.

Mechanism for Technical Administration

Let us consider for a moment some of the technical administrative mechanisms used in conjunction with the far flung cooperative research and development program carried out under the Applied Physics Laboratory. In such a program it is essential that the general and detailed planning be placed on as broad a basis of technical knowledge and judgment as possible. Attempts are made to realize this breadth of basis not only in the initial planning but in liaison and follow up which continues as the work proceeds. The general ideas underlying the administrative mechanisms for planning are illustrated in Figure 3, where the idea of the regenerative circuit is used to emphasize the need for discussion, technical assessment of possible results, and even preliminary research in the considerations that underlie the initial decisions as to whether a project should be undertaken at all. The processes illustrated in Figure 3 take place at various levels of generality. These levels may be characterized by formal objectives. For example, four types of objectives may be considered: (1) the "tactical objective", which defines the needs to be fulfilled, the broad military problem to be solved, or the market to be served; (2) the "systems objective", which defines the system which gives a technical solution to the tactical problems; (3) "technical objectives" which must be reached separately and whose combinations lead to the systems objective; and finally, (4) "prob-

²These are Applied Science Corporation of Princeton; Bendix Aviation Corporation; Capehart-Farnsworth Corporation; Consolidated Vultee Aircraft Corporation; Cornell Aeronautical Laboratory, Inc.; Experiment Incorporated; The Johns Hopkins University, Baltimore; New Mexico College of Agriculture & Mechanic Arts; Princeton University; Radio Corporation of America; Standard Oil Development Company; University of Michigan; University of Texas; University of Virginia; University of Washington; and the University of Wisconsin.

RESEARCH PLANNING — PROJECT TYPE

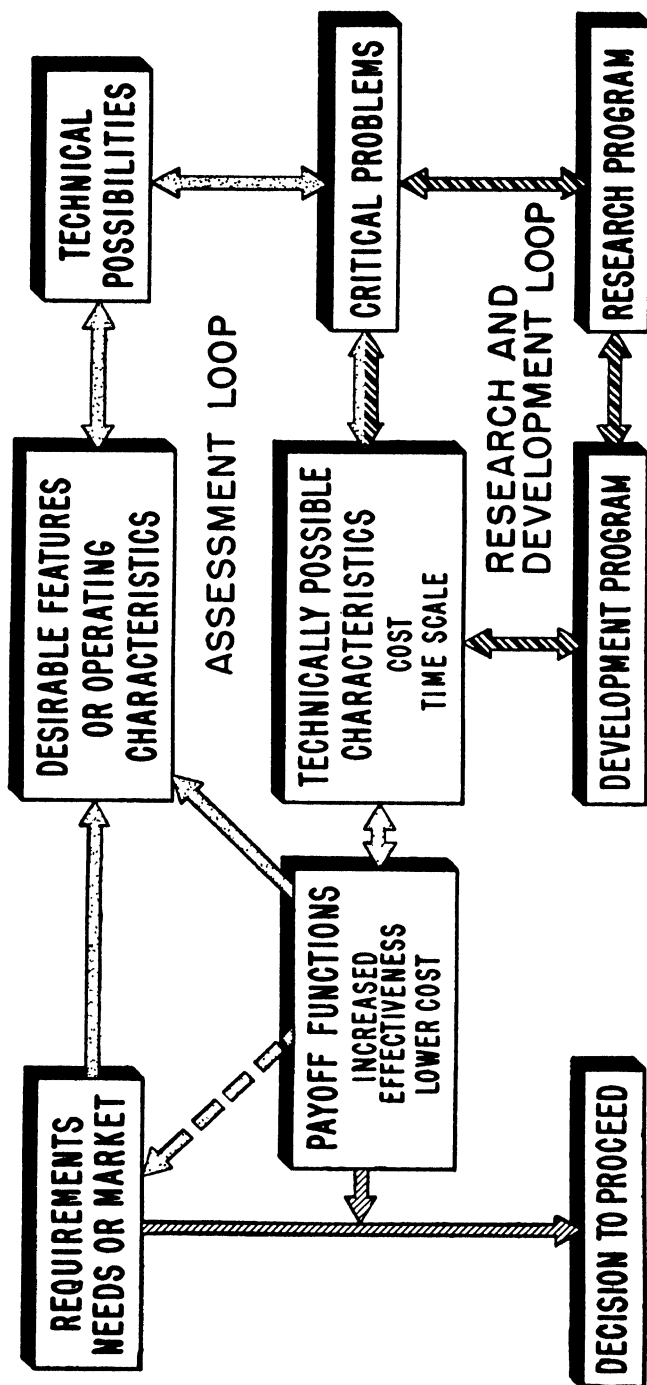


Fig. 3.

lems" to be solved on the way to the achievement of technical objectives.

Each type of objective represents a program of greater or smaller scope on which planning decisions must be made, and, in each case, the general process consists of a preliminary analysis to determine feasibility, a further analysis to isolate the critical problems, and, finally, an investigation to solve these problems and apply the results, together with available understanding and art to achieve the objective. In every case it is desirable to define what constitutes the "payoff" functions and to plan the work and set objectives accordingly. Thus, in considering a course of action, one assumes that the research and development program will be successful and asks what improvement is likely to result in the ability of the user to do the job required of him. One goes even further and attempts to express quantitatively the advantage that will accrue to the user in comparison with means now available to him. In this quantitative analysis, certain functions of crucial importance occur; these are the payoff functions. For example, if we compare antiaircraft guided missiles with antiaircraft guns, we find that the number of planes brought down per man hour of effort is a significant payoff function. Such an assessment of the value of the results of a development is of utmost importance in decisions about what is to be done. In the past, such decisions were made intuitively. Nowadays, intuition is still needed, but the growing complexity of technology requires thorough-going analyses before a clear picture can be presented to the intuition of a director.

In the operation of the Applied Physics Laboratory and its associates, the unit of technical work is the "problem" which defines a small area in which research and development is to be carried out, this area being related to a large technical objective. Generally speaking, problems are formulated by discussions between the problem sponsor, who is a member of the Laboratory, and who is responsible for directing the work in terms of the technical systems objective, and the group or agency which carries out the work. Problems are of necessity subject to change as results dictate, but their written formulation and amendment from time to time is essential if larger objectives are to be met.

It goes without saying that if the Laboratory is to live up to the principles set forth in the preceding sections, it must have on its staff people who are strong technically in all the fields wherein problems are undertaken. Indeed, experience has shown that where

this is not the case, the work done by associate contractors often loses its significance.

In order to utilize as fully as possible the technical resources available for planning, follow-up, and criticism in Section T, the Laboratory established several years ago a number of Technical Panels, each having cognizance over a specific technical field and holding meetings three or four times a year. The members of each panel are technical men appointed by the responsible authorities in associate contractor organizations interested in the field of the panel and are supposed to be able to speak for the contractor in these technical areas. The panel chairmen are members of the staff of the Applied Physics Laboratory. The functions of the panels may be summarized briefly as (1) liaison and communications, (2) planning, (3) critical discussion of progress, and (4) formulation of recommendations on the initiation or termination of problems. The emphasis placed on these different functions is largely at the disposal of each panel chairman and depends on the state of the art in the panel's particular field. Experience has shown, however, that the panels could justify their existence by the first function alone, namely, in promoting up-to-date and informed liaison and communication among parties interested in the same general subject. This phase of their work has proved to be so successful that at each meeting special sessions are arranged to which representatives from all interested organizations in the country are invited and, indeed, seek to come to interchange descriptions of their latest work. From the technical administrative point of view, the panels serve the valuable purpose of providing a forum where proposals for new problems or the termination of old ones may be discussed by competent men of different backgrounds and affiliations. As a result, it is possible to develop technical arguments with a minimum of personal or local bias upon which decisions for future work can be based. This is especially useful in cases where the value of the work in question is neither obviously high nor obviously low. It should be noted that every member of a panel is in a position to place items for discussion and recommendation on the agenda of its meeting.

Types of Activity at the Applied Physics Laboratory

I should like to conclude this paper with a short summary of the main types of activity at the Applied Physics Laboratory which, I would emphasize, are concerned both with providing practical solu-

tions to the needs of the present and building up resources to meet needs of the future. In brief they are as follows:

1. Formulation of military problems in technical terms and the continuous assessment of the pay-off functions to be derived from technical devices currently under development in Section T.
2. Prosecution of research, development, and engineering to develop new ideas and reduce them to practical devices (weapons and equipment) for solving broad problems.
3. Fundamental research to supply radically new ideas and furnish a reserve of active scientific men, and knowledge and understanding to support new developments and anticipate new needs.
4. Conduct of administrative operations needed to implement, control, and maintain the external and internal relations of the laboratory and its associate contractors on a stable, sound basis.

I have already referred to the first type of activity in preceding sections, but I would repeat that the decision to undertake a piece of development and engineering is an extremely important one and a sound basis for this decision requires nowadays a quantitative analysis of the factors involved. Furthermore, changes in the over-all technical picture may enhance or diminish the ultimate value to the user of a device under development. The ability to keep the sponsor fully and impartially apprised of the potential value of the product being developed for him is essential to any organization which sets scientific honesty and integrity at the top of the list of its resources. The second type of activity, namely, research, development, and engineering, has shared with the fourth type of activity the major portion of this paper. Using the technical resources in a combination of institutions, Section T seeks to combine that knowledge accumulated in the engineering arts with understanding available in the sciences or obtainable by research to develop on a moderately short time-scale prototypes of proved and understood performance, that is, prototypes upon which production of weapons and equipment can be founded.

The third type of activity mentioned above is the laboratory's chief but by no means only mechanism for preparing to meet future needs and has been supported wholeheartedly by the Bureau of Ordnance. It involves the maintenance of a small number of scientific investigators and their assistants in fundamental research work under conditions that approximate closely those found in the graduate schools of a university. Two general objectives may be distinguished in this activity. The first is the generation of new ideas

or understanding in fields related to those in which the laboratory's main efforts lie but without any prescribed time scales being attached to the work. In this way, a fundamental understanding of some of the problems encountered in the development work has been obtained; and even in cases where applications were not obvious sound contributions to science were forthcoming. In certain cases such research has led to radically new devices of immediate application. The second objective is the maintenance at the laboratory of a staff of scientists who are active in the forefront of different fields of research. The close association of such men with applied scientists and engineers is a feature whose value is already widely recognized. The sceptical attitude of the research scientist excellently complements the zeal of the engineer to get things done, particularly when complicated problems arise. The presence of scientists actively engaged in fundamental research is essential if the problems of tomorrow are not to be neglected in the urge to clear up the problems of today.

Over the past six years the pattern of organization and administration outlined in this paper has functioned successfully. Changes have been necessary from time to time, and the emphasis on engineering has grown as the technologies under study have developed. However, the Applied Physics Laboratory and many of its associate contractors remain essentially research and development organizations, having learned that the fruits of research and development are only mature when they are well engineered and specified.

In all institutions the formal organization chart is merely a framework; the real dynamic power lies in the personalities of the individuals who make up the organization and in their will to work together to achieve recognized objectives. The spirit of an institution transcends its formal organization. I can describe the organization to you—you can grasp the spirit only by first hand experience.

16: TEAMWORK IN OPERATIONS RESEARCH

GEORGE S. PETTEE

In talking about group research in operations research, I am a little inhibited and embarrassed because much of the best teamwork I have engaged in recently I can't mention until my security officer asks your security officer whether you have the appropriate clearance. On the other hand I shall try to skate around among the impediments of that type and give you some of the story of teamwork in operations research.

First I will indicate the kind of problem operations research deals with, because that is the basis for any teamwork that is required. We study operations in order to arrive at results that will be useful to operators. We study operations for command. It is in many respects a staff function. We are one more source from which a commander can get advice bearing upon a problem upon which he has got to take an action. It may, or may not, be useful advice, but we at least have commanders indicating to us a fair part of the time that they think the advice is useful. We would not stay in business long if that was not so, of course.

The kind of problem may be anything from soup to nuts. There was a nice illustration recently. One of our people told the story of an experience in Korea. Officers of First Corps Headquarters, First Corps G-2, showed him a fancy statistical chart and said "We are using this as a means of predicting enemy offensives. You do a critique on it and see what you think." He found out by mathematical analysis that the shape of the chart was perfectly explicable as due to factors that had nothing to do with whether the enemy was going to have an offensive next week or not. It happened on two or three occasions to coincide, so that reading the chart a certain way you would find that certain phenomena that appeared on the chart just preceded an enemy offensive two or three times, and they thought they had an obscure unexplained parameter of enemy intentions. Mathematical realistic analysis of why the shape of the chart was the way it was showed that the factors causing that shape certainly were irrelevant to enemy intentions. That's a miniscule illustration of the usefulness of operations research by one man—not a team.

Since the problems are operating problems, I want to go into the question of how they are related to the existing disciplines. This may seem pretty remote but I think it is fundamental to the question of what kind of teamwork has to arise in operations research. This calls for some momentary thought about the origin, history and nature of the existing disciplines.

I would put it this way. Nineteenth century scholars at their convenience recognized major systems of thought and reality and logic in the world. They developed subject fields or disciplines around them—chemistry, physics, biology, economics, psychology and others. Those are pretty good categories and quite convenient, and I can't imagine the growth of science and thought having occurred in any other way. You might start it over again on another planet and have it come out with quite a different set of disciplines, but you would still have to have some sort of a set of disciplines. Then I would put it this way. God way back in the first chapter of Genesis hadn't heard of these disciplines. He hadn't read the textbooks. He didn't know that economics is exclusive of sociology and sociology is exclusive of economics and so on. Cause and effect in the world He created do not work that way. Economic causes have political effects, and political causes have economic effects. Biological causes have psychological effects. Chemical causes have biological effects and what have you across the field. Now, in operations and conspicuously in military operations, everything gets involved. The physical properties of the metal in the shell determine how many pieces it makes when it bursts. How many pieces it makes affects statistically in the long run how many wounds it causes. How many wounds it causes has an effect on the morale of the men that don't get wounded and so on. And the complexity of the weapon itself has an effect on the psychology and morale of the men who use it. With some modern weapons you get queer fatigue problems out of sheer complexity of the weapon.

In what discipline does the solution to an action problem lie? Well, for my money, systems analysis essentially is the label of how you deal with such problems. The action problem comes up the way God made the world—if you don't mind my using that religious term—I think it is the most expressive term for the way action works. The disciplines were invented at convenience in the nineteenth century for various purposes, especially for the advancement of knowledge. The disciplines don't fit the action problem, but if enough action problems had come up along a certain line, there would have been a discipline around this category of

action problems instead of around the one that the discipline is built on. Each discipline does comprise a great many action problems. That is why it was convenient. The economist developed economics because there were a lot of economics problems that were relatively pure economics. They weren't pure economics before economics was invented. Economics was the abstract system within which such problems are pure economics. They wouldn't have been pure economics if the boundary between disciplines had fallen through those problems instead of around them and dividing them from others, the way you break up the world of reality into a system so that it is manageable, analyzable, and so that you can work out theories about it, collect facts about it and build a science about it.

Now, dealing with action problems you have to begin, to all intents and purposes, by an *ad hoc* abstraction of a fresh science whose boundaries are the same as those of the problem. And systems analysis is, I presume, the proper term to use if there is a label for this sort of systematic management of systems, analysis of systems, and setting up of *ad hoc* systems. It is the design of a system that matches the scope of the problem. A good many of the modern developments in connection with economics comprise as much politics or as much administration as is required. Economics has developed institutional economics which takes in as much of administration, organization, and the human side of the business as is required to make head and tail of the economic processes, the economic facts that arise, which otherwise are inexplicable.

We can all remember illustrations of the kind of economic phenomena that occur which are inexplicable in terms of previous economic thinking and of the economic logical system. One illustration is the old one that John Williams at Harvard was very fond of. We all know that if you raise the price, people won't buy so much. The amount transferred on the market will be less if the price goes up, because the demand presumably is reduced. It went along with the fact that if the demand is measured by a constant volume of dollars, you won't buy so much when the price goes up. Probably you will even discourage the thing. The normal curve runs that way, the demand curve. Now, everybody understood this and everybody knew that if the New York Federal Reserve Bank raises its discount rate, brokers' loans will go down, so sometime in the summer of 1929 the Federal Reserve Bank of New York raised its rediscount rate from 6% to 7% and then the following week, brokers' loans went up \$200,000,000. How could such a thing

happen? Very simply. The brokers were discounting the next rise from 7% to 8%.

Now, as of the time when the Federal Reserve Bank did that in 1929, they were leaving that kind of psychology out of their economic-logical system and the means to the end just didn't fit because the cause didn't have the effect. Now, it is when you find in the course of action that your judgment of cause and effect and, therefore, your judgment of means and ends, pans out so that the consequence is not the intended consequence, it is disappointing instead of satisfying, but you know there is something wrong with your system, and something wrong with the sensible logical structure according to which you analyze the problem.

With reference to military problem analysis and operations research, some of the following questions are with us: How effective is night illumination in the Korean fighting by present methods? What kind of new gadgets do you need? How effective is artillery fire? How effective are our present infantry weapons? Is the Garand a good gun? Is the carbine a good gun? What is the best combination of means, methods, weapons and tactics to stop the type of attack that the North Koreans or the Chinese can deliver? From little problems to big problems, from real Korean ones to prospective European ones, whatever the problem is, you have to begin at the common place of a study design and in accordance with a study design, you then come out often with what is essentially a group design. You analyze the structure of the problem and design a sort of *ad hoc* discipline whose boundaries match the problem and then you think: What kind of Americans in the year 1951 have in their heads the pieces that can be assembled to make a facsimile from several people of what one man would be if there was a discipline to match this problem? If this problem was at the heart of a discipline and there was a "logy" or "ism" that matched it, what kind of a man would that guy be who is a first-class professional in that discipline? How can we assemble him by assembling pieces?

I can give you some illustrations. I worked in a group in Tokyo in a hurry last Christmas, where, without perfection because our resources often force us to compromise, on one occasion four physicists, one political scientist, and one professional soldier were brought together into a research team. In another group were one economist, one historian, one chemist and one meteorologist, and that group turned out a first-class report which was effective. Another group consisted of two psychologists, two historians, and one educa-

tor. Another was made up of two economists and two engineers. They were working on a logistics type problem where economists and engineers between them were to figure out how to get bales, boxes, crates and other physical objects from places like Kansas and Chicago to places like Seoul and Taegu.

Another team was made up of one soldier, one engineer and one physicist. In another case one psychologist and one physicist were faced with the challenge of thinking up new gadgets beyond the means we have now by which to get leaflets from our printing press into the hands of an enemy soldier. There are various ways, of course. We shoot them in shells, we drop them in cluster bombs and a great many have been peddled in Korea by people flying around in liaison planes and throwing them out with their hands. Some planes are good for that. A two-seater plane is pretty good for it. Some marines tried it in F4U's and Corsair planes. The Corsair plane is a marvelous plane for the job because it has a great range of high speed and low speed and can settle down over a place and fly around throwing a few of them and watch them drop and then throw some more that will really land where they are supposed to after you have found out where they will land. The only trouble is that the F4U with the canopy open has terrific turbulence in the cabin, or cockpit, and the pilots don't very much appreciate trying to deal with a carton of leaflets and throw them out by hand because every once in a while the leaflets get loose and fill the cockpit like snow.

In a bigger program on a big problem we had a team composed of ten physicists, five political scientists, five economists, two meteorologists, one geographer, some chemists, and several other types of personnel assigned to the project for varying periods of time.

What are the implications of all this? One of the implications is this: There has been a lot of talk about the necessity for cross-field research and about the necessity for integration among the disciplines. Educational and research programs in philosophy and political science, political science and classics, political science and economics are scattered among the universities with committees to administer them and in some places they are fairly effective. They may get somewhere. But, in general, there has been an amazing sluggishness about accepting and implementing the agreed principle that more cross-discipline integration is needed. It has made very slow progress. Why? I think for very real socio-psychological reasons. It is hard work. Once you have acquired a discipline

it is far easier to "stick to your knitting" and mind your own business. The ultimate sin that arises out of that in the extreme is what I would use the term "academicism" for. It is the attitude of the expert on Shakespeare that politics is none of his business and it never occurred to him that Shakespeare was a political thinker. And a political scientist, a political theorist never thinks of reading Shakespeare's historical plays for the massive chunks of political theory that are in them. The Shakespeare business is in the English Department and not in the Political Science Department. In general, the attitude of a great many historians, economists, biologists, political scientists is that they have got enough to keep them busy and if everybody minds his own business everything will add up to the best possible world.

Now, I have often thought that we disemboweled that old legend in 1930-1931-1932 so far as the doctrine of the harmony of interest is concerned. We at least settled that it doesn't work in the economy, or not very effectively, or not effectively enough. The doctrine of automatic harmony of interests is that God designed the world so that if every man just minds his own business everything will be perfect. In the extreme that is a doctrine of anarchism. Much academic life has been conducted as if anarchism was solemn doctrine and there is a great deal that goes on in society on an "as if" basis by people who would deny the principle but who nevertheless act as if they believed it. It is perfectly common in modern institutions, just as common in modern institutions as in those of the Trobriand Islanders, as in those of the Kwakiutl Indians that we read about in good, nice, fascinating anthropological books which leave us with the conviction that *we* are their superiors.

However, any operations research agency does cross-field research because it can not do anything else except rarely. Now, correspondingly, I would say integration or cross-fertilization will happen in the operations research agencies if it is going to happen anywhere. They have the most intensive prospects of cross-discipline integration possible. Teamwork across disciplines is the *normal* condition of work. It is very seldom that you have a chance to do anything completely within your own discipline. It is a very relaxing, pleasant, accidental experience when it happens. I would say three hours in one day and six hours in another and once for a week in the course of three years I have been a political scientist with nothing but political science to think about in the course of my work in operations research. I know a psychologist who has been able to think purely about psychology for as much

as a month at a time, and I know a physicist who has thought nothing but physics for as much as a month at a time, but I would say eight months' work out of twelve is less than the average of enforced cross-discipline work because that is what goes on and you are either on the team or you are not. And it runs as high as 364 days a year of cross-discipline work out of 365 possible.

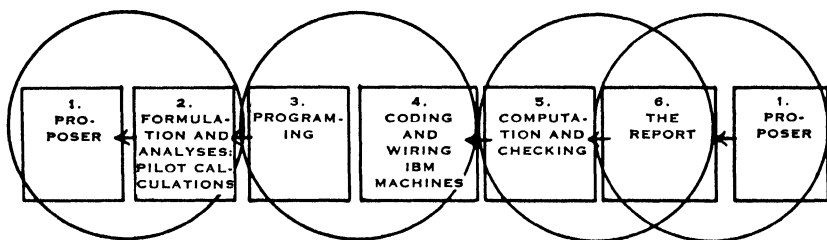
Correspondingly, operations research is strenuous because it is really hard work to define the problem and design the study in a common language so you are sure you will all understand it. If you subcontract in cross-discipline work, you must start watching the subcontractor in his work. If you want to get your money's worth, you have to put out exceptional effort in order to exploit the researcher's brains effectively enough so that the study that comes in is oriented on the target that was in your mind. It is by no means simple.

Versatility is required and versatility does not come too easy. We try to get versatile personnel. In some cases we find it very simple. Every once in a while a young man walks in who had 100 fighter sorties and also has a Ph.D. in economics. Well, we think he is a good man to work on either air defense or tactical air support or ground operations. We at least have the feeling that in his case two big subjects are planted in his mind so that he has got a conditioned familiarity with more than one—I think the "more than one" is the all-important factor there. It doesn't matter whether it is two or three, half as much as it matters whether it is two or one. To have become saturated with the language of two subjects gives you a sense of what semantics is all about, which it is very difficult to get as long as you are saturated only in one subject. It is a key to versatility and flexibility, but even for that kind of person this cross-discipline teamwork is strenuous. It is arduous and fatiguing when the pressure is on.

17: TEAMWORK IN A COMPUTATIONS LABORATORY

J. H. CURTISS

The daily operations of a great computation laboratory, such as the National Bureau of Standards' Institute for Numerical Analysis in Los Angeles or its Computation Laboratory in Washington, form an excellent example of teamwork in science. The accompanying chart gives an idea of the course of a typical problem through such a laboratory. A problem originates, for example,



in the research department of a large aircraft concern engaged in government contract work. It is brought, in a more or less clearly defined mathematical form, to the attention of the computation laboratory, where at stage 2 it is formulated more precisely in mathematical terms and the methods used to attack it are chosen. (For instance, if the problem consists in solving a differential equation, it is decided here whether to employ an infinite series solution, or to replace the equation by a finite difference equation and use direct numerical methods, or to use any of the many other methods available.) Generally at this point a *task manager* is chosen, who has responsibility for choice of methods, for accuracy of final results, and for preparing the final report. He is also responsible for cost estimation. He is in practice frequently the chief (or sometimes sole) analyst working on the problem.

At stage 3, the chosen mathematical solution is broken down into a stated sequence of basic arithmetic operations (addition, multiplication, comparisons of magnitude, etc.). Various checks will be set up in this sequence, some of which consist merely in doing

parts of the sequence twice in the same way and comparing answers, some of which consist in counting digits or other characteristics of intermediate results to see if the results are reasonable, and some of which consist in using two different methods which should give the same result.

At stage 4, if the problem is to be done on IBM machines, the sequencing boards of these machines are wired to perform the sequence of operations (or pieces of the sequence of operations) specified in stage 3. If the problem is to be done on an automatic digital machine, such as the SEAC, the sequence of operations is translated into a sequence of symbols which stand for numbers and orders which the machine "understands." Stage 5 consists of operating the machine or machines; this may be more or less complicated depending upon to what extent the solution of the problem is done entirely inside the machine without human intervention. Last but not least is the preparation of a clear, usable final report.

The entire process from stage 2 onward through stage 6 is presided over by the task manager, working under the very general supervision of the computing laboratory's director. In this loose sense, the solution of the problem is all one big teamwork effort. As in all teamwork, the success largely depends on the degree to which the captain understands the capabilities of the individual members so that successful delegation of parts of the problem can be accomplished.

But this is only a part of the story as regards teamwork. The fact is that teamwork of a more explicit kind is necessary to integrate certain stages of the solution. The areas in which cooperation is particularly important are indicated by the circles in Figure 1.

The first circle binds together the mathematicians in the computing group and the personnel who have identified the requirement for the computing job. Often the latter persons are busy practical engineers who are not mathematically trained and who have not yet thought through their problem in precise terms. Quite often the problems which such individuals first propose are not the problems which they really need to have solved at all. It is the duty of the problem analysts to sit down with the originators of problems and go deeply enough into the physical bases to be able to guide the formulations into fruitful channels. Sometimes the apparent need for an expensive computation job vanishes right at this point.

The next circle binds the analytical and the programming stages

together. These two stages are in fact sometimes carried out by the same person, but since programming is easier than analysis, it may be more efficient to assign personnel with less formal training in mathematics to the job of programming.

One prerequisite of a programmer is to be thoroughly familiar with the characteristics and limitations of the computing machinery for which he is programming. If different groups handle the two stages, then the analyst must either make a rough program of his own or be in constant touch with the professional programmers to be sure that the method of solution he chooses will not exceed the capacity of the machines or take an intolerably long time.

Similarly, coding and operating is sometimes done by the same person. When it is not, there must be constant teamwork between coders and operators, all supervised by the task manager. One reason for this is that one of the frequently encountered sources of trouble in using automatic or semi-automatic computing machines consists of errors in the coding or sequencing. In the case of a long complicated problem, it can be a most difficult job to check out the code to be sure it is correct.

Finally, in the writing of the report, the task manager must again cooperate with the proposer of the problem to be sure that results are put in the most convenient form.

Thus it is seen that a computing problem involves a chain of scientific activities, with teamwork necessary both in the overall sense and in carrying out the activities forming the links of the chain.

But teamwork plays a role in various other aspects of computation. For example, a great computation laboratory has a responsibility to develop better methods and new theories of computation; but to avoid performing research in a vacuum, there should be constant contacts between the researchers on the one hand, and on the other, the analysts who are meeting the real-life problems day after day. Now high-class research work in mathematics is traditionally academic, and it is next to impossible to get good work out of a research mathematician on problems in which he has no interest. Therefore, the primary aim in setting up the right sort of interplay between researchers and analysts must be to interest the researchers. One device for doing this which has proved successful at the National Bureau of Standards' Institute for Numerical Analysis has been to hold a weekly problem meeting to which various researchers are invited, at which the one or two

hardest and most challenging problems before the analysis and computation groups are discussed.

Teamwork of another sort is necessary between mathematicians and electronic engineers in (a) computing machine design, and (b) troubleshooting for complicated computing machines. In fact, to develop adequately just these aspects of teamwork in the science of computation would require an exposition considerably longer than this one. But limitations of time and space are now becoming pressing, and this discussion must come to a close.

In conclusion, mathematics has historically been a subject in which teamwork has been the exception rather than the rule. Such teamwork as there has been, has generally taken the form of collaboration between two—very rarely, three—individuals. But as we have now seen, the science of computation requires teamwork on a large scale. The recent great growth of interest in this branch of mathematics has brought an entirely new point of view into the “Queen of the Sciences,” and teamwork is now beginning to play the important role in mathematics that it plays in so many of the other disciplines.

CONCLUSION

18: TEAMWORK IN RESEARCH: A COMMENTARY AND EVALUATION

GEORGE P. BUSH

The purpose of this concluding chapter is twofold: to emphasize a few of the many points made during the course of the Third Institute on Administration of Scientific Research and Development; and secondly to point out some of the existing literature that is pertinent to the concept of teamwork, a field which is as yet largely unexplored.¹

It will be noted that the book is divided into four principal parts: (1) organization, (2) personnel factors, (3) aids, and (4) case examples, the presumption being that these would constitute a sufficient goal for the week's work of the Third Institute. A reading of the papers indicates the difficulty of specializing on a particular segment without talking somewhat within the realm or segment assigned to another speaker. Hence, a first point is this: All the thought pertaining to an assigned title is not necessarily contained in the paper bearing that title. On the contrary, some thoughts of greatest pertinence are to be found in "gem sentences," some of which literally stud others of the presentations. For example, Part Two is devoted to personnel factors in teamwork. The four speakers are experts in their specialties. They speak to the point of their respective assignments. They draw upon their wide experiences. Page is basically an astrophysicist and Rothrock is a physicist; Tolley is an agricultural economist and statistician; Hertz, an industrial engineer. And yet our reader will miss much if he fails to read what other speakers have said about personnel factors. Tuve's talk is not labeled "personnel factors," yet it fairly tingles with the vibrant recollec-

¹For a recent resume on the body of literature on the management of scientific organizations see Robert N. Anthony, "Looking Around," *Harvard Business Review*, Jan-Feb 1952, Vol. XXX, No. 1, pp. 127-136. For a bibliography on the management of industrial research see "Management of Industrial Research: A Selected and Annotated Bibliography" (Cambridge: Arthur D. Little, Inc., 1950), 14 pp.

tions of the personnel factors that pervaded Section T.² Here an experienced researcher, speaking "off the cuff," talked at a high rate of speed to a small group, his words being captured by a tape recorder. This talk breathed "the spirit of the thing" even as Section T did so breathe. Your editor sensed a high correlation between Tuve the man, Section T the organization, and the personnel factors within that organization.

Trend. A frame of reference for "teamwork" was established by some of the speakers as they introduced their subjects. Some interesting definitions were developed. These definitions and these frames of reference are important in reminding one that man-in-relation-to-teamwork goes back to the dawn of history and this not alone teamwork of the *body*, but teamwork of the mind—planning, advising, decision-making: ". . . the idea of team attack really is not very new."³ In 1945 Midgley noted some reasons for its popularity:

"The past twenty-five years have established certain concepts of research organization that we may expect to endure for some time to come. It is scarcely necessary to discuss these accepted principles at this time. The research 'team' as a unit in this organization has gained popularity in the recent past. The individuals of any particular team are chosen for their qualifications in their field of specialization, as it is related to the problem to be studied. This is a different approach to organization from the conception of a departmental head, with a variety of assistants. Both unit types have their places. The 'team' is better adapted to the solution of problems involving two or more fields of science, while the 'head,' with assistants, works best on problems substantially confined to a single field. It has been observed that the problems involving multiple fields are becoming more numerous and hence the team conception is gaining in practice."⁴

One might ask: Of what present importance is this teamwork of the mind in the realm of technological research or of scientific research? Is there any qualitative or quantitative measurement of

²C. E. K. Mees notes that: "The Carnegie Institution, particularly, originated a new type of scientific laboratory. The Geophysical Laboratory and the Mount Wilson Observatory are of the convergent type, in which the work of many scientists, specializing in diverse fields of science can be concentrated upon certain groups of problems." *The Path of Science* (New York: John Wiley & Sons, Inc., 1946), pp. 176-177 and p. 180. It should be borne in mind that Tuve was in this environment from 1926 until the summer of 1940, when Section T was established.

³Edwin F. Pike, Chapter 2, *supra*.

⁴Thomas Midgley, Jr., "The Future of Industrial Research, the View of a Chemist," *The Future of Industrial Research* (New York: Standard Oil Development Co., 1945), p. 42.

trend? This editor endeavored to approach this question by making a cursory check of the two periodicals *Science* and *Industrial and Engineering Chemistry*. The technical articles appearing in the years 1951, 1936 and 1921 were examined to see if there was any trend in joint authorship, the presumption being that this would be an indicator of joint research. *Science* was chosen because of its close relation to scientific research, and *Industrial and Engineering Chemistry* because of technological research.

The tabulations from *Science* were as follows:

Year	Number of Authors							
	1	2	3	4	5	6	7	8
1921	63	11						
1936	60	68	13	5	2			
1951	156	168	77	27	5	2	1	1

The tabulations from *Industrial and Engineering Chemistry* were as follows:

Year	Number of Authors								
	1	2	3	4	5	6	7	8	9
1921	160	40	7	2					
1936	151	118	50	10		1			
1951	199	206	105	36	11	5	1	1	35

In order to show a trend these data were translated in terms of percentages per year and are graphed in Figures 4 and 5. It will be noted in these two charts that for both⁶ periodicals there has been a marked trend away from the single researcher to the team-research group. In fact the lone researcher is now in the minority. Moreover, there is an observable correlation between the two charts. This subject deserves a more comprehensive exploration so that future institutes in this field may have objective data.

Related to the subject of joint authorship is that of the author who seldom or never publishes a paper alone. A clue to this was obtained by analyzing those authors appearing under the initials "A" and "B" in the Author Index to *Industrial and Engineering Chemistry* for 1951. Of the 31 entries in "A", 12 were in collaboration. Only two of these 12 had a publication in the preceding five years and these two were also in collaboration. Of the 100 entries

⁵Stuart Chase mentions: "... Dr. Clyde Kluckhohn, at Harvard, assisted by a team of 60 scientists is now conducting an area study of Russia..." in "Careers Ahead in Social Science!", *The Reader's Digest*, August, 1952, p. 51.

⁶Emil Ott says (in bold type) "Group effort is not alone a tool for the field of industrial development. . . . Its advantages apply equally in basic research" in "The Team approach in Research and Development," *Chemical and Engineering News*, 28, (June 12, 1950), pp. 1994-1996.

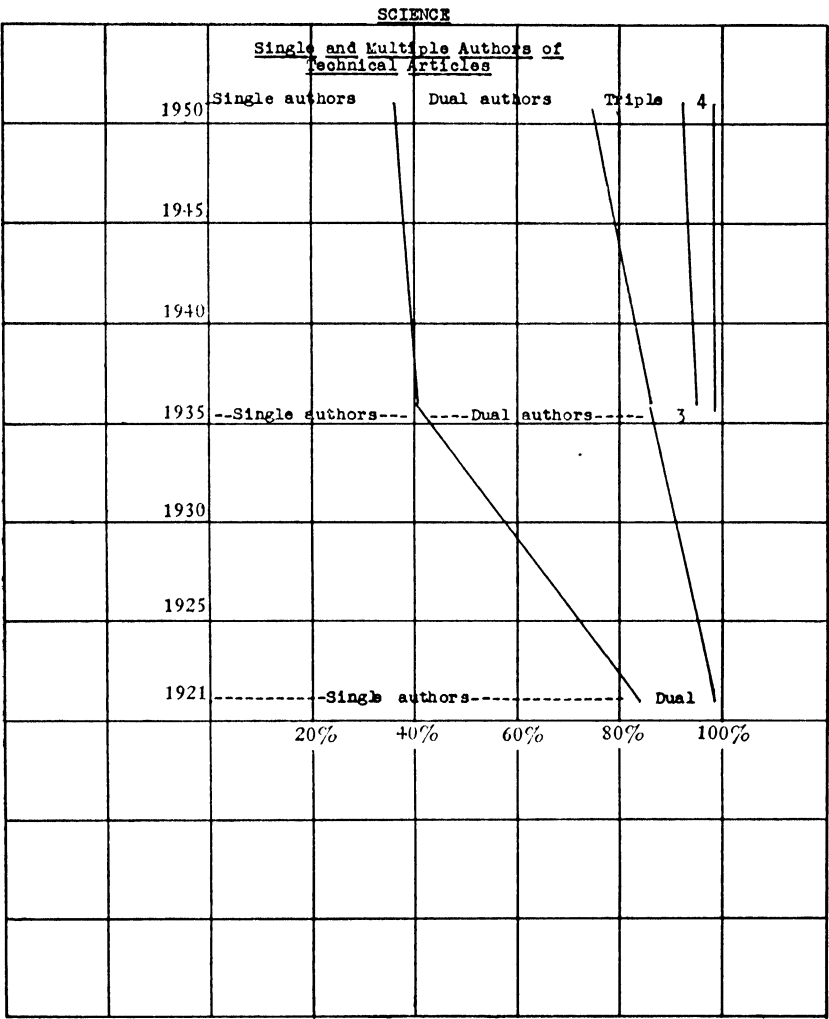


Fig. 4.

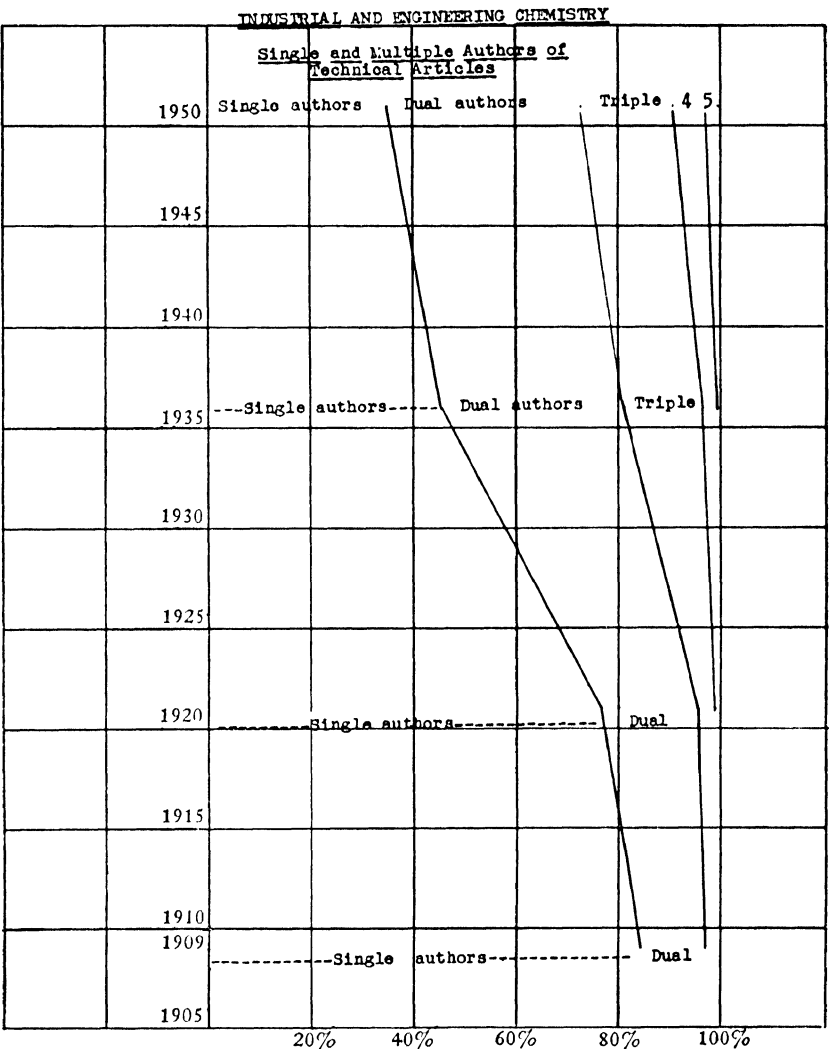


Fig. 5

in "B," 38 were in collaboration. Only six of these 38 had a publication in the preceding five years, five of them in collaboration and only one published alone. On this small sample one might say that one-third of the papers in *Industrial and Engineering Chemistry* are published by persons who apparently seldom, if ever, engage in individual research. In this connection we might recall that: "The less an individual desires to work as part of a team the higher must be his brilliance to justify his continued effort in the applied field."⁷

Complexity. This trend toward greater frequency in teamwork on the part of researchers appears to be explained by the presence of certain factors surrounding the research situation. It is obvious that if a lone researcher can do the job alone, no team is needed.⁸ Or, if he needs few, if any, tools other than his mind, he can do good work alone.⁹ But such situations appear to be decreasing in frequency because it is seldom that one man will have all of the knowledge and all of the manipulative skills required in coming to a research decision or a research operation. As Siepert observes:

"... there are relatively few laboratory scientists today who do all their work alone or rely on only one or two assistants to supply their total needs. The complexity of a wide range of research problems requires that the bench scientist have access to the knowledge of various scientific disciplines, to extensive physical facilities or to complicated apparatus which he cannot obtain or maintain through his own personal efforts."¹⁰

Further, the devices used in research are becoming more complex and more difficult to operate, thus causing dependence upon many scientific knowledges. "The problems faced," says Rothrock, "may become individually so difficult and so complex and so intermingled with other equally difficult and complex problems that an entirely new order of team activity is required."¹¹ Nevertheless certain cautions should be observed so that one does not presume that teamwork is the solution to all research problems. We are reminded by Freedman that "... Today [presumably 1950] teamwork in

⁷Addison M. Rothrock, Chapter 10, *supra*.

⁸Dante Alighieri: "XIV.—And where a thing can be done by one agent, it is better to do it by one than by several, . . ." *De Monarchia*, Bk I, Ch XIV, as translated by F. C. [sic] J. Church (London: Macmillan and Co., 1878), p. 203.

⁹P. L. Kapitza in speaking of an institute employing only a few scientists says: "Good work cannot be done with other people's hands." (*Voks Bulletin*, No. 9-10 [1943]).

¹⁰Albert F. Siepert, *supra* p. (His MS pp. 1 and 2)

¹¹Addison M. Rothrock, *supra* p. (His MS p. 3)

scientific research has become something of a fetish, . . ."¹² Another British writer, W. Lawrence Balls, introduces a recent article in the same vein: "Perhaps I may be permitted to express scepticism about the team-work in science which is nowadays fashionable. . . . At its worst a team becomes a device for 'passing the buck' from one member to another, a mere piece of machinery which survives although there is no external fuel to drive it. . . ."¹³

Human Relations. With these cautions in mind one may proceed to examine other factors which bear upon teamwork. In the course of a talk, Lillian Gilbreth pointed out that: "A team, unlike a partnership, is not an equal sharing. The use of a team recognizes that *one* cannot do a particular job; but no team member should lose his individual identity."¹⁴ This factor of individuality was brought out by some of the discussion at Columbia University during June 1951 when members of the Second Annual Conference on Industrial Research were relating their experiences, for example:

"*Member:* How long did it take for the group to be able to talk to each other?"

"*Member:* Having been a member of the group, being the chemist involved, I can say that the first two weeks were pretty bloody because each member of the group, almost without exception, was suspicious of the other."¹⁵

It is this sort of interpersonal relationships, this mode of human collaboration, which must be understood if teamwork is to be useful in the area of research. As Ahlberg and Honey have pointed out: "The individual scientist or engineer approaches his technical task with elaborate patterns of personality and of intellectual behavior thoroughly established. . . ."¹⁶ To this end Hertz has contributed useful ideas. In a previous chapter,¹⁷ as well as in a recent book,¹⁸ he considers the sociological and psychological factors which have such an important bearing upon the phenomenon

¹²Paul Freedman, *The Principles of Scientific Research* (London: McDonald & Co., 1949), p. 135.

¹³W. Lawrence Balls, "Cotton: Years of Experiment," *Journal of the Textile Institute*, Vol. 42, No. 8, August 1951, Manchester, England, p. 319.

¹⁴Lillian M. Gilbreth: From a report by a student of a speech given at the University of Maryland, April 27, 1951.

¹⁵David B. Hertz, editor, *Selection, Training and Use of Personnel in Industrial Research* (New York: King's Crown Press, 1952), p. 217.

¹⁶Clark D. Ahlberg and John C. Honey, *Some Administrative Problems in Governmental Research*. (Washington: Washington Research Office, Maxwell School of Citizenship and Public Affairs, Syracuse University, 1951.) p. 7.

¹⁷David B. Hertz, Chapter 8 *supra*.

¹⁸David B. Hertz, *The Theory and Practice of Industrial Research* (New York: McGraw-Hill Book Co., 1950), pp. 85-86, 187-188, 234-235.

of teamwork.¹⁹ And in this connection one should heed the admonition of Roethlisberger when he says: “. . . our hope is to stimulate more research and less talk about matters of human collaboration. . . .”²⁰ A long range viewpoint that offers hope to free peoples was expressed by Montagu:

“On the basis of the facts we may conclude that the more cooperatively the members of any group behave, the more harmonious the social organization of that group is likely to be. In 1944 a group of distinguished biologists summed up the principle of cooperation in the statement that the probability of survival of living things increases with the degree in which they harmoniously adjust themselves to each other and to their environment. . . .”²¹

Creativeness. The enhancement of creative ability by the device of teamwork is another factor which justifies its use. One can visualize many situations in which team-action increases the creative ability of the individuals in the particular team. The team as a team can create and can solve problems and even make decisions where an individual may not have the lone ability to do so. This phenomenon operates in various ways, e.g.,

- A. By reinforcement between individuals in the same discipline
- B. By differences between individuals in diverse disciplines
- C. By combination of the contributions of the “less-gifted” to the “greater-gifted.”

¹⁹For a discussion of group behavior see Herbert A. Simon *Administrative Behavior: A Study of Decision-Making Processes in Administrative Organization* (New York: The Macmillan Company, 1947), pp. 70-73; Herbert A. Simon, Donald W. Smithburg and Victor A. Thompson, Chapter Five, “Building Blocks of Organization: Group Values,” *Public Administration*. (New York: Alfred A. Knopf, 1950), pp. 111-129; Ordway Tead, *The Art of Administration* (New York: McGraw-Hill Book Co., Inc., 1951), pp. 153-155, 164-165, 193-194.

For a brief discussion of teamwork from the group dynamics viewpoint see Leland P. Bradford and Ronald Lippitt, “How to Develop Democratic Work Teams” in *The Management Leader's Manual*, edited by James O. Rice and M. J. Doohar (New York: American Management Association, 1947), pp. 13-24.

For a brief discussion of teamwork from a still broader view see: “Human nature demands teamwork,” “Religion and morality demand teamwork,” “Experience shows the need for teamwork,” in *Human Relations in Modern Business*, no author (New York: Prentice-Hall, Inc. 1949), pp. 2-7.

For a discussion of human relations, primarily at Mellon Institute see William A. Hamor, “Human Relations in Research Institution Management,” *Advanced Management*, December 1946, Vol. XI, No. 4, pp. 132-141. The article deals with teamwork indirectly.

²⁰F. J. Roethlisberger, *Management and Morale* (Cambridge: Harvard University Press, 1947), p. 177.

²¹M. F. Ashley Montagu, “Man and the Social Appetite,” *The Saturday Review of Literature*, November 19, 1949, p. 56.

Manifestly A, B, and C are highly variable from situation to situation. Perhaps the situation is most effective which creates the greatest challenge to a particular individual at a particular moment, which draws from him a creative thought or decision that normally would have lain dormant. This creative ability (self-ignition) of the team as such appears at times to operate as a sort of chain reaction. Mary Follett has expressed it in terms of a management principle: "... coordination as the reciprocal relating of all the factors in a situation."²² She illustrates it in these few words: "... A adjusts himself to B and *also* to a B influenced by C and to a B influenced by D and to a B influenced by A himself. Again he adjusts himself to C and *also* to a C influenced by B and to a C influenced by D and to a C influenced by A himself—and so on and so on. . . ."²³ We can envisage such chain reaction of thought within a team as something akin to a "cyclotron" of thought due either to reinforced stimulation on the one hand or grinding differences, attributable to disciplines, backgrounds, temperaments, etc., on the other. One might phrase as a truism: The combined efforts of a group of men working as a team usually add up to more than the sum of the individual efforts. An insight into the reasons for this phenomenon is provided by Beveridge in his elaboration of "Discussion as a stimulus to the mind."²⁴ If creative

²²Henry E. Metcalf and L. Urwick, *Dynamic Administration: The Collected Papers of Mary Parker Follett* (New York: Harper and Brothers, n.d.), p. 299.

²³*Loc. cit.*

For a more extensive discussion of cooperative action see Chester I. Barnard, *Organization and Management: Selected Papers* (Cambridge: Harvard University Press, 1949), pp. 113-118.

"Men who are only average when dealt with singly may become extremely able by the mental stimulus provided by association with other men working on similar problems. . . . it is also probable that the minds of men are quickened by contact, and a group of men who taken individually would be only average can be raised to a high level of intellectual activity by association, and especially by the precept and example of one first-rate man. . . ." C. E. Kenneth Mees and John A. Leermakers, *The Organization of Industrial Scientific Research* (New York: McGraw-Hill Book Co., Inc., 1950), p. 208.

"The ability of the human mind to solve a problem through the use of combined brain power is the very foundation of our many successes." William H. Dow, President, Dow Chemical Co. as quoted in *Battelle Technical Review*, January 1952, Vol. 1, No. 1, p. 12.

Clyde Williams reminds us that: "... When the integrated laboratory came into being, research became as systematic as a planned sales or production campaign. It became highly organized, carefully planned, and expertly executed. . . ." From an editorial in *Battelle Technical Review*, April 1952, Vol. 1, No. 4, p. 35.

²⁴William I. B. Beveridge, *The Art of Scientific Investigation* (London: William Heinemann, Ltd., 1950), pp. 62-64.

ability can be enhanced by the device of teamwork, how can we measure it, if at all? This brings us to an unexplored area so far as this editor was able to determine. We need to set up experimental controls over team research versus non-team research if we are quantitatively to determine that team research is advantageous. This should be done, but it is difficult because man is unpredictable and the chain reaction effects are unpredictable. Nevertheless, with all the teamwork that is indicated by the previously appearing tabulations of joint authorship, it would seem feasible for some of the larger research organizations to set up such controls as will give some quantitative data for future institutes to ponder.

Policy and Planning. Research teams are governed by policies, at times by elaborate policies. Teams are not the free agents some might presume them to be. What shall the team investigate? Or, more usually, what shall the team investigate next? These simple questions engender a whole series of subordinate questions, as was brought out by Pike. It is concerned with the historical past, the present talent, the raw materials, the resources in terms of facilities and funds, the competition, the imagination to see ahead.²⁵ The policy for the team should be carefully defined and painstakingly imparted to the team, some parts of it to all members of the team. Policy usually begets planning, setting a course for future action. Planning is the first responsibility of management. Planning covers a wide scope; it "... helps to plan policy at the one extreme, plans detailed execution at the other extreme, and has a finger on the pulse of actual execution. . . ."²⁶ In the military, planning has first priority. In research teamwork it should have a high priority. Much is at stake.

Structure. The form or structure of a research team is of importance. The form varies from a simple two-man team to large and complex patterns such as Section T, which has hundreds of employees. Linked with size and complexity are such matters as unity of command, span of control, span of attention, areal distribution and communications. In speaking of Section T, Gibson noted three principles: "(1) The focusing of a variety of talent, training, or skills, on a complex problem, (2) the utilization of these talents or skills and the special facilities required where they

²⁵Edwin F. Pike, Chapter 2, *supra*.

²⁶Harlow S. Person, "Planned Execution—The Issue of Scientific Management," Catheryn Seckler-Hudson, editor, *Processes of Organization and Management* (Washington: The American University Press, 1948), p. 148.

occur, and (3) the promotion of independent centers of initiative by decentralization."²⁷ (1) is related to inter-discipline and complexity, but (2) and (3) are areal. One might say that Tuve evolved a form of teamwork which was unique in that it widened the areal scope of research. Manifestly, an infinite variety of these structures is possible. However, there is implicit in such applications varying combinations of management factors of "principles" whose effective implementation measures the success or failure of that particular team structure. Whereas Section T is a teamwork structure primarily in the field of technological research, the Computation Laboratory at the National Bureau of Standards is a teamwork structure primarily in the field of science. The structure there provides for sequential actions by sub-teams. As Curtiss points out: "The entire process from stage 2 onward through stage 6 [as per his diagram] is presided over by task managers working under the general supervision of the computing laboratory's director. In this loose sense, the solution of the problem is all one big teamwork effort."²⁸ Structure also provides channels of information both within the team and to and from the team. Scott has aptly pointed out that the nature or kind of information makes a difference in the channels utilized. Official information should follow strict hierarchical lines, while technical information takes appropriate short-cuts.²⁹

Leadership. Several speakers touched upon the necessity that effective and qualified leaders should head up teams in research. In this area as in others: "There is no substitute for good leadership. . . ."³⁰ As was previously observed teams are not spontaneous. They *require* leaders. These leaders must have unique qualifications. On the one hand they must be sufficiently versed technically and on the other sufficiently versed in understanding human relationships. The combinations are infinite. Meader has said that: ". . . The achievement of a congenial atmosphere of cooperation . . . is one of the greatest factors in creating a productive team. . . ." and ". . . to a great extent it is a matter of personal attributes of the leader of the team or group. . . ."³¹ Gibson has most aptly reminded us that: "In all institutions the formal organization chart is merely a framework; . . . The spirit of an institution trans-

²⁷R. E. Gibson, Chapter 15, *supra*.

²⁸J. H. Curtiss, Chapter 17, *supra*.

²⁹Eugene W. Scott, Chapter 11, *supra*.

³⁰Catheryn Seckler-Hudson, *Processes, op. cit.*, p. 43.

³¹Ralph G. Meader, Chapter 6, *supra*.

cends its formal organization.³² He attributed team difficulties largely to: "... the personalities of the people involved. . . ."³³ In speaking of research leadership at the several levels in an organization, Dryden notes that:

"... We thus have a whole team of research directors, division and section heads, and project leaders, with whose responsibilities we shall be concerned. The term research director will be used to include all members of the team."³⁴

Since one can visualize a great range of team sizes and team complexities as previously mentioned in this chapter, the question arises: What exposure to the principles of human relationships is given the scientist while in his formative years? Quite true, he might engage in group athletics or group military training or some group duties in the laboratory. All these would be informal, though useful, exposures. But how about such courses as "Human Relations in Management," or "Personnel Psychology," or "Psychology of Management," or "Supervision in Administration,"³⁵ or "Administration of Research Activities in Government"³⁶ The chances are that the scientist when he takes his Ph.D. has never been exposed to principles of human conduct which in his later years may be of prime importance to him in his team-relationship. Just imagine the human relationship problems that exist in the 60-man team at Harvard.³⁷ It would seem that since the trend is toward more teamwork, either the university or the research organization should provide an exposure to this essential knowledge. It can be and has been acquired in the school of hard knocks, but Page has implied that we must conserve our precious research manpower. Training for team leadership assists such a conservation.

Control. Teamwork is not a spontaneous phenomenon. People do not drift into coordinated thinking and acting—it is the result of some degree of organization on the part of research management, with a range from "slight suggestion" to "arbitrary compulsion." One can presume that results in such a range are unpredictable, because the variables are infinite. Scott uses the word "bind":

³²R. E. Gibson, Chapter 15, *supra*.

³³*Loc. cit.*

³⁴Hugh L. Dryden, "Responsibilities of Research Directors" in George P. Bush and Lowell H. Hattery, editors, *Scientific Research: Its Administration and Organization* (Washington: The American University Press, 1950), Chapter 6, p. 37.

³⁵Offered during the Spring Session 1952 by The American University.

³⁶Offered during the Spring Session 1951, *ibidem*.

³⁷Mentioned in footnote 5.

"... these individuals are put into the team because of the fact that you thereby *bind* together a number of information resources."³⁸ Hertz indicates that "... the amount of intellectual activity or creative activity within a group is probably related to the pressure exerted to get the job done." But his next sentence cautions that: "If there is too much pressure on a research team, the results will suffer. . . ."³⁹ It appears to the present editor that much depends upon the kind of research being undertaken, the personalities of the researchers, and the stakes of the research in terms of money or time or life itself. Either pressure or lack of pressure could become critical and even ruinous. "... research workers are unwilling to accept forms, rules, or techniques," says Anthony, "unless they see some logical reasons for the existence of these things. They will *tolerate* illogical control practices if they are required to do so, but they will not *cooperate* to make these practices effective unless they are convinced that they are worth while. . . ."⁴⁰ It is this last clause which deserves special consideration. It appears to be a function of research management to convince or to "sell" the research worker on the necessity for controls. In a free world one is apt to smugly accept "freedom of research" and presume that behind the iron curtain there is not this freedom and hence research there is inferior. Such an assumption could be misleading provided the research management has done a sufficient selling job (one way or another) to convince the worker that varying degrees of control of research and of the team are absolutely necessary. This is not to disagree with Vannevar Bush when he said:

"A democracy is efficient in emergency, for the free spirit which it engenders in its normal course is an essential ingredient of great accomplishment under stress. The old contention that only totalitarianism can cope with the complexities of modern life is a fallacy."⁴¹

Nor is it to disagree with Sebrell and Kidd when they say: "... we believe that sound research cannot be done with fear as the motivating force. Pressure to produce in research defeats itself. . . ."⁴² And yet we read that:

³⁸Eugene W. Scott, Chapter 11, *supra*.

³⁹David B. Hertz, Chapter 8, *supra*.

⁴⁰Robert N. Anthony, *Management Controls in Industrial Research Organizations* (Boston: Harvard University Graduate School of Business Administration, 1952), p. 55.

⁴¹Vannevar Bush, "The Teamwork of Technicians," *Endless Horizons* (Washington: Public Affairs Press, 1946), p. 129.

⁴²W. H. Sebrell and C. V. Kidd, "Administration of Research in the National Institutes of Health" in *The Scientific Monthly*, March 1952, p. 158.

"In Russia, friends of the NSF (National Science Foundation) are quick to point out, science has become a crusade. . . .

"Observers rate Russia's top men as capable as any in the world. . . .

"Students of Russian Science say Americans underrate it. . . .

". . . Those who don't cooperate—and those who refuse to work on assigned research—don't eat. Belief that this kind of bureaucracy makes for poorer science is wishful thinking, observers here say."⁴³

What are we to conclude when a sociologist tells us: "Man, therefore, *must* not be *forced* to work, but must be offered the opportunity to engage in activities which are individually and socially meaningful."⁴⁴ There is a partial answer in the words of a psychologist, who reminds us that: ". . . We may achieve our end by acquiring better research equipment, by mustering men with greater ability or by *creating more interest and drive in the men at hand*. . . ."⁴⁵

Coordination. Teamwork in research in certain areas is the normal condition of work. It is a logical development where cross-discipline integration is required. Pettie in speaking of operations analysis, for example, states that: "Teamwork across disciplines is the normal condition of work."⁴⁶ This normality is intriguing. Imagine the trend. Specialization in most aspects of research is increasing and deepening. Yet, coordination of specialized research is imperative if cross-disciplinary research is to be effective. One might phrase it this way: As disciplines fragment due to ever-increasing specialization and as problems increase in complexity, the need for coordinated cross-disciplinary approach increases, is the normal state, and is mandatory. Like other forms of teamwork it is not spontaneous or automatic. Pettie says it is strenuous, arduous, fatiguing and requires versatility and flexibility.⁴⁷ Since these factors are found in individual research also, it would be instructive if comparative data were available to research management regarding the wear and tear on research workers when engaged upon inter-disciplinary research. It is of importance as was indicated by Page in his passage: "There are so many re-

⁴³"Keeping pace in science," no author in *Pathfinder*, May 7, 1952, p. 25.

⁴⁴Bruno Solby, "Industrial Psychology and Personnel Management," being a summary of a series of lectures to Navy officers, processed August 3, 1945, p. 7.

⁴⁵Milton Dean Havron, "Incentives from the Viewpoint of a Psychologist" in Bush and Hattery, *Scientific Research*, *op. cit.*, Chapter 13, p. 79.

⁴⁶George S. Pettie, Chapter 16, *supra*.

⁴⁷*Loc. cit.*

search projects being set up that we are in great danger of using up all our scientific manpower before we have finished all the important research problems."⁴⁸ Howard has related the importance of coordination of wide-scale research by a management staff and he mentions the variant coordination required for a major development project requiring the setting up of "a special team, cutting across all department lines, to make up a team of scientists, engineers and patent attorneys. . . ."⁴⁹ This variant is akin to the coordination required in the inter-disciplinary approach.

Time. The factor of time frequently is of paramount importance as related to a projected research. Time may transcend cost in importance. In such instances, as Wallace has indicated: ". . . more manpower and skills are focused upon the solution of the problem. This begets not only a quicker but a broader answer than an individual could obtain."⁵⁰ To do otherwise might involve a risk commercially or a risk militarily as the case may be. In Gibson's introductory remarks he indicates the great importance of time by reminding us of ". . . the fever heat of war activity, where time was worth more than money, . . ."⁵¹ Curry⁵² also stresses the time element in transition from war-time to peace-time and pertinently comments that: ". . . Dr. Tuve's running orders are history and although picked up and actually published by the Navy, they cannot serve today's rules of how to get things done. . . ."⁵³

In sum, teamwork in research is an area largely unexplored. Its rapid increase in the past thirty years indicates the need for further understanding—for an understanding of human values, human relationships, sociological and psychological aspects, managerial "principles." Individual research, while now in the minority, still holds a firm place, particularly in certain areas of pure science and especially in the fortuitous presence of a brilliant mind. Teamwork requires varying degrees of organization and management, because it is not a spontaneous phenomenon. The management factors are common to management in general: policy making, division of labor, planning and programming, methods and procedures, budgeting of resources, delegation of authority and responsibility, structural form, effective leadership,

⁴⁸Thornton Page, Chapter 7, *supra*.

⁴⁹Frank A. Howard, Chapter 4, *supra*.

⁵⁰L. W. Wallace, Chapter 3, *supra*.

⁵¹R. E. Gibson, Chapter 15, *supra*.

⁵²R. B. Curry, Chapter 13, *supra*.

⁵³*Loc. cit.*

unity of command (and the related feasible span of control), accountability (at some levels but not at all of them) for tasks assigned, coordination and decision-making, and finally and importantly in this area the ability to assess the future in terms of the past, giving due consideration to all matters. Such management as one finds in the team is usually fortuitous, because research workers seldom are exposed to the "principles" of organization and management. This is regrettable and calls for remedial action because the pool of research manpower is already restricted and should be preciousy conserved. Rothrock struck a keynote with this editor when he said:

"Principles that lead to teamwork in research are essentially those that lead to teamwork in any endeavor."⁵⁴

⁵⁴Addison M. Rothrock, Chapter 10, *supra*.

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