Proceedings of the Symposium on Engineering Research

held at

Center for Continuation Study
University of Minnesota
March 14-15-16, 1949

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Edited by

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ENGINEERING EXPERIMENT STATION
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Foreword

This publication presents the papers of the first Symposium on Engineering Research held at the University of Minnesota, Center for Continuation Study, on March 14, 15, 16, 1949.

The primary purpose of this conference was to promote a closer cooperation and a better understanding between governmental agencies, industries, and universities in furthering the advancement of engineering research. It provided an opportunity for representatives of each group to present their views and concepts on problems of mutual interest. Because of the increasing number of research centers being established, it was felt that a conference of this nature would aid in unifying the positions of these groups.

It is hoped that this conference and the resulting published proceedings will assist in furthering the purpose intended and that greater coordination of the three units will be effected.

Acknowledgment

The sponsors wish to express their sincere appreciation to the persons representing local industries, to the staff members of the Institute of Technology, and to representatives of the Center for Continuation Study, University of Minnesota, for participating in the planning and arranging of this conference. They are also greatly indebted to the speakers and to the chairmen presiding at the different sessions, all of whom so willingly volunteered their time and effort in participating in the program.

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Address of Welcome

J. L. Morrill
President, University of Minnesota

I am glad to add my greetings to those of you who have come here on this balmy spring morning in our Minnesota climate where, it has been said, the delicate die young. More often than not you find the word "welcome" written on or woven into doormats. I suppose it is not inappropriate, therefore, that the president of the University should be asked to extend greetings to groups such as this.

Indeed, being neither a scientist nor a technologist nor one experienced either in industry or in government, I can think of no other obvious reason why I should be here except to welcome these very representative guests from universities, from the government, and from our leading Minnesota industries; and this I do, most cordially and sincerely. My interest, both personal and professional, in this meeting is very real and I appreciate the privilege of being here.

I do not know how industry and government may feel, but it seems to me there is a great need in the academic and university world today for such conferences as this one. We need to be more aware of the fast-growing partnership among universities, industry, and government. Of course, there is a great post-war public awareness of the spectacular results of research; and this awareness has been a factor in piling up problems and programs on most major campuses, sometimes too fast for sound appraisal and assimilation.

The very large influx of funds for research has affected and changed—though perhaps unwittingly—the traditional philosophy and organizational pattern of many universities more than we realize. Perhaps we should stop, look, and listen.

Here at Minnesota we have a special need for wisdom and counsel, and have been rather selfish, perhaps, in calling this conference to meet that need. Here is a university which, like almost any other major university these days, has hundreds and hundreds of thousands of dollars in research contracts with industry and government as well as large grants-in-aid in the field of health and medicine. We find that the war contract relationships with government and other agencies have been continued, and in many cases enlarged. There is more subsidized and sponsored research here at Minnesota now than during the war; and I suppose our experience is typical. In addition, there is likely prospect of a National Science Foundation which will raise new questions and provide new relationships.

One very definite need in this field is the need of better administrative coordination, and promotion, of the research possibilities of the University.

I am not thinking of "promotion" in some Chamber of Commerce sense of just getting more contracts and a bigger payroll. And by coordination I mean more soundly conceived and administered policies and procedures.

Now in most matters it is generally conceded that all that a university president knows, to paraphrase Will Rogers' classic remark about newspapers, is "what he soaks up by some kind of academic osmosis from members of his staff." I was impressed by a sentence in Winston Churchill's memoirs when he was discussing his need, as leader of the goverment during the war, to deal with scientists on very abstract and difficult matters. He just remarked that he had been pretty well fortified for that task by a large administrative experience in dealing with matters he did not understand. But in this matter of sponsored and cooperative research in the fields of science and industry, I am not completely an amateur, having had the responsibility of helping to pioneer and pilot the organization of the now very successful Ohio State University Research Foundation. Some years later, at the University of Wyoming, I prevailed upon the legislature to organize a Natural Resources Research Institute. The subjects you will discuss are therefore not entirely new to me. I am very anxious to be helpful to our people here in Minnesota in the same direction.

Universities were not really ready, as everyone knows, for the large postwar volume of enrollments and the influx of thousands of students, chiefly veterans. Neither were they quite ready for the sudden increase in research resources, which has been no less spectacular. I can remember a report written by Chancellor Hutchins of the University of Chicago four or five years before the war in which he stated that money could be obtained for buildings and for teaching, but it was almost impossible to get money for research. Actually, I believe almost any administrator, as he looks ahead these days toward the development of his university program, feels more sanguine about the underwriting of research than about any other phase of the university's operation.

Whitehead said that science has always suffered from vice of overstatement. Perhaps this observation is also true of the popular thinking about research. In the public mind, perhaps research to the modern university enterprise is the same as glamour to the movie industry. We seem to glorify it; we discuss it glibly without very much understanding of the serious problems and limits that lie in this significant field.

We who represent the universities must recognize that we face many serious problems in the wake of the suddenly-expanded opportunities for research. Perhaps we too blandly assume that every professor and every department could do a good job of research if the money were only available. On this assumption are we falling into the fallacy of promising to industry and the government more than we can perform? Are we leading public officials, industrial managers, and the public-at-large to expect results too soon; and, in addition, to expect a dollar of usable results for every dollar invested in research?

If the answer to either of these questions is yes, there will be a resultant disappointment and disillusionment and a reaction which would be very dangerous to universities. Inside universities we must ask ourselves still another question: Does this flood of earmarked research resources, directed toward highly specific ends, mean the diversion of creative genius and imaginative intelligence from teaching, and I mean teaching at the undergraduate level?

I like to remember my freshman professor of chemistry at Ohio State, Dr. William Lloyd Evans, who received the Nichols Medal of the American Chemical Society for top-level research. I think of Dr. Evans as a teacher of freshmen, identified with young people who had the promise of becoming top-grade chemists and research chemists. Are we in danger of diverting this kind of intelligence in the staff from freely chosen, autonomously conceived channels of investigation?

I am pretty pragmatic minded, personally, and I have very little interest in the ancient argument over basic and fundamental *versus* applied research. It is like the debate about vocational and liberal arts education in that it poses an unrealistic problem. I remember hearing President Conant of Harvard say at a meeting which I attended about a year ago that his war experience had led him definitely to the conviction that research and development go best together, and there is no one who has a more fundamental respect for basic research than Dr. Conant. Moreover, I have always admired the common sense of Arthur Morgan's rather brusque remark that when a scientist expresses unconcern for the usefulness of research, he means simply that he does not accept current appraisals of value. If the scientist means more than that, Morgan said, he is in error.

On the other hand, all of us do realize that the reservoirs of fundamental scientific concepts are dangerously low. They were largely used up in the war period. In the past, America has been too dependent upon contributions from abroad. We need to do much sheerly creative and fundamentally conceptual investigation to replenish these reservoirs of depleted knowledge. We can't assign all of our energies to think out projects. We must ask ourselves whether we are making it more attractive and remunerative to engage in sponsored research instead of the old-fashioned individual or departmental research whose productiveness we must not for one moment ever depreciate.

Because of the need for speed and recognizable progress and results, and sometimes because of the necessary secrecy of certain government projects or industrial projects with patentable results, we must ask whether we are tending to set up separate research institutions on the Russian or European pattern with a resultant loss of cross fertilization and intellectual impact upon the whole university enterprise. The problem is a difficult one and brings up serious questions such as separate and competitive conditions of tenure, salary, incentive, and security within the faculty itself. The question is sometimes raised as to whether government contracts lead to government control, the *bete noire* of the academic world these days.

On the more optimistic side, isn't this partnership with government and industry one of the most hopeful and long postponed developments in academic life? See what it has meant in agriculture in this country. Dating back to the simultaneous organization of the U. S. Department of Agriculture and the land-grant colleges of this country in 1862 and, more particularly, to the Hatch Act, which set up the Agricultural Experiment Stations, the growth of agricultural research has gone steadily forward. The experiment stations have done the most notable nationwide research job of any country in the world, and there has been plenty of fundamental research included. This development in agriculture is a hopeful thing. Will these new alliances with government and industry make cooperative research the source of more generous resources for research elsewhere in the University?

Can we use the influx of new and larger and very welcome research funds to create many more opportunities for graduate study, thus promoting that contagion among students which comes from contact with top-level scientists and scholars—from contact with intelligence in action? Can we set the example in cooperative research projects of good progress-reporting which we do not now have in other aspects of university research? Can we utilize the expectation of reportable results for the establishment of a better criteria of competency in the matter of staff appointments and promotions? Can we round up some of these considerations (as well as many more which this symposium will explore) and express them in good, sound, administrative principles and policies and, if need be, in desirable patterns of university re-organization, compatible, of course, with university ideals? These are questions worth considering, it seems to me. And so we hope this conference will be useful as well as enjoyable for you and that, remembering it later, you will regard the University of Minnesota as a cordial and cooperative host.

The University, Industry, and Government as a Research Team

A. F. Spilhaus
Dean, Institute of Technology
University of Minnesota

The objective of this symposium on engineering research is to promote a better and closer relation in cooperative research among Universities, Industries, and Government. For this reason, I have included in the title of my talk to you this morning the idea of the three participants in research as a team. In team play in a game each man is assigned a particular position according to his best abilities and he tries to maintain that position. If he gets out of position temporarily he tries to get back so that when his teammates need him for support he is on the spot. There are special phases of research and development which are particularly suited to each of the three principal research agencies—the universities, industry, and government—and there is very little conflict between these phases so that elements of competition should not arise within the team. As in the team, each of the three *needs* the support of the other two. In the addresses which follow in the next few days, we shall hear outstanding experts present all three views and I would like to see us end up with an evaluation of the proper position of each on this research team so that we all may be guided in our future activities.

Let us try to examine what are the primary over-all objectives of each of the three agencies to see whether research, which is a part of their activities, can be made to fit in with these over-all objectives. I hope that I will be pardoned if I state these objectives in a greatly over-simplified fashion.

1. The objective of the university is to educate men and extend knowledge.

2. The objective of industry is to produce things needed by the people: food, clothing, things needed to insure their security, and things that will enable them to work more efficiently.

3. The function of government is to preserve a balance by an over-all plan so that a healthy situation will exist within the country and so that the country will be in a position to be unassailable from outside.

Starting with the university, what kind of research is proper to its objective? We apply the criterion above: does the research contribute to the education of men and/or extended knowledge?

1. It contributes to the educational function of the university if the project is completely in line with the desire and interest of some member of the university faculty to follow the research.

2. It contributes to the educational function of the university if it enables the university to attract other scholarly men who are needed to round out the faculty of the institution but who might not be able to be attracted

without the support or research. (A highly specialized individual might not be able to be supported by the university full time in his teaching function and therefore the research, if it be sponsored, aids the university to meet the financial obligation to obtain and keep the man; or a very desirable individual of this type might only wish to be associated with an institution where he was allowed a large proportion of his time for following his own line of work.)

3. It contributes to the educational function of the university if it permits graduate theses on a scale which could not normally be allowed to the graduates so that these men, before they obtain their advanced degrees, have had the invaluable training in research which can only be obtained by participation.

4. It contributes to the educational function of the university if it permits the operation of a facility which is considered essential for the education of the students but which could not be justified or maintained for teaching only.

5. It contributes to the educational function of the university if it increases the productivity of a very good man on the faculty of a university by providing him with the means to have assistants do the routine things to which, if he were working by himself without assistance, he would have to devote a lot of his time. This releases his time for the higher level type of work of which he is capable.

To examine as to whether a particular project extends knowledge or not is not as easy but one criterion is this: Will there come from the project sooner or later scholarly products or by-products in the form of creditable publications?

If these criteria are accepted, they lead to interesting conclusions. For example, the desirability of graduate student participation and the ability to publish seems to preclude or at least discourage a university (except under extraordinary and emergency conditions) from taking on work which is classified. Again, the criteria that the research should be rather completely integrated with the thoughts and inclinations of the faculty mean that when a project gets to the stage where a great proportion of the men on the project are not active members of the university staff or if the project is tending toward the operation of some huge installation where the preponderence of the work is devoted to the maintenance of the equipment and where the majority of the people become essentially operators of this equipment rather than research workers, the university may be doing what is more properly the function of industry. It is getting into operations. It may then be time for the university to "pass the ball" to industry.

If I were called upon to do so, I don't know how I would exactly define research atmosphere. I do know that it is an extremely important thing. Perhaps one definition is to say that it is the thing which generally universities have and which industrial and government laboratories don't! I say "generally" because there are exceptions both ways. There are universities which are run like a factory where the research atmosphere has withered and died and there are excellent laboratories in industry and government where the research atmosphere flourishes. Research atmosphere is essentially a matter of freedom for the research worker. If a man is most productive with his shoes off, let him take his shoes off; if answering routine memoranda upsets a scholar who otherwise is productive, he must not be troubled with these. And this very atmosphere of freedom is why basic research flourishes in the universities and it dies when great emphasis is put on "heavy machinery" facilities and when the research establishment develops into a semblance of a noisy production plant with hundreds of machine operators scurrying around (even though these machine operators may be Ph.D's).

How about industry's place in this team? The criterion of industrial research is: Does it contribute to the production of things people need? There is a tremendous step always between the development or the discovery of a basic idea and its application to practice. We may call this stage "development" simply to distinguish it from "basic" discovery. It is not easy to say where research ends and development begins and it is not terribly important to closely define these points. Engineering being an applied science is often quite properly concerned in a university with what the physicist would call "development." It is like sitting in a theater. When the curtain parts a little, what you see depends on where you sit. In engineering research particularly there must be complete cooperation between the university and industry so that they can cooperatively determine the point at which the particular item should be taken out of the university and continued by industry. Industries maintain in many cases their own research laboratories and (with the notable exceptions of the great research laboratories that exist in some industrial corporations) in most cases the industrial laboratories are restricted, and properly so, to a field of interest closely allied to the normal products or activity of the enterprise. (See the "objective.") But research problems invariably require the assistance of a specialist or diverse group of specialists in fields which the laboratory staff in the industry does not cover. In this case, as also in the more basic studies, industry should turn to the university. Or, to use our simile of a team at play, industry should "pass the ball" to the university, just as I have mentioned that the university should "pass the ball" to industry when a project develops to the stage where it becomes largely a matter of operations.

Now where does government come into the research picture? Considering the function we have ascribed to government, namely, preserving the balance, government should watch how the research of the country is proceeding and step in and foster by aid or by setting up laboratories where necessary, those phases of science or technology which are not being attacked by the universities or industry. This would mean certain special things, such as phases of weapon development, might be in the hands of the government laboratories.

The government's position in research is to restrict itself to those fields which cannot be covered, as we indicated above, by industry or the university. Examples of these fields are not only the special weapon laboratories that we have indicated but also laboratories which are maintained to set standards (Bureau of Standards), the geophysical sciences where nation-wide and world-wide networks of observations are required, and the all-important field of protecting the natural resources of the country as a whole as, for example, soil erosion. These can really only effectively be made by national participation. If we look at our government's record in the support of science over a long term, we gain a rather favorable impression of proper method of exercise of control and it makes us feel a little badly about the criticisms that many of us make from time to time of the short period activities which we do not like.

Team work between government and the universities and industry is very well exemplified by the various official and semi-official research steering committees and boards which have been set up and which in most cases provide a fairly even distribution of governmental representatives, academic representatives, and industrial representatives. Examples of these are to be found in the panels and committees of the Research and Development Board, in the committees and sub-committees of the National Research Council, and many others. While it is perfectly true that you cannot do research by committee and while it is also true that sometimes such committee activity assumes proportions so as to give diminishing returns, I think that the general principle of the partnership of government, industry, and the university, the top level planning of research programs of the country as a whole, is one which we can only applaud.

In the attitude that I have outlined for the place of government research, it is clear that if a research field, perhaps one that should properly be supported by industry is not so supported, then to prevent this field being neglected, the government should step in and encourage the universities in this field. It is, therefore, squarely up to industry to maintain a proper balance and to see that all the support of research is not gradually absorbed by the government. It is up to industry to actively participate, as of course they are doing to a large extent, in the direct support of university research by grants, fellowships, establishment of professorial chairs, or by liberal, broadly-written contracts to see that their stake in the universities' research activity is maintained.

To sum up the positions of the interdependence of the university, industry, and government in research, we might say this:

1. Both government and industry are utterly dependent on the universities for the training of the leaders in scientific and professional fields which they must employ.

2. Unquestionably engineers and technologists will play a more and more important part in government as they have played a leading part in industry in the past.

3. The research in a university must be considered not as a separate function of the university but as an integral part of the training function. This is true not only as it directly affects the graduate students who participate in the research but goes right down to the most junior levels of training. The quality of the offering to the students depends on the man who teaches it. The amount of stimulation and enthusiasm which he can com-

municate to these students depends on his store of its being replenished by his being enabled to satisfy his intellectual curiosity by research or other scholarly work.

4. The university, particularly in connection with engineering curricula, is dependent on industry for a continual exchange of ideas between their staffs so that on the one hand the colleges may know the needs of the industry in the various professional courses, and on the other hand industry may benefit by having a knowledge of the latest trends in the colleges in the various fields.

We shall hear the terms "pure" and "sponsored" research in the next few days. Let us examine what this means. In relation to the term "pure research" I might make the remark that I have made several times before—that it is worth while emphasizing that some people seem to think that because research is done normally by the staff members of a university in the course of their activity, somehow it is not paid for at all. Of course this is completely erroneous. It is paid for as part of the ordinary operating cost of the university. It is a recognized part of that staff person's activity and research is not necessarily "pure" because it is paid for by the university and not necessarily "impure" because it is paid for by outside funds. The appropriateness of the research in a university must be gauged by other considerations, some of those which have been outlined above.

If we would try to define what an individual means when he prefers pure research to sponsored research we might say he is thinking of restrictions that go with sponsored work. The important thing is that, regardless of where the money comes from, the university must keep the complete freedom under which creative ideas flourish. It has never seemed to me that it should be any more difficult to do this if the funds came from the government or from industry than if the funds came from the university itself, provided that there is a realization in industry and in government of the importance of this freedom so that restrictive clauses in contracts or agreements are kept to an absolute minimum. It is utterly important that the funds which are used for research in a university have the minimum number of strings attached. Not only the strings attached, but the time element is important. Federal funds for research being on short period contracts cause problems of instability in the staff. Lengthening contracts is a solution. I can envisage a private endowment with such restrictive clauses as to be unacceptable to a university. On the other hand, I see around me every day an institution where academic freedom flourishes as well as anywhere and yet derives its income from the state.

Industry's Concept of Cooperative Research

H. N. Stephens
Director of Research, Minnesota Mining
and Manufacturing Company, St. Paul, Minnesota

After getting a look at cooperative research from what might be called the celestial viewpoint, through the eyes of two high ranking representatives of the university, it may be somewhat of a letdown for you to have to listen to someone who fell from grace a number of years ago by forsaking the academic sanctuary for gross commercialism. However, I am reminded every once in a while, when I can not for the life of me remember where I parked my car, that I have never made a complete recovery from my academic experience and perhaps I can justifiably claim to be able to see equally well the viewpoint of the university and that of industry. If at times I may seem to the out-and-out industrialist to be a bit indulgent toward the universities —that is a result of my earlier contamination. If at other times there seems to be rather heavy emphasis on some of the hard facts of life—that is a result of my later contamination.

The subject assigned to me is one which I have thought about a good deal for some time but largely from one viewpoint. Frankly, I do not know what industry's concept of cooperative research is, and even if I thought I did, it would be presumptuous for me to speak officially for industry. The best I shall attempt to do is to present some personal views regarding the concept of cooperative research which I think industry ought to adopt and by the same token, which the universities ought to adopt. If what follows seems very elementary and obvious, I make no apology for that because sometimes the obvious may be more in danger of being overlooked than the obscure.

There are, of course, several types of cooperative research in which industry might participate, but presumably the emphasis in this symposium is meant to be on relations of the universities with other agencies and not on relations within industry or between industry and government. In any event, what I have to say will apply primarily to industry-university relationships.

In the first place, I should like to ask what we mean when we talk, sometimes rather glibly and euphemistically, about cooperative research. Perhaps the term, in itself, creates the impression of something noble and exalted and the first unconscious reaction is that we ought to have some of that, whatever it is. However, there is also an unconscious, but very human, tendency to apply the term a bit too promiscuously, in the extreme case including even work which is neither cooperative nor research. It is in order, then, to consider not only what we mean by cooperative research but also whether we mean what we ought to mean.

Everyone in this audience has a pretty definite idea of what is involved in research, and although the wording of our respective definitions might vary considerably, they would probably be very close together in spirit. Also, we all know what the word "cooperative" means. However, when we put those words together, we are sometimes a little careless with their accepted meanings. For example, at the risk of belaboring the obvious, it should be emphasized that the relationship involved in cooperative effort of any kind is not that of buyer and seller, of master and servant, or of teacher and pupil—but one of partnership. Therefore, if we really mean what we say when we talk about cooperative research, a status of partnership is a prerequisite.

Partnership is a pretty vague and fuzzy term when applied in the abstract to industry and the universities. Partnership, or cooperation, to mean very much, must be thought of in terms of people and the success of any partnership rests largely on the qualities, ambitions, and incentives of the people involved. To be most successful, the partners should have complementary rather than equivalent skills and abilities. Each should stand on his own feet and make his own individual contributions toward the success of the enterprise; each should take such pride and satisfaction in his own contributions that he would have no desire to copy the other; and above all, each should have the other's confidence and respect. If there is lack of respect or distrust of the other's motives on the part of either partner, sooner or later the partnership goes on the rocks.

Now, I do not want to view the practical problem of cooperation in research between industry and the universities entirely through a golden haze of noble and sentimental ideals, but if that cooperation involves people, we must take into consideration the basic fact that people are funny. If we do not recognize that fact, cooperative research may often be funny. To some industrial people, the funniest people in the world are some of these long-haired university professors. To some university professors, responsible people in industry are equally funny—in this case not "funny-ha-ha" but "funny-peculiar," and in a sinister sense. I cannot afford to expose myself to prosecution for libelous statements, but very pointed examples might be given of active distrust and suspicion on both sides, on the part of extremely competent and well known people in academic and industrial work, respectively.

As an antidote for what has just been said, it would be very easy to dish up some comforting platitudes and tell you that all that is necessary is to get together and promote good fellowship and understanding; then, cooperative research would flourish and we would all live happily ever after. However, our purpose at this symposium ought to be to face realities and not to sooth ourselves with platitudes. One reality we must face is that there is an inherent difference in viewpoint and outlook of life between a substantial proportion of university professors and a more or less corresponding proportion of the responsible people in industry. This is said neither disparagingly nor pessimistically—quite the contrary. In fact, it would be a bad thing both for the educational system and for industry if university professors and industrial researchers were all cast in the same mold. Society needs both the highly creative, fundamental scientist, who is apt to have strong introvert tendencies and the practical, profit-minded industrial research man, who will probably have equally strong leanings toward the extrovert type. It is to be expected that the extremes of these respective types, because of their deep-seated differences in psychological make-up will have difficulty in understanding each other but that is simply a fact to be recognized and not an occasion for despair.

Well, that is about enough of generalities. Suppose we take a look now at the practical problem of cooperation between industry and the universities. To repeat, cooperation is effected not by industry and the universities in general—but by people. Research is carried on, not by organizations, associations, or institutions—but by people. People are funny, and although they are not all funny along the same lines, there is one characteristic which we must accept as universal, and that is selfishness. Therefore, in order to stimulate any individual to his best efforts, he must have incentives which appeal to his selfish interests. Fortunately, all people do not have the same selfish interests and do not require or respond to the same incentives. Some respond most readily to money or possessions but to others fame, authority, or even an inner sense of importance or personal satisfaction may be the most important reward. In any case, incentives toward cooperation must coincide with the selfish interests of the respective individuals if that cooperation is to be most effective.

A common and typical case of industry-university cooperation involves a university professor and a director of research, or some similar representative of industry. Ideally, it would seem that such a pair of individuals would constitute a natural team with a maximum chance of the partners complementing each other and a minimum chance of conflict in interests and incentives. The university professor would be expected to provide the more fundamental approach to the problem, while the industrial representative would supply the practical considerations. The professor could be given the opportunity to broaden his experience and increase his stature as a scientist by directing industry-supported research and getting new material for publications. In addition he would get a little jam for his bread and butter. The industrial partner would stand to gain by developing something of value to his company for which he would get some credit directly or indirectly. Ultimately, because of his responsibility, that "something of value" would, of course, have to be capable of expression in dollars and cents profit for his company.

Now the question arises, "How do a pair of such ideally suited partners get together in a cooperative research program?" It has already been mentioned that one of the prerequisites for a successful partnership is mutual respect and confidence. In cases in which that has developed on a personal basis, perhaps over a period of years, there is no problem of getting together, and the most satisfactory, productive and truly cooperative research programs known to me have developed precisely in this way. By "truly cooperative" it is meant not merely that the partners call each other by their first names and slap each other on the back whenever they meet but that they implement that superficial camaraderie by complete confidence in one another. That implies that the industrial partner respects the interests of the professor and the university; that he welcomes the professor into the industrial laboratory and gives him free access to what is going on there; and that he makes him feel that he has some stake in the progress of the company. It also implies that he will see that the professor receives a financial reward commensurate with his contributions.

On the other side, cooperation of this type implies that the university professor will respect the integrity of his industrial colleague and will show a genuine interest in and sympathy for his problems; that he will be generous with any information which is pertinent to the problems of the company and not suspicious that his confidences will be abused or his ideas stolen. In brief, he ought to identify his interests, at least in part, with the interests of the company which supports his work and provides him with some income. To repeat, cooperative research programs of the type just described, which have developed naturally on a personal basis, have resulted in great benefits both to the company and to the university concerned. Unfortunately, they are all too rare, perhaps for three chief reasons: (1) There is, at best, not a large proportion of university professors who have both the capabilities and the psychological make-up which would qualify them for the most effective cooperative work with industry. (2) Of those who are qualified in all respects, perhaps too few happen to make the right contacts by the haphazard method of personal acquaintanceships or friendships. (3) The short-sighted and sometimes bad-mannered and grasping selfishness of some industrial concerns, which cannot help but be reflected in their research representatives, gives university people some cause for suspicion of motives and may stand in the way of development of cooperative projects.

Now, if we accept these three reasons as limitations, we must admit that truly cooperative research between industry and universities is practicable only on a rather restricted scale. That raises two questions: (1) Whether it is possible to aid and foster that type of cooperation by means of organization and (2) whether it is important to stick to the idealistic concept of cooperative research and insist that the only industry-university research program which is of any value is the type which fits the strict meaning of the word "cooperative."

A great deal has been said and written, particularly since World War II, on the subject of university research institutes, departments of industrial cooperation, or other similar organizations, which now are a part of, or appended to, many educational institutions. Unfortunately, most of the pronouncements have been written from highly partisan viewpoints and it appears that the partisanship is becoming more and more violent as these organizations grow in size and numbers. On one hand they are represented as the answer to the maiden's prayer (industry, and particularly small industry, being the maiden) and on the other hand as the consequence of the witch's curse (the witch being the educational system, the New Deal—or something). It may be worth while, therefore, to examine the opposing viewpoints which have been publicized and see whether, or to what extent, it may be possible to reconcile them. It will also be of interest to see whether the experience of the research institutes offers an answer to either or both of the questions asked a moment ago regarding the possibility of fostering cooperative research by organization and also regarding the importance of giving such prominence to the strict meaning of that term.

I shall make no attempt to analyze throughly the cases for and against but shall simply list a few representative arguments on each side. The critics of university research institutes maintain that:

1. The introduction of commercial research into a university distracts from the main function of training students.
2. It diverts effort from fundamental research.
3. It introduces unfair competition with commercial laboratories by using low cost student labor and by applying overhead rates which are predicated on tax-exempt facilities.

Proponents present such arguments as the following:

1. Contacts with industry are a vitalizing influence on the training of students for their life work, through stimulation of the teaching staff and bringing students into contact with applications of their book-knowledge.
2. The more basic research problems of industry are better adapted to the university atmosphere than to the industrial laboratory.
3. A valuable service is offered to small businesses which cannot afford versatile research organizations.

It is obvious from the nature of the above opposing arguments that it is possible for each side to present a plausible case and that reconciliation is not a simple problem. When the respective viewpoints are as divergent as these, there is room for suspicion that each side is attempting to rationalize the case which supports its own interests; so perhaps one way to approach the situation impartially is to examine the motives and incentives behind the establishment and operation of university research institutes. As a purely personal opinion, I believe that the idea of the university research institute is neither good nor bad. The results of its operations may be either good or bad, depending on the nature of the motives and incentives which determine the operations.

Suppose we consider first the motives which may be behind the establishment of a cooperative research organization at a university. One well-defined case is the one in which individual professors have established contacts with industrial organizations and the aggregate amount of industry-sponsored work has created a number of administrative problems such as accounting, provision of space and facilities, questions of patent rights, etc. In order to meet these problems and establish some fair and uniform practices a separate department or an independent corporation is set up to handle business and administrative details. In this case the establishment of the research organization has been the result of a natural growth of projects entered into independently by individual professors. If the projects are worthy ones and the professors involved keep a reasonable balance between their outside activities and their obligations to the university, it seems to me that the university is to be commended rather than criticized for attempting to provide a single agency to handle administrative and business details.

On the other hand, many if not all of you know of cases in which research institutes or special departments have been set up, not for the purpose of solving an existing problem, but in order to provide an organization which could solicit industry-sponsored research projects. Perhaps in many of these cases the motives may have been, to put it very bluntly, "to keep up with the Joneses" or, still more bluntly, "to get aboard the gravy train." Of course, it is quite possible (and very human) to rationalize situations such as this and discover some noble and altruistic motives for starting from scratch to establish a cooperative research organization. I hope I am not being unduly suspicious of the motives of others, but there seems to be room to question not only the judgment, but also the sincerity of some recent ventures in soliciting industrial sponsorship of research at institutions which have little more to offer than an appetite. To me it is one thing to organize for greater effectiveness an activity which is in existence and which has developed naturally, and quite another thing to organize for something which is merely an appetite.

To return to an earlier statement, cooperation involves people, whether it is in research or any other activity. It is possible to assist cooperative research by organization of the accessory mechanics, but impossible to create it by organization. Therefore, a research institute, organized from scratch, may provide a basis for undertaking sponsored research, contract research, or research for a fee, but the organization in itself provides no basis for cooperative research. That basis can be provided only by the individuals who are available to participate and will only be as good as those people. The people who are good enough to have established their own cooperative projects need no organization except to render a service in the mechanics of operation. The real question, then, is what organization can do for the people who are not good enough or who have not been fortunate enough in their contacts.

In the latter case it would seem that organization might render a service by furnishing a medium of contacts for those who are inherently capable of carrying on cooperative research with industry. However, that raises a rather delicate question—whether the service should be of a promotional nature or merely diplomatic. My personal view is that it should be the latter because, after all, the success of continuing relationships depends on the professor being able to stand on his own feet. If that viewpoint is accepted, it follows that faculty members who are not clearly fitted to stand on their own feet in their relations with industry should not be promoted into such relationships; that no pressure should be exerted, directly or indirectly, toward participation in industry-sponsored programs just for the sake of being "in the swim."

The real danger in organization for the promotion of sponsored research may lie in keeping the organization under control. Once an organization is started, the human tendency is to attempt to increase its importance; to follow the great American plan of making it bigger and better. If the primary purpose of the organization is to get business, the natural thing to do is to staff it with people who have demonstrated their ability to get business. One of the chief qualifications will be a bit more of the sales personality than is commonly found in the best research people, and once the sales personality is turned loose to get business for the university or its affiliated research institute, it will get business—or else! If it cannot get the kind of business that is readily integrated with the educational program and will render a distinctive service to both university and industry, it will still get business if that is its job.

If the objective of the university, or its research institute, is to aid and foster research which is truly cooperative, the organization should be carefully designed for that purpose and should be willing to accept both a limited volume of business and a slow rate of growth. Results should be evaluated in the light of long-term benefits to the university and to industrial progress and not in terms of the immediate applicability of the odd job completed in record time.

Professors who have been able to establish their own cooperative programs with industry should be rendered a service which relieves them of detail but should otherwise be left pretty much alone as long as their obligations to the university are given first consideration. It has been said, "You can organize for research but you cannot organize research." In other words, organization should serve cooperative research and not attempt to run it. Perhaps the ideal organization would have as its objective the protection of the university faculty from those who would like to organize their work. It should impose a minimum of regulations and restrictions and those only for the purpose of protection and the maintenance of fair and equitable practices. It should not make a big hullabaloo about protecting the professors from exploitation by industry and under cover of that smoke screen exploit them for its own glory.

To be very blunt, I believe not only that research of the truly cooperative type should be fostered and encouraged by the universities but that there should be active and unequivocal discouragement of the type of project in which the faculty offer themselves, or are offered, in the labor market to do odd jobs for industry. I believe that the professor demeans himself and his institution when he offers his services to do pre-determined jobs on a piecework basis. I submit that industry contributes to delinquency every time a job is farmed out on this basis. Commercial laboratories are available which make a business of this type of work and there appears to be no legitimate excuse for universities permitting their facilities to be used in setting up cut-rate competition with their own graduates. Conversely, industrial corporations have reason to be somewhat shamefaced when they shop around the universities for bargains of this kind. In fact, the company is to be blamed more than the young professor who at least has the excuse that the prospect of being able to buy a steak once in a while is very tempting. Odd jobs at piecework rates make no contribution to the educational program of a university; neither do they render any service to industry which would not be better obtained from a commercial laboratory. On the other hand, real cooperative research can benefit the university by broadening and dignifying the faculty member who participates, and can benefit industry by exposing its problems to a fresh and more fundamental scientific viewpoint.

The odd-job type of sponsored work not only fails to make any contribution to the educational program but may do active damage to it. An increase in this type of business in the university or research institute may create more jobs for graduate students but at the same time it tends to lower the scientific level of the work which employs them. It puts pressure, directly or indirectly, on the faculty to provide more supervision for the expanded activities and the prospect of making some money on the side becomes an active and pressing temptation to lure them away from fundamental research. Then the final degradation comes if or when faculty members become so absorbed in contract work that they go out of their way to find thesis material in the industrial jobs, so as to permit a student to get an advanced degree while working on a paid job.

Now, I am not prepared to malign the universities and research institutes by stating or even implying that the picture which has just been painted is representative of conditions as they exist today. However, there are some indications of a dangerous trend toward such a situation. Any trend in that direction should be considered inimical to the future welfare of the nation because it is exactly the opposite of the one which should be encouraged, namely, toward increased emphasis on fundamental research. The plea for greater self-sufficiency in fundamental research in this country has been made so eloquently by so many people during the past two or three years that I shall do no more than echo it here. The main thing that needs to be emphasized is that an uncontrolled rush of universities into the establishment and expansion of industry-sponsored research is completely incompatible with their responsibility toward fundamental research. Also, as a purely practical consideration, some of the present over-enthusiastic scrambling to get in on profits from sponsored research may end in rather sad disillusionment when the next business recession arrives.

Now it has already been admitted that a great deal of emphasis has been given to the strict interpretation of the term "cooperative research." Perhaps an additional liberty has been taken with the assigned topic by directing so much attention toward the university and saying little about the role of industry in these cooperative programs. If that is an adverse criticism, my only defense is that I have been talking about things I have been thinking about instead of trying to think up something to talk about. Now that I have got a lot of gripes off my chest perhaps a little consideration ought to be given to the role of industry in cooperative research programs.

At the risk of repetition *ad nauseam*, may I repeat once more that cooperation involves people who have mutual respect and confidence. That should be a prerequisite to the establishment of any industry-sponsored research project at a university. It would be good insurance against disappointments and misunderstandings later on if the professor selected to direct the work had already established himself in the esteem of the research director or other industrial representative with whom he is to deal. By the same token the university professor should not accept too eagerly as a partner an industrial research man who has not already gained his respect and confidence.

If a research project is started off under some professor who is hired on the misconception that he is a magician instead of a scientist, the worst may happen. If some unknown industrial representative wanders into a university and purchases a project on the spot without the professor having too clear an idea of what he is getting into, something equally bad may happen. If the company goes ahead on the basis of being willing to take a little gamble in which they do not stand to lose very much even if the professor does turn out to be a screwball, he probably will turn out to be a screwball—according to their standards. If the professor takes a chance, with the qualification that he is going to keep his eyes open to be sure that this chiseler from industry does not slip a fast one over on him, probably he will find sooner or later that a fast one has been slipped over—according to his standards. If a company starts a sponsored project on the basis that these long-haired goons in the universities are not to be trusted with too much confidential information and if the professor is told just as little as possible about related work in the company's laboratories, it is almost a foregone conclusion that the company will find some justification for its suspicions. If the professor holds his cards pretty close to his chest for fear the company will get a lot more than they are paying for, he is almost certain to be robbed—at least in his estimation.

The university and its faculty certainly have the primary obligation toward the educational program and should resist any activities which interfere with its effectiveness. However, industry should not wash its hands of all responsibility in this connection and in fact, should be just as much interested from the point of view of the product of the educational system as the universities are from the point of view of the process. Industry should, therefore, have a little longer range objective than getting something out of a university next week, or next month, or even next year and should recognize that the protection and improvement of the educational system is just as important to its long range selfish interests as to the interests of the universities themselves.

To be specific, industry ought to accept equal responsibility with the university for controlling the type of project which is offered and for setting the pattern of operation. The project should be chosen not only on the basis of its prospective benefits to the sponsor, but also on the basis of its value in the educational program. That does not mean that representatives of the company involved should take the responsibility for evaluating the suitability of the project to the university; it simply means that the professor who is to be responsible for the work should be accorded sufficient confidence and respect to permit him to contribute to the definition of the project. If he does not merit that confidence and respect, the procedure should be not to hog-tie him with restrictions and supervise him to death but to look for someone else who will command respect. No project should ever be presented as a cut-and-dried proposal on a take-it-or-leave-it basis.

Once the project is defined and accepted, then there is the matter of implementation. Again, confidence and respect are essential. The professor, and perhaps even some of his students, should be welcomed into the sponsor's laboratory just as the sponsor's representatives expect to be welcomed into the university laboratory. If university projects get off the beam unless they are frequently checked up on and supervised, I am afraid that it is largely because the most elementary principles of psychology are ignored. In general, the more one expects of a man, the more one gets out of him. The more one expects of a university project and particularly of the professor in charge of the work, the more he is treated as a partner instead of as hired help; the more he identifies the interests of his sponsor with his own interests, the more he will keep on the beam.

Industry should not be criticized for being selfish and specifically in matters pertaining to money. That is the way it has to be. Any company which is not selfish simply does not last long. That is one of the facts of life which no amount of wishful thinking or sentimentality will change. On the other hand, it should be admitted that many companies and their official representatives lay themselves open to criticism for the short-sightedness and bad manners which sometimes accompany the expression of their selfishness. A little patience, good manners, and recognition of a few elementary principles of psychology might go a long way toward improving relationships with the universities, to the great benefit of both parties.

One final remark might be worth making in connection with the responsibilities of industry, although it may be somewhat off the main track with respect to the topic which has been assigned to me. It has been emphasized that university professors who are not fitted by temperament or interest to enter into cooperative projects should not be coerced or even encouraged to have any part in such programs. However, that does not necessarily mean that industry should have nothing whatever to do with them. Many of them may have valuable contributions to offer to the long-term interests of industry if they are permitted to make those contributions in their own way and without interference.

As indicated before, this country needs to become more self-sufficient in fundamental research and industry has a long-term selfish interest to serve in supporting such work. Unfortunately, we in industry are open to criticism for our short-sightedness in putting more and more pumps to work on the wells of fundamental scientific knowledge and ignoring the fact that the water-table is continually dropping. It is neither equitable nor sound for industry to stand by and leave the job of digging new wells entirely to the universities and government, and sooner or later we must wake up to the fact that if we do not take some responsibility in the matter we may have a short-term instead of a long-term problem on our hands. This is a problem, however, which does not fit into the pattern of cooperative research but which should be solved by fellowships, grants-in-aid, or other similar support, with no strings attached. A few companies are now voluntarily taxing themselves to contribute toward increasing the fund of basic scientific knowledge but industry as a whole is doing far less than its duty. Perhaps some special incentive plan, tied to corporate taxation, would be the fairest and most effective way of inducing corporations to join in the support of fundamental research.

Phases of Cooperative Research Pertaining to Universities

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Man has been on the earth for many centuries, but in the brief span of perhaps 1 per cent of his total existence, as Dean S. C. Lind reminds us, he has multiplied his speed of transport by 50-fold, multiplied his speed of communication by 30 million, multiplied the power available to him 100-fold, multiplied his illumination by 1000-fold, and increased his life span by 2- to 3-fold. All of this accomplishment has been due to man's ability to explore, and utilize, the facts of nature for his own betterment. All of this has been due to scientific research and development.

From the day of the lone inventor of the last century, modern applied research has evolved as a system of group study and organized action under a plan of efficiently organized teamwork. This is the industrial research laboratory of today. Results are obtained by 95 per cent hard, scheduled, directed work; and only 5 per cent by inspiration, genius, and hunch. Organized research activity with its beginning about 1900 has created American industry. It is no coincidence that the creation of our high standard of living and the expansion of American industry have been simultaneous with the development of organized research. American industry today enjoys its enviable position because it has learned the true value of new scientific knowledge applied to its problems and has learned to depend upon the research laboratory as the cradle of new ideas, new products, and new industries.

Continued industrial supremacy depends on intelligent use of our huge natural resources, which, incidentally, must be more carefully conserved, developed, and improved; depends on the maintenance of our position of leadership in mass production techniques; and vitally depends on the extension of our technology. The latter factor is the only one that appears to have no limit of possible development. It is more and more apparent that the creators of wealth and earnings are the research laboratories.

Industry as a whole is spending today somewhere near 2 per cent of its gross sales income on research to improve its products, improve production efficiency, lower costs, or for new products and processes. Many industries, notably the chemical, pharmaceutical, and metallurgical industries, are spending more than 2 per cent of their gross sales. It appears that 1 per cent of gross sales is a minimum figure for research investment to secure the future of an industry or of an individual company, but the exact expenditure should be governed by the life expectancy of profits and the acceptable rate of profits.

Some industries, of course, are lagging in their appreciation for, and use of technology. The textile industry, one that is recognized today as being vulnerable to competitive development, spends about six-tenths of 1 per cent of gross income on research. The food industry, according to recent surveys, spends about nine-tenths of 1 per cent. The railroad industry spends less than one-third of 1 per cent of its gross income on research. One cannot help but compare the rapid growth and booming vigor of the technologically based industries, such as the chemical, petroleum, pharmaceutical, electrical, etc., to the slow growth of the oldest industries of food, textiles, flour milling, and railroads.

Erwin H. Schell, of the Massachusetts Institute of Technology school of business management, lists research as a "current certainty in a time of low visibility." Quoting him directly, "Organized research has become the dominant competitive weapon for the individual establishment. It is safe to say that within the next decade the company which cannot introduce into its processing the new product, the new design, the new formula with as great facility as it introduces raw material into its process will be definitely obsolete from the point of competitive armament."

Dr. Coolidge of the General Electric laboratories pointed out in his testimony before the Temporary Economic Committee of the seventy-sixth Congress that the public paid about $90 million for electric lamps in 1938. If it had to buy the carbon lamps of 1900 to produce the same amount of light the lamp bill *alone* would have been increased about $600 million for that year or $2 million per working day. Furthermore, the public's electric bill would have been increased by about $3 billion or $10 million per working day. Thus, research saved the public about $3½ billion in its bill for illumination—more than the cost of all private automobiles sold in 1938. He also pointed out that electric power rates had been reduced by more than two-thirds through research, since 1900, so the saving through research is actually three times the figure cited. Not only does research pay to the company using it, but it is definitely in the public interest.

Investment in research—even more than investment in plant, equipment, or inventory—is an investment to secure future profits since continued research does not wear out, is not consumed, and is made obsolete only by itself.

A part of the increasing effectiveness of the research laboratory is due to the excellent precision tools available today to the technician. In the observation of very small scale phenomena, the best optical microscopes give magnifications in the order of 1,500 diameters. With the electron microscope, magnifications up to 200,000 diameters are possible. As an illustration, if an electron microscope were designed to observe the entire surface of a dime the dime would appear to be two miles in diameter! A human hair magnified 200,000 times would appear as large as the Washington monument.

Equipment and techniques available today also enable the scientist to observe and record events occurring in extremely short lengths of time and to measure quantities which change with exceeding rapidity. In the study of natural lightning, one of the most elusive and most capricious phenomena in nature, engineers are now able to record the instantaneous variation of current, voltage, and energy in a lightning stroke and to obtain a permanent photographic record of those quantities as they vary with time. The duration of a stroke of lightning is indeed a short length of time. The crest of the current and voltage is reached in one microsecond (a millionth part of a second) or less, and the entire stroke may be over in 40 or 50 microseconds. To give a general visualization as to how short that time interval really is, an airplane traveling at the rate of 500 miles per hour, which is truly a fast plane, would move only one thirty-second of an inch in one microsecond! Yet, engineers can observe quantities varying that rapidly and, better still, obtain a photographic record, with accurate representation of quantity variation with time, for such an awe-inspiring and dangerous manifestation as current in a stroke of natural lightning.

In the recent perfection of an infrared device for accurate measurement of distance it was necessary to measure time intervals of one one-hundredth of a microsecond or less. The 500-mile-per-hour plane would travel one one-tenth the width of a human hair in that length of time! Thus does research serve itself.

Dr. A. M. Zarem, manager of our Los Angeles Division and chairman of our Physics Research, has just received the citation as the "Outstanding Young Electrical Engineer of the United States for 1948" for the development of the Zarem High-Speed Camera. This camera will make an exposure in less than one one-hundredth of a millionth of a second—the time it takes light to travel ten feet! The shutter is closed for about the same time, so that it is possible to take between 50 million and 100 million exposures per second with the camera. It has been extremely useful in recording the character of shock waves around projectiles in flight, shock waves from bomb explosions, and other very high-speed transient phenomena.

We have always wanted to find machines that could do our thinking for us. We are approaching that goal with the new computing machines now available. One such machine can multiply a ten digit number (such as 3,468,754,278) by another ten digit number (such as 9,875,456,869) in three milliseconds. Considering the fact that the time of human reaction is about 200 milliseconds, this machine can perform 60 such multiplications in the time required for us to feel the prick of a pin! These machines are able to compute the path of a projectile to great precision while the projectile is in flight, so that the trajectory can be computed, and the landing point accurately predicted, faster than the projectile itself can travel its course! Answers to difficult problems can now be computed and an accurate solution obtained where, heretofore, the solution could not have been computed even with years of calculation.

These and other interesting new applications of known scientific facts greatly strengthen the power of the research scientist to produce the new ideas and new devices needed by industry, and by humanity.

An approach relatively new to research was introduced during the war when scientists from one field of training and experience were called upon to assist research and development in other scientific fields. For example, physicists were asked to investigate problems in metallurgy. The results of such transplantings were good, and the system has been adopted in many fields of research. An optical lens may sometimes be studied, with advantage, as a transformer. The study of the brain as a mechanical calculating machine with each element as a "yes" or "no" device is yielding very promising results. It is of interest here that the new science of control mechanisms, cybernetics, as developed by Dr. Norbert Wiener, reveals that calculating machines, like the human brain, can—and do—go insane following essentially the same mechanism as the human brain. The approach of both the theoretical and the applied physicist or chemist to medicine may well revolutionize the entire theory and practice of medicine and bring scientific order into a body of knowledge which has been, all too often, empirical and "rule-of-thumb."

What is the place of the college and university in the industrial research picture?

At a time when endowment income is low and costs of operation are high, also when even the word research has an aura of mysticism and romance about it, all too many of our colleges and universities are eagerly accepting—and even seeking—almost any research investigation either industry or government is willing to sponsor and pay for.

There are two unfortunate, and perhaps tragic, aspects of this situation. All too often the research investigation does not contribute to, and in fact detracts from, the primary and basic function of the university; and nearly all universities have been willing to accept sponsored projects on a financial basis which does not pay all the costs. This situation is due in part to an eagerness to have a large volume of research—whether or not it is constructive to the basic function of the university; and in large part to the inadequacy of university accounting systems to show true costs for sponsored research. The research institutes such as Mellon, Battelle, Armour, Stanford, Midwest, which exist solely for service to industry and government in sponsored research, have clearly demonstrated that an overhead of 100 per cent or more on salaries of technical personnel is needed to cover operating costs—even when certain facilities of building and equipment are contributed.

Those universities which accept sponsored research contracts at overhead rates of 25, 40, or even 60 per cent are, without question, subsidizing the research investigation. There is clearly, in my mind, an ethical question involved regarding the use of endowment funds, tuition income, state or federal support, or gifts from corporations and individuals to partially support research for a particular company or for a government agency. The present situation in many universities and for many sponsored research projects is not a healthy, sound, and constructive one.

The basic function of a university is twofold: (1) to train young men and women culturally and professionally, and (2) to extend the frontiers of knowledge of the arts and sciences. These objectives should be kept clearly in mind when determining the research program of the university. It is not always easy to make a clear cut division regarding acceptance of a particular research investigation, but perhaps the following considerations can be used as general guides:

1. The research investigation should contribute to the educational program of the university, should further the training of young men and women, should be suitable for graduate theses research.

2. Results of the investigation should contribute to the storehouse of basic and fundamental knowledge—opening many avenues for further investigation and for application in the development of new processes, new products, and for exploitation by industry—or, in many cases, so basic as to have no immediate practical or commercial application.

3. The research should definitely be of real interest to the staff members concerned and should contribute to their scientific and professional development. There should never be a situation of "assigning" staff members and students to an investigation just to get a job done.

4. There must be complete freedom of publication (except for the very unusual cases of top military secrecy) in order that the findings may be widely useful.

5. The researcher must be free to pursue the investigation as he sees fit, as to time schedule and direction following his interest, abilities, and the scientific facts as they are revealed. In general a specific answer or objective should not be required or expected; to leave the researcher as free as possible.

6. In practically every case the sponsor should not expect patentable developments; and if they do occur, he should not expect exclusive rights under the patents. The right of a university to make available its facilities, staff experience and know-how for the benefit of a particular company for its exclusive use is certainly questionable.

How, then, can industry use the university and how can the university contribute to industry and help with its technical development?

The research in colleges and universities must be recognized as an invisible, but powerful and vitally necessary ingredient in our industrial economy—even though it is so often ignored and not fully understood. All too often industry leaves the support of universities to chance.

Any university staff member worth his salt has something very special to contribute in his advanced knowledge of a particular field. His students share this knowledge and carry it to industry.

Just as one example, consider the influence of Dr. Stephen Timoshenko, a world authority in engineering mechanics. About a year ago he was awarded the James Watt medal by the British Institution of Mechanical Engineers—the second American to be thus honored. To indicate what his presence means on the Stanford University faculty, I quote from the award citation:

"Timoshenko's contribution to engineering science as a brilliant and inspired teacher would sufficiently merit the highest honors. . . . Probably more than any other man has he influenced and guided the teaching of applied mathematics in the U.S.A. From his untiring pen have come a succession of about 20 books on the theory of elasticity, dynamics, stability, vibrations, structures, strength of materials, etc.; noted for the penetrating insight, high quality and creative ability displayed—and always directed to emphasize the practical bearing of the principles they expound—they have become standard engineering textbooks. Timoshenko's books form a bridge between the often abstruse presentation by pure mathematics of classical theory and the solution of practical problems encountered in design.

"But apart from Timoshenko's services to engineering in the fields of academic work and authorship, he has achieved international fame and renown as a research worker and investigator. He is the author of nearly 100 major papers, contributed to learned societies and technical institutions, which cover a field of inquiry of an amazing scope."

Each year more than 100 students come in close contact with Timoshenko in his classes and researches. Through these young men, Timoshenko's presence at Stanford today will influence industry for at least the next forty years. You can think of many other cases of outstanding men in all fields of knowledge of use to industry. The pay-off of fundamental research is through the young people whose training it effects.

It has happened, not infrequently, that graduate students have used directly the knowledge obtained from fundamental research investigations to found new industries. As examples:

1. Hewlitt-Packard Company in Palo Alto, growing from a laboratory oscillator developed by Mr. Hewlitt as graduate thesis, now headed by Russell Varian, inventor of Klystron tube.

2. Magnetic Recording, with major developments by Marvin Camvas who, while at the Illinois Institute of Technology, developed the basic ideas for his M.S. thesis. There are now 70 licenses.

Industry can support university research through:

1. Fellowships to train men.

2. Grants-in-aid to provide background knowledge for the technology of the industry.

3. Support men—professorships—both to secure the trained students and the scientific information produced.

4. Occasionally, support a basic investigation to obtain the answers to specific problems; sometimes using brains and facilities not available elsewhere.

Money thus spent by industry is an investment in the future—to obtain well-trained men, new scientific information, the knowledge of new discoveries, new trends.

The university gains much from such support and assistance, not only financial to help maintain their program of education and research, but also through a better and broader perspective of industrial problems and needs to better train men, through a cross-fertilization of ideas, and through the stimulation of contact with applied research, development, and active industrial operations.

When industrially sponsored research projects are accepted by the university, they should be closely related to the normal program of education and research of the university, and to the objectives of the institution; should be related to the educational, research, and professional programs of the staff; and there should be no restrictions of publication, or restrictions resulting from patent protection.

Industry should look to the universities and should substantially support basic research in both its phases of fundamental research and background research. Applied research, the determination of generally accepted principles with a view to specific applications, usually has no place in the university; and development and engineering design very seldom has a place in the program of a sound university.

Industry must recognize how much the technical "know how" of its engineering and industrial research personnel depends on information drawn from external sources, usually the universities, but it must also recognize that good basic research is seldom patentable, and that only a small fraction of basic research projects will lead to the development and production of products which will be profitable. It has been estimated that only about one in twenty basic research projects leads to products, processes, and developments of commercial interest.

Recognizing the need of industry for confidential research assistance, with full patent protection and restricted publication, on problems involving applied research and development, several universities have cooperated with industry in the establishment of independent research institutes and foundations such as Armour Research Foundation, Stanford Research Institute, Purdue Research Foundation, Ohio State Research Foundation, and others. Research institutes such as Mellon, Battelle, Midwest, Southwest, and Southern Research Institute have little or no connection with an educational institution. The primary purpose of such organizations, and their major objective, is to render a confidential service to industry and government in applied research and development, as contrasted with the university research program devoted to basic and fundamental research. Experience has shown that the research institute of the type with which I am familiar at Armour and Stanford, with its fulltime, permanent staff operating in a semi-industrial atmosphere can effectively supplement the university research program to the mutual advantage of both. The distinct and different sphere of activity for each should, however, be clearly recognized. Moreover, let me state emphatically that no research institute should be organized with the expectation of bringing funds into a university for other purposes. The ultimate to be expected is that the research institute will be self-supporting. The major function of the university research institute is not to aid the educational program and fundamental research program of the university, although it can and should do both, but rather its major function is to provide a service to industry and the community as another facet of the university's service.

In spite of the vast storehouses of scientific information now available, in spite of the extensive combing of this information for practical applications, and in spite of the tremendous strides made in the development of new products and processes, there are many new avenues for research that promise high rewards to industry. The science of ultrasonics, for example, practical applications for the use of sound energy, has hardly been touched. We know that one frequency of sound energy can be used to disperse fat particles in milk, and thus homogenize it, and a commercial device is now being built to accomplish that purpose. Interestingly enough, another frequency of the same kind of sound energy will cause the fat particles to collect together, or agglomerate—exactly the opposite effect. Sound energy can be used to precipitate matter from liquids or gases and offers the possibility for a means of purifying or cleaning gases and liquids. Air and other gases suspended in water or other fluids can be quickly separated. Interesting experiments are now being conducted to use sound energy for the dispersal of fog. There is an interesting possibility for improving the efficiency of carburetion by sound energy rather than the present system used in automobiles and other engines. Experiments have already shown this carburetion system is entirely possible.

Sound has been used as a surgical tool to destroy tissue, and there are possibilities that it may also be used to stimulate growth of certain tissues and organisms.

Sand and other aggregates of granular material can be made to flow like water under the influence of sound energy, and perhaps ultrasonics may have application in the unloading of freight cars and in other problems of materials handling.

The use of ultrasonics has possibilities in the metallurgical industry for the casting of thinner sections, for the preparation of alloys, and for the removal of occluded gases in molten metal; and in the chemical industry for the acceleration of chemical processes.

Opportunities to investigate the practical applications of ultrasonics are indeed many, and should constitute an interesting and rewarding field of research.

Another entire field of science open for investigation is that of extreme high pressure. Dr. Poulter, on our staff, has for several years been investigating pressures as high as one million to one and one-half million pounds per square inch. At such pressures solid and liquid substances, as well as gases, exhibit new and unusual characteristics. Ferrous and nonferrous metals have quite different characteristics when solidified under extreme pressure. The viscosity, refractive-index, and other physical and chemical characteristics of liquids behave in peculiar ways under extreme pressure. A practical application of these characteristics has already been made to quickly identify the origin of an oil, since oil from each field has its own peculiar characteristics under extreme pressure. The method has also been used to reliably identify the origin of oils in a sample which contains oils from several fields. It can be used to detect the presence, in a mixed sample, of a few per cent by volume of a particular oil from a particular field. To make such tests, it was necessary for Dr. Poulter to develop entirely new techniques, including the development of glass windows one-half inch in diameter which could withstand pressures up to 500,000 pounds per square inch. As happened in the investigation of high-temperature phenomena, it is entirely possible and likely that explorations at extreme pressures will lead to new materials of wide commercial application, to new industrial techniques and processes, and to greatly increased knowledge of behavior of gaseous, liquid, and solid materials.

Although much has been accomplished in electric illumination in the conversion of electrical energy to light energy, much yet remains to be done. It is theoretically possible to obtain a conversion of efficiency of 636 lumens of light energy per watt of electrical energy. How well have we done? The carbon lamp gives 2 to 3 lumens per watt; the neon lamp gives 10; the arc lamp gives 40 to 65 lumens per watt but has certain undesirable features for general use; the sodium lamp gives 45 to 50 lumens per watt; and the most recent development, the fluorescent lamp, which uses an entirely revolutionary principle of an indirect carrier for converting electrical energy to light energy, gives only 35 to 75 lumens per watt. Seventy-five lumens per watt out of a theoretical maximum of 636! Our engineers and scientists should feel humble indeed in the face of knowledge that the simple firefly, or lightning bug, has a comparable energy conversion efficiency of 600 lumens per watt! Industrial support of basic work in this field is badly needed, would extend fundamental knowledge, and should lead to practical results.

Much remains to be done in fields of petroleum chemistry and petroleum physics. All too little is known about the basic characteristics and behavior of oil shales and oil sands. Basic investigations promise the possibility of easier, cheaper, and more complete recovery of oil from such sands and shales. Not only is this an important economic problem, but also one vital to the national interest in the conservation of natural resources.

The ceramics industry has been somewhat deficient in technological developments. Bricks are made and placed in position today very much as they were in Biblical times. An intriguing and arresting problem is posed by the situation that it costs $2 to lay in place brick costing $1 delivered to a building site! The industry is vitally dependent on the quality and character of its source for clays. At this time no one knows exactly what makes one clay different from another or what characteristics of the clays effect the quality of the end product. Technical studies will undoubtedly show how to improve or beneficiate clays, and how to process an inferior clay to cause it to have desired characteristics and yield high quality products.

Obscured today, at least partially, in military secrecy, are recent developments in radar, television, and nuclear energy. The fascinating possibilities for additional work in these fields will undoubtedly uncover new products, new tools, and new industries of great commercial and economic value.

Neil M. Clark, of the *Saturday Evening Post*, reports that a Kentucky farmer found that cattle he was fattening on one farm made a daily gain of 1.4 pounds per day, while those being fattened on another farm with the same ration gained 2.1 pounds per day. In other words, cattle on the second farm with the same ration gained weight 50 per cent faster than those on the first. The bewildered farmer could find only one variance in the way his cattle were being tended; those on one farm drank well water, while those on the other farm drank rain water and city water. Turning to the laboratory for assistance, he found that well water contained a larger percentage of minerals, particularly sulfur, and that the cattle drinking it gained faster. To this day, however, no one knows exactly why those particular cattle gained more. We are accustomed to drink water just because it is wet. Although we insist on purity, we have not questioned the possible nutritional or therapeutic benefits to be gained from the gallons of water we drink. Here, again, is an immense and fruitful field for exploration.

Truly, we are only at the frontiers of scientific knowledge and its commercial application. An enlightened, progressive industry cannot help seeing the great opportunities for financial return from an investment in research—the creator, the builder, and the perpetuator of industrial activity. So many scientific and technical stones remain unturned that the problem is largely one of selecting the most promising stones that can be lifted most easily, quickly, and with the least manpower.

The late Dr. H. D. Arnold, formerly director of research of the Bell Telephone Laboratories, has said, "Research is not constructing and manipulating; it is not observing and accumulating data; it is not merely investigating and experimenting; it is not 'getting the facts'; although each of these activities may have an indispensable part in it. Research is the effort of the mind to comprehend relationships which no one had previously known. And in its finest exemplifications it is practical as well as theoretical; trending always toward worth-while relationships; demanding common sense as well as uncommon ability . . . These are the three requirements in research: the spirit of adventure, the wit to question, and the wisdom to accept and use."

The research laboratory has been of great service to the nation in its extensive and rapid economic development. This nation, leading in the development of applied science, and now a leader in fundamental science, has also led all others in economic development. Research has an important role to play in the preservation of our way of life. We have already seen that research does not and cannot exist in a totalitarian state. It is also my belief that a totalitarian or communistic state cannot exist where scientists and engineers are free to pursue the avenues of scientific discovery and development. Sooner or later the restricted, biased, and directed views of such states are opposed by a free scientific knowledge. We see increasing evidence of conflict between science and the state of Russia.

To the entire world, the research laboratory renders an important service. It is inevitable that free research and invention leads to increasing interdependence of peoples and hence to an economy of peaceful states and free exchange of ideas and goods, even though there are transitory periods of difficult adjustment as in World War I and World War II. The application of scientific knowledge leads to greater comforts, more leisure time, better health, longer life, more pleasures, and, we hope, to greater happiness for us all.

These are not theoretical, philosophical, idealistic, or academic viewpoints: the history of industrial development and growth in this country; the attendant increase in the importance of our economy in the World reference, both financial and political; and the rapid increase in our standard of living during the last 50 to 75 years is sufficient evidence and proof of the importance of, and our vital dependence on, scientific research and technological development.

The creation of new industry; the maintenance of our present industrial position—company wise, industry wide, and nationally; the preservation of our economic level of living; these rest squarely on research in all of its phases. It is vitally important that industry and government recognize the proper role of the university, and instead of diverting it from that role, assist the university in every possible way.

In Psalm 144: 13 and 14, we find an excellent statement of the objectives of research:

"That our garners may be full, affording all manner of store; that our sheep may bring forth thousands and tens of thousands in our streets; that our oxen may be strong to labour; that there be no breaking in, nor going out; that there be no complaining in our streets."

Phases of Cooperative Research Pertaining to Industries

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It may seem that an inquiry into the status of scientific research or a stock taking of the employment of research in industry might properly start at the beginning. Apparently, the history of science in its early growth, particularly, has been understandably neglected by scientists engrossed as they are with the effective application of the modern tools and mental devices of modern research. Indeed the early history of science is essentially the history of man's own mental development. Although Ruskin assures us that for a thousand men who can think there will be found only one who can see, nevertheless, the art of reasonably faithful observation was, I believe, an earlier and easier step toward the creation of science than the step of avoiding the pitfall of the scientific *non sequitur* in drawing conclusions from observation. We can all agree that the origins of science lie with those first men who were able to recognize (and record) and finally to control the conditions underlying the phenomena being observed. Only then, were those few men able to discard the assumption of a capricious and quasi-anthropomorphic causation and accept the concept of a constant universality of cause and effect. This dependable mode of observation is, of course, the reproducible experiment and its refinement, the critical experiment. But it requires apparatus of measurable and permanent characteristics. Could it not be that the Greek mind, lacking nothing in logic, evolved before there was the remotest possibility of constructing experimental equipment, and in frustration turned to abstractions and pure dialectics. Small wonder if they rationalized and said the grapes of experimental studies were sour.

In the Renaissance, in 1550, we find Ceredi, an early and almost forgotten teacher of the great Galileo saying, "Inventors without scientific training can find out useful things only by chance, while scientists draw conclusions consciously from generalized principles." At any rate, an increasing number of men found in this mental discipline the fulfillment of their curiosity and an urge was upon them. This inquiring and creative drive, apparently employed to spare men discomfort and drudgery, brings us today the heritage of a technological advance in industrial environment. However all this may be, we are discussing a human activity which has molded the very pattern of our daily comings and goings. For ours is a society wherein industry, given technological guidance by industrial research, is a dominant social influence. The unparalleled standard of living in America supports the premise that American industry has succeeded in its objective of producing more needed goods and services for less of the time and effort. It may be said that industrial research is the technical reconnaissance branch of an agency which in itself fills great material need of man.

Research in industry as presently organized was in its infancy in America at the turn of the century. In America, things seem naturally to grow to bigness, be it government, labor, education, agriculture, or industry. Industrial research itself is today an activity in which well over 125,000 persons are gainfully employed and for which industry is probably spending nearly 500 million dollars annually. This is, in any units, a human force of such magnitude that its potentialities warrant careful guidance that it serve the people of the nation well. This guidance, in our competitive society, may ultimately be supplied in an unequivocal manner by the final authority, the consuming buyer.

Forty years ago we should have discussed industrial research in a mood of conjecture; depending upon our several temperaments, we might have been mildly skeptical or hopefully speculative, but almost certainly we should have been prophetically vague. At a conference held at *that* time we should probably have heard some stirring reports from a few young research organizations in America's more courageous industries. Returning visitors from Germany would have reported the amazing employment of thousands of exceedingly well-trained scientists in making discoveries of great usefulness in the chemical and metallurgical industries and in the manufacture of fine equipment and instruments. Mention would have been made of the hundreds of German graduate students and teachers sternly enthusiastic about their several researches. Before another decade, we were to become very well aware, indeed, of the industrial might of Germany based upon the utilization of scientific research by the German industries.

It was during World War I that the general public first began to read of research and to talk about it, and in a quite well-informed way. It scarcely need be recalled how almost everyone in America with background and aptitude for research was pressed into scientific service by the time of the Armistice in 1918; how we found potash for use where it was really needed—made sulfuric acid without lead sheets, contrived creditable submarine detection devices, made optical glass, synthesized photographic and other complex chemicals hitherto purchased abroad. American industry had full proof that American scientists could achieve in a hurry when called upon—perhaps our scientists were themselves somewhat surprised at their own competence. The important point is that by 1920, industrial research was established in 300 laboratories employing about 9,000 people. In retrospect, it seems that there was almost as much awe of research at that time as there was understanding of it, but it functioned well and grew continually until the depression years, the early thirties, when, even then, the retrenchments were less than might have seemed justifiable. So established as a necessary arm of industrial planning had it become that research organizations were reduced with greatest reluctance. In two decades, 1920 to 1940, the number of industrial research establishments and the total employees increased over seven fold. Since then the activity has almost doubled; and what achievements these latest years brought forth!

There is not time to give even a proper word of admiring appraisal in appreciation of the crowning research achievements of the recent great research teams of World War II who created radar, the proximity fuse and finally exemplified Dr. Einstein's compact little equation $E=MC^2$, but this time with an accompanying release of a reported 39 billion Btu per pound of fissionable fuel. And for a demonstration of scientific ingenuities assembled in one device the Image Orthicon of television deserves a prominent place.

While the sciences have expanded tremendously since 1940 and the processes of research and invention have grown complicated, the *objectives* of industrial research can, nevertheless, be simply stated. In brief they are, for a large enterprise, about as follows:

1. To improve products and develop new ones for old and new markets.

2. To improve processes and equipment in respect to cost, safety, and comfort of operators, hygiene, and work environment.

3. To select and adapt raw materials for conservation, and to offset depletion and deterioration of raw material supply.

4. To assist in instrumentation, standardization, and quality control.

5. To aid customers in best utilizing the product.

6. To provide training in technological matters.

With great nicety Raymond Stevens, of A. D. Little, Inc., has put all this into a comprehensive definition: "Industrial research consists of organized and systematic search for new scientific facts and principles which may be applicable to the creation of new wealth and pre-supposes the employment of men educated in the various scientific disciplines."

Acceptable definitions have been set up for varieties of research ranging from basic, through fundamental, background and applied, to development. Industrial research is emphatically "applied," but it employs them all; and perhaps it is not of controlling importance to discriminate closely among those overlapping categories. Nor is it necessarily a characteristic of the research itself, that someone in industry may be anxiously awaiting the results to employ in improved goods for sale.

A composite schematic sequence for a typical industrial research and development project in some industries might be summarized as follows:

1. A need for an improved product or process is perceived.

2. A domain of investigation appropriate to the problem is selected by Research Management and outlined as a quest for new knowledge instead of a commercial desire.

3. A group under responsible leadership is assigned to the project. (It may be broken down into more attackable parts.)

4. The existing knowledge is reviewed, the literature is critically read, and, after individual preparation for conference, the project is discussed and a first attack decided upon—but only the first.

5. Exploratory work is done in the laboratory to gain first-hand acquaintance if no tentative hypothesis is yet forthcoming.

6. When the tentative hypothesis is formulated it is tested by critical experimentation.

7. Previous step is repeated and repeated as required.

8. The new knowledge is applied on minimum scale of embodiment.

9. Pilot plant scale is operated until successful operating probabilities are secured.

10. Research transmits a report with the full functional specifications and recommendations to the manufacturing or other department concerned.

It is hardly necessary to point out that such an orderly sequence is rarely wholly followed. The exploratory period may be short or it may be very long. One person cannot constrain another to discover. In fundamental research work, the team principle, with groups of constant personnel-makeup during the investigation, is generally very effective. Both the evolution of leadership and the technique of joined efforts are fostered by this method. Scientists like most other people dislike belonging to a losing team and they play to win.

One might infer that the year 1900 marked the beginning of the application of science and the scientific methods to industry. This is, of course, not true. There were precursors of the research era: individuals who made notable contributions to science—but essentially as individuals. Samuel Luther Dana, for example, in the first half of the nineteenth century had a real laboratory in which he studied the bleaching and dyeing of textiles with great practical profit. In this preresearch era the names of several stand out as pioneers in applying scientific techniques to industry: Dr. Fricke, a German scientist, hired by Carnegie for his blast furnaces; Professor Silliman at Yale, who distilled and fractionated petroleum; Charles B. Dudley, who gave up the teaching of science in a military school to join the staff of the Pennsylvania Railroad; Durfee, who examined chemically the materials entering the early converters of the Kelly or Bessemer type. Some of these men of inventive genius, just prior to the establishment of early modern research in industry, virtually created new industries out of their investigations; Eli Whitney, Robert Fulton, Elias Howe, Samuel F. B. Morse, Cyrus McCormick, John W. Hyatt, and Charles Goodyear are typical. The productive period of some of these American geniuses, who, almost single-handed, founded industries, extended well into the new research era: E. G. Acheson, the discoverer of silicon carbide and a process of graphitizing carbon; Charles M. Hall, who electroplated aluminum from a fused electrolyte at elevated temperature; Leo H. Baekeland, who improved the process of making a phenolformaldehyde resin; all names to typify the connection of the older era of the individual with the new organized system of industrial research.

The great industrial era could not have flourished until there were turned out a sufficient number of scientifically trained men to supply the new technologies required in the great period of competitive industrial expansion. Between 1845 and 1870, Sheffield Scientific School at Yale, Columbia School of Mines, Worcester Polytechnic Institute, and Massachusetts Institute of Technology were established, the latter, in part, "to meet the more limited aims of such as desire a scientific preparation for special industrial pursuits . . . having their foundations in the exact sciences." The great boom to scientific (and other) education was the Morrill, or Land Grant, Act of 1862. The purpose of these institutions was clearly stated by Andrew D. White in 1874: "It was to provide fully for an industrial, scientific, and general education suited to our land and time—an education in which scientific and industrial studies should be knit into its very core . . ."

Although the scientific schools of Europe were flourishing earlier, America has taken the leadership now and the objectives of the founders seem to have been abundantly realized. Many schools were established and endowed by private contributions and this source of support is rapidly drying up. Means for the training of men for research who have aptitude and the necessary determination must be provided if we are to maintain our technological position, in keeping with the requirements of today. An idea of those requirements has been set up by the President's Scientific Research Board; in the report by the chairman, John R. Steelman, it is estimated that the nation's research bill for 1947 was $1,160,000,000, over half of which was paid by the federal government and some 40 per cent by industry. This board recommends doubling this expenditure by 1957, or, in any event, the expenditure of not less than 1 per cent of the national income each year for all research.

All seem to be agreed that certain domains of the public welfare must look to government, national or state, for active support of, and participation in, the needed research. The national defense, pre-eminently—and also the improvement of agriculture, the public health, the establishment of standards of measurements and the applicable methods therefor—are in their nature peculiarly constituted for governmental research. Valuable background research, as an accompaniment, has been well accomplished also in government institutions. Any vast emergency investigations, should they become imperative, which are beyond the financial scope of industries or even groups of industries, would of necessity be sponsored by government with taxpayers' money. Because of the peculiar and unique nature of the materials and the need for secrecy it is understandably desirable that considerable part of the research for defense be carried out in government-owned and government-operated facilities.

As for the responsibilities which fall to industry, it is agreed that industrial research is at an unprecedented level; it is desirable that it be not reduced in effectiveness. The Steelman Report states: "Together with advances in basic research, it provides one drive for an expanding economy and for a rising living standard for our people." It further suggests in connection with the expansion in industrial research facilities, "We should provide a favorable climate for such expansion through tax incentives and other established methods, without making direct grants to industry." The competitive atmosphere of industry is tremendously stimulating to certain types of applied research and development and its almost automatic yardstick or practical accomplishment makes it a vital and dependable aid to industrial progress. This is not to say that groups of competitive units of one industrial type may not, with advantage to everyone, cooperate in assigning some of the background research to well adapted agencies for handling. They may still all compete aggressively on a market race-course which, through such joint effort, has been improved to better the performance of all competitors.

It is not difficult, indeed it is usually singularly easy, to bring about full cooperation among research people and thus of different segments of research; to the benefit of scientific progress. Any who have heard General L. H. Campbell, Jr., describe his Ordnance-Industry Team for Firepower will recall that the Armed Forces regarded that cooperation somewhat highly, and presumably it included the research efforts of both. There is no possible reason to imagine that anything but close cooperation could continue between industrial research and that of the National Military Establishment. Indeed, throughout the whole of the prospective nationwide research effort we are compelled to think of cooperation in its best sense, in view of the magnitude of the task. Cooperation is best when it fosters mutual aid and prevents interference.

This leads us not to the central subject which has been implicit in much that we have covered. The universities have a critically important part in the nation's research program. From their training must come the young scientists—prepared *to become* competent research workers. To do the research job ahead, these university-trained men must continue to have great ability as well as to be sufficiently numerous. At the moment, in part because of the Veterans' Readjustment Act, they are probably being graduated in nearly as large numbers as are presently required in the physical, and perhaps also the biological, sciences. For the universities to accomplish this task, certain favorable conditions should exist. It is, I believe, a reflection of the university opinion that the teaching staff should not be depleted to fill other needs. Furthermore, there is, I believe, agreement that the teachers of science should have frequent and close contact with the lively kinds of research, such as is fostered in industry and in many research activities in the governmental domain. Only in some such way can the research point of view permeate the teaching of undergraduates and dominate sufficiently the postgraduate work. While most research and university people feel that education is the *raison d'etre*—the business of the university and the teaching staff—nevertheless, training for research is best accomplished in an environment where research is "in the very air." There appears to be a satisfactory solution now well established; for happily there has been a mutual advantage in the bringing by industries and government of a portion of their research work to the university, whose teachers, on this account, may thereby better indoctrinate their advanced students in its prosecution. They may do the best teaching of advanced students in science who do not do full-time teaching.

One source of such cooperative industrial research is the smaller industry with a narrower scope of science fields for which even a small laboratory of its own would be burdensomely large. Another source may be the marginal problems of a large industry which fall in a domain foreign to its principal technologies, but, none the less, highly important. Actually, many of the large industries with great experimental establishments are referring a substantial part of their work to university and other outside research institutions. Such "farming out" of research may possibly amount to as much as 10 per cent though no actual figures are available. In a general way the impression is created among the leaders of industrial research that the investigations made in the universities may be of top rank quality with a freshness of viewpoint not always secured within the industrial laboratories. Perhaps the industries ultimately gain almost as much through the indirect improvement in the training of their future employees as from the actual reports rendered by the university consultants. Grants-in-aid and contracts for work *in definite directions* are both desirable.

Leaders of industrial research are not usually active teachers—they are not often experienced in pedagogy. Apparently they are, however, coming to believe that they now have some elementary notions, at least, of the qualifications the college graduates should have for research careers. We may venture to guess a few. It seems that (1) they should be able to think habitually in a mathematical pattern (mathematics should be an everyday tool, a practical aid to setting up hypotheses, not merely a matter of manipulations), (2) they should imagine *quantitatively* rather than descriptively, (3) if chemists, they should be grounded well also in physics, (4) if physicists, they should have some facility in the disciplines of physical chemistry, (5) they need not have a wealth of detailed knowledge of any domain, but should be able quickly to acquire it. Perhaps, above all, one might say, they should greatly desire to do research competently, and if so they will fulfill those requirements to meet their own high standards of performance.

And what, one may ask, are these research people to do; some suggestions are at hand. Now, while we learn to use substitutes, we may have to conserve some metals, the ores of which are not being found in quantities to maintain the reserves. Gradually we shall have to learn to use even iron ores of inferior quality to produce steel of sustained quality; the sulfur content of metallurgical coke grows higher. It is time to intensify the rerearch on liquefaction of coal against the day when the petroleum supply, which so amazingly resists our enormous consumption, begins to fail. Perhaps powdered coal is more usable directly than we now know. Soil for efficient agriculture must be enriched and maintained to feed a growing population. These are largely matters for industrial research.

Men still feel they spend too much effort in building adequate housing for themselves. What a boon would be a really low-cost, low-maintenance house! We could do with some more basic materials of construction, tough and strong inside with esthetically treated surfaces to resist moisture, sunshine, and heat. Transportation is amenable to improvement; and we are, in these items, still a long way from the field of "gadgetry," itself so dear to Americans.

A wealth of new devices suggests the kind of unexpected aids to our researchers which may evolve to help solve the more difficult problems. A little piece of germanium and a bit of wire may replace a vacuum tube. A Krypton light flashes 3.3 billion candle power of light for a few microseconds when triggered by an external voltage. We treat synthetic rubber at low temperature instead of the usual elevated temperature and avoid adverse reactions. Servo-mechanisms do half the control work in myriad operations, while we do counting, or even fantastically long mathematical manipulations, electronically. Wetting agents emulsify almost anything, including cutting oils; they help put out fires, beneficiate ores, degrease metal stampings, and aid in dust removal from air. Silicones make lubricants at once applicable to both high and low temperatures. Many of you are adding to the list. It would not appear that industrial research is in imminent danger of abandonment.

There is no basis for regarding the nation-wide employment of research as an obvious or settled matter. Our hopes and assurances were high for a good world in the first decade of the century. By the attainment of objectivity, the subjugation of emotion and anxiety for self in the pursuit of science, we had begun an era of rapid understanding and control of more and more of the whole physical environment. We traveled a high road of aspiration. But the world could not escape two global clashes of hostile camps in three decades. Did these tragedies of aggression occur because man is inherently incapable of dealing objectively with any questions touching upon his own individual or collective self? If not, can our social science soon break through to some new objective level in the comprehension of human relations—as epochal as was the era of steam or the nuclear denouement in the physical realm? In time, perhaps. Then we must be patient and to dare be patient we must be competent and technologically strong. Small as even the great day by day advances in science and technology may seem by comparison with man's central problem of peace, they are, nevertheless, the known approaches to strength, the things to be done now. The frontiers of technology can still be pushed to widening horizons. These things we know how to do, with the devices of organization and distributed responsibility; each group to do its task well, so not to fail the others.

We must somehow make real the brave words that you see graven on the beautiful auditorium right here on this campus. The words—"man is ennobled through understanding." It is startling and in some respects discouraging to recall those penetrating observations of Roger Bacon, made over 600 years ago at the close of the thirteenth century, on the four stumbling blocks to truth. They are:

I. The influence of fragile and unworthy authority.

II. Custom.

III. The imperfections of undisciplined senses.

IV. Concealment of ignorance by ostentation of seeming wisdom.

In our quest for wisdom to be distilled from our vast knowledge where could we turn, if we would, but to the university for the development of men of a stature to meet the incalculable problem of the preservation of man's dignity?

Phases of Cooperative Research and Governmental Agencies

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In selecting as the topic of this symposium, "Cooperative Research," the Institute of Technology of the University of Minnesota has chosen a most timely and important subject. There is, I think, no question in anyone's mind these days about the importance of research, nor that more research needs to be done, nor that country is badly in need of more trained research men whether for government, industry, or for colleges, universities, and technical schools. Neither is there any question about the importance of cooperation in research, at any rate among those who know the field. If there are any who are dubious about it, they are certainly not to be found among research workers themselves. Research is and should be a truly democratic activity. Its planning and support should never become a monopoly; a dictatorship for research is unthinkable. Its strength rests in large measure upon the degree to which scientists and engineers have opportunity to exchange and discuss views, in scientific and engineering publications, in conference, and in personal contacts. As in all democratic processes, an element of competition is very desirable, as are teamwork and cooperative enterprise. As long as the professional reputation of a scientist or engineer depends upon the soundness and originality of his work, artificial and forced methods for coordination in true research are unnecessary; it is only essential that research men and women in the same field are aware of each other's work.

The problem of cooperation in research is therefore essentially one of providing ways and means for increased opportunity and to do so in such a way that integrity of research is maintained and that a proper balance is held, say, between basic and applied research and among the different fields of knowledge.

I have said that the subject is timely and important. This is partly because there is general realization, not only in this country but in others as well, of the importance of science and engineering in national strength and welfare. For another thing, fields are opening up, in nuclear energy and supersonic research and engineering for example, where elaborate and costly equipment and facilities are required, which are beyond the means of single institutions. It is therefore highly appropriate that universities, industry, and government give the matter serious consideration and formulate cooperative plans.

My own subject, "Cooperative Research and Government Agencies," is indeed a broad one and, as far as my qualifications go, represents a considerable extrapolation. My limited experience in the government has been entirely with research and development for the military and, in any case, my remarks, except as they apply to the activities of my office, the Office of Naval Research, can only represent personal observations and views.

The current emphasis upon research is, of course, due primarily to the realization of its power in technological progress. Now in the ordinary course of events, technological advances occur by suggestive stages in the sequence: basic research, with or without background research, applied research, and development. This process is a time-consuming one and generally requires a minimum period of from five to ten years under present conditions. One of the technological problems of the future is how best to streamline this evolution. For the present I wish to stress two fundamental aspects of this sequence: (1) That each step in the process is invariably present and, in fact, indispensable, and (2) that each step in general requires a different kind of talent and hence a different class of experts for successful progress. The latter is one of the cogent reasons for cooperation between universities, industrial, and government agencies. The steps involved may, as often happened in the past, have taken place over very many years, by different generations and in different countries. In particular the basic research step may come from our library of scientific knowledge, without the need for special investigation. Many indeed are the items of research which remain only in our library of knowledge, and for which no practical use is foreseen—some to await the day when they are brought forth to fill urgent practical needs. But right now accessions to this scientific library are critically needed, in view of the thorough going-over it got during the war and the lack of contributions received during that period.

On the basis of national need alone, the *Report to the President* by Mr. John R. Steelman, chairman of the President's Scientific Research Board, dated September, 1947, recommends a national contribution to scientific research and development that should increase to twice the present rate in ten years. In fact, it suggests that national spending for this purpose constitute 1 per cent of the national income, or an estimated amount of over 2 billion in 1957. (It was about 1.1 billion in 1947.) Of this, roughly one-fourth should be devoted to basic research—thus between 400 and 500 million as compared with the 110 million spent in 1947. The Steelman Report considers that about half of this should come from existing governmental departments and agencies outside government leaving a balance of the other half, 250 million, to be furnished directly by some appropriate agency created for the purpose.

At first sight, the problem of increased government support of research seems to have a ready answer. Most of the government departments have research programs which receive continuing support. Since the importance of research is well known it should be a simple matter to increase this support. Unfortunately this is not so easy. The government departments in general have had to accept their share of budget reduction as part of the return to peacetime economy. Research represents a small per cent of their total interests, which may be lost in the effort to retain a highly important developmental program already under way, the value of which can be clearly seen and presented, while the less spectacular and more speculative research work may get lost in the argument. As for broad government assistance to research outside the government structure, presumably this could be increased by appropriate legislation, as for instance by the establishment of a National Science Foundation, with a charter broad enough to take care of the direct support of research and advanced study. But after three years of sincere and patient effort by scientists and by Congress, we still have no National Science Foundation. This is ample evidence that the problem is far from simple and that a ready solution is not at hand. One may only trust it is not evidence that the seriousness of the situation is ignored. The needs and the scientific deficit remain and mount with every year of delay.

But what of the problem of scientific man power? If we grant the desirability or even the urgency of a national program in support of research of the magnitude recommended, have we actually an adequate number of scientists and engineers for the job we need to do? It is commonly said that we have not, and that no considerable expansion in support of research can be started at once without serious dislocation of existing programs. The demand for qualified scientists by industry and by government is very great, while universities and colleges are understaffed to handle their high enrollments. But this statement is only partly true and, like all part-truths, can prove a serious obstacle to proper action. It is true that the need for competent scientists in industry and in government is great and that the available supply is low, and the same can be said with even more force with respect to the teaching of science at the more elementary levels. But—and this is the essential point—there is still abundant room for support of research in colleges and universities, and this may take place with little if any detriment to existing programs for combined research and development. Furthermore, by application of increased support along this avenue we should at the same time take the most direct step toward alleviation of the shortage of highly trained scientific man power. This research is almost entirely basic in character and is, consequently, universal in availability to all. The results of assistance in this direction could not of course be counted on in general to produce immediate practical benefits. The work would not yield a new type of television set nor a more effective guided missile. But the by-products, if not the direct fruits of research, would in many cases certainly lead to important applications. This would be especially true of medical and biological research. From straight content alone, the outcome would merely add to our store of scientific knowledge. But ideas beget ideas and we should thereby greatly enhance the likelihood of turning up untold treasures, still in the rough.

I have stated categorically that support to university and college research is far from saturation and can be absorbed without serious detriment to other important interests. This statement requires justification. That justification is provided by the experience of the Office of Naval Research, where we have undertaken during the three years of our existence to establish a broad, comprehensive program of research in all the major fields of the physical and the life sciences, as well as in the more strictly naval research. This research program was developed by inquiring among leading scientists what, in their opinion, were the important fundamental research problems to be solved, each in his own field. This policy led to the encouragement of proposals for research projects, which are duly considered by our scientific staff with the aid of special advisory committees of experts from outside. These are evaluated from a number of standpoints, among which are the scientific worth of the project, its relation to the total program, the competence and experience of the proposing group, the backing of its institution, the possible bearing of the research on naval interests, and last but not least, the state of the budget.

I do not mean to bore you with the details of the operational procedure of the Office of Naval Research, but I wish to bring out the fact that in the ordinary course of our operations we have abundant opportunity to acquire evidence on this particular point—the extent to which the nation's basic research institutions can absorb additional scientific work. Upon the basis of actual research proposals received, the evidence is that our office alone could profitably support twice its present volume of research in such institutions. Lest you have any misunderstanding on this point, may I remark at once that this should by no means be interpreted that we seek any such growth. Our level of support of research has been stabilized in accordance with what seems appropriate to Navy needs and in conformity with our staff limitations. This estimate should be regarded simply as an indication of current opportunity for national spending by any agency which has an interest in basic research. Since this increased aid would at the same time provide corresponding increase in turning out trained scientists, such as new Ph.D's, it is very much in the national interest to take advantage of this opportunity. It is important to add that the estimate I have given is based upon research proposals received, which have been evaluated and which our usual analysis indicates are worthy of support. Actually we have made general studies on the country's potentialities for basic research in two individual fields—biological and medical research and chemistry. These fully substantiate the foregoing and indicate that the nation's current potentialities for research are indeed considerably greater, perhaps three or four times the present extent of support, especially when extension to nonmilitary interests and to education is contemplated.

One may properly ask at this point how it is possible that this situation may exist—an unfilled demand for research scientists and yet an unfilled capacity for accomplishment of research. The answer is evidently that there are many competent scientists who prefer the academic environment and who cannot be induced to leave it. Many have spent most of their lives there and I do not feel it derogatory to either party to say that many would not be happy or effective in an industrial or a government laboratory. But many are good research scientists and can, with help of a graduate student or two and funds for equipment and materials, turn out good research without interfering seriously with their present share of educational work.

Thus we see that there is opportunity to give financial aid to research which is predominantly basic without overloading and without upsetting the balance between research, educational, and development needs.

It is important to keep in mind in discussions like these the difference in aims of the three interested fields of activity represented in this symposium. In the support of research, government and industry have in common the idea of satisfying a consumer. In the case of industry, profit considerations are of course essential. In the case of government, consumer interest is not always as definite as in industry. Thus, while the armed services must be satisfied with the results of research and development on weapons, it is the general public which must be satisfied with progress on cancer treatment or with support of education. For another thing, generally speaking, government undertakes support only when a consumer need has already been demonstrated; it is not often that Uncle Sam pioneers except to satisfy some national need, though the consumer need may be very broad. In any event, as is proper, the taxpayer is entitled to a review of government accomplishments and an accounting of the way in which his money has been spent. More importantly for the purpose of this discussion he wants, if possible, to have the commitment of his money justified in advance. Since funds procurable from the federal government may be of large magnitude it is considered essential that the purposes for which they are to be used be subject to careful scrutiny.

In spite of what I have just said, an asset which government has in its support of research and development is its ability to back a costly venture at a stage when economic considerations would not warrant industrial investment, at least in the immediate future. A typical example immediately comes to mind in the case of nuclear power and, of course, most weapons of warfare. In such cases the cost and economic exploitation are not the first considerations, but rather the national welfare, health, or security.

It seems more fitting for others on this program to speak of the advantages and disadvantages to industry and to academic institutions of government support of research as a cooperative measure. The advantages to government are many—it keeps government in touch with the broad fields of science and engineering, it interests research men in national problems, it provides healthy competition for the government's own research establishments, and it fosters contact and exchange of information among research workers in these three broad fields. Above all, it can bring directly to government agencies the best that the country has in the way of basic ideas and expert scientific and technical knowledge.

In the past the scientist or engineer in government has been handicapped in a number of ways, all of which tend to insulate him from his fellows in industrial and academic life. Among them are name; lack of encouragement, interest, or even permission to attend scientific meetings; erratic and often inadequate budgets for research; a slow rate of promotion with a premium upon administrative rather than researchability; inadequate top salaries, etc. On the other hand, however, his tenure has been reasonably secure (sometimes perhaps too secure) and reasonable provision is made for retirement. All in all, the net effect has been to tend to insulate him from his fellow research group. Furthermore, the necessity felt by his agency to justify its program, and thus its budget, has been an important factor in aggravating this tendency toward insulation, in that the agency feels itself forced to highlight and stress the accomplishments which it can claim as its very own. Thus each agency builds a wall about it, which militates against cooperation and provides an unhealthy kind of competition in so far as research is concerned. Sponsorship of outside research and support of cooperative research efforts with agencies outside the framework of government obviously will do much to correct this situation. In fact, the experience of the Office of Naval Research furnishes unmistakable evidence that this beneficial effect does in fact occur.

I now come to what may in the long run become the most important question in the whole problem, namely, what will be the effect upon scientific and engineering research itself of stimulating and encouraging increased cooperation between academic, industrial, and federal interests? Since, as I have already mentioned, government and industry have a practical approach to their research problems, closer cooperation between the three areas may be expected to interest (a) industry and government to a greater extent in the possibilities of basic research, and (b) universities to a greater extent in applied research.

Of course it is easy and appropriate for all parties concerned to consider and discuss ways and means of improving cooperation. This can be profitable in a general way, and a good time is had by all, but the prospect of any definite action to be taken is often rather slim. Generally speaking, good cooperation is not achieved unless the parties concerned have both interest and responsibility. By all odds, the most effective way to insure full responsibility and cooperation is to create financial and operational responsibility. A very pertinent question, therefore, is the following: What would be the effect upon scientific and engineering research of strong federal support to universities, research institutions, and industry?

There are various ways in which financial support may be given. Aid may be given to the institution or industrial firm, to be used at its discretion. Or aid may be furnished to some one specialized department representing some field of research. Finally, aid may be provided directly to a chief investigator and his staff for a particular research problem. Time does not permit me to discuss these alternatives in detail. Suffice it to say that most scientists and engineers whom we have consulted agree that the last alternative is by all odds the best, and that selection of research problems for support should be decided by scientists and engineers competent in the field under consideration. In other words, the research planning should be undertaken in each field by the experts in that field. This is the point of view which the Office of Naval Research has taken.

No matter what form financial support may take, the question must be faced by each recipient as to the degree of support it should accept. This should be accomplished without jeopardizing its independence as an institution.

But from the standpoint of fundamental research, in the long run perhaps an equally serious though more subtle question is that of maintaining the independence and integrity of research itself. This question arises from the fact already mentioned that the government is interested in tangible achievements and practical returns for its investment. Thus, unless ample precautions are taken, money will tend to flow into channels which have good prospect of quick returns or ready application. Now history shows very clearly that the highest accomplishments of research and the most revolutionary applications of science generally originate in research undertaken with no practical aim whatever, often quite unexpectedly and often as a complete by-product. History also shows examples where a major scientific discovery comes as a result of gathering together a large number of research findings, some apparently unrelated. Out of this mass of material a touch of genius may then bring forth some far-reaching generalization. The distinction between the two types of research can be illustrated quite often in the prospect lying before a young post-doctoral research man. Should he follow the most direct path toward his future by undertaking short problems along the lines of his specialty which offer opportunity for frequent publication, or should he undertake a long-range rather difficult problem which may require years to complete, in the hope that out of it may come a major contribution? The choice of the latter alternative is by no means easy since the major contribution may not be forthcoming and the proverbial mouse appears instead of the elephant. By and large it might be expected that government support of research would tend to discourage the latter type of research. As Dr. Bush pointed out in his *Science—The Endless Frontier*, a general characteristic of this whole activity is that applied research tends to drive out basic. Too heavy a concentration on applied research inevitably means that pure research in the end suffers from lack of attention and lack of concentrated thought. In order to overcome this tendency, my own opinion is that emphasis should be constantly directed toward the encouragement of research in its freest form and that we should be quite frank about this. For example, it should be understood that money provided by a given agency in support of research should include provision for a definite fraction of funds to underwrite pure research problems with no questions asked about justification in terms of direct application.

At this point, one may well ask how a decision is to be made regarding the placement of such funds. In planning the research program of the Office of Naval Research, we have attempted to answer this question as follows: By consulting the leading experts in a given field it is possible to identify the areas which appear to justify the most thought and effort, considered from the standpoint of extending basic knowledge in the area. One might call these areas "research bottlenecks." When these have been identified, the problem then is to select projects for support by the ablest investigators that may be found, each following his own bent and his own ideas with regard to the exact approach to be made.

In order to be sure that the sponsoring agency will not have the pressure of its practical interest exerted unduly, nevertheless, in the direction of utilitarian purposes, I should like to suggest certain guiding principles of operation as follows:

1. In initial selection of items for support, emphasis should be placed upon the field of interest of the agency and upon the caliber of the investigator. Final selection should be made from specific projects proposed by the prospective research scientists. This ensures that the personal interest of the investigator and his competence enter strongly into the selection.

2. Every effort should be paid toward ensuring that the work may be carried out under conditions appropriate to research. This means freedom and encouragement to publish in scientific journals as usual and in general to exchange information with colleagues. It means freedom to devote a maximum of time to the actual research.

3. Administrative details of negotiation, accounting, and other business matters should be handled as fully as possible by the administrative offices of the institution and the supporting agency.

4. The staff of the supporting agency with whom the scientists deal should themselves be scientists with research experience who know thoroughly from personal background the conditions that should be maintained. This staff should be competent to discuss the work intelligently and intimately with the research group.

5. The scientific staff of the supporting agency should also be competent administratively and organization-wise, in order to deal effectively with planning and operation of the program, and with the other units, such as legal, fiscal, personnel, and administration, which are involved in the setup, and also with other agencies with which the work may be coordinated.

This policy would ensure that the best ideas of the scientific fraternity would be present in the selection of the program; it would tend to safeguard basic research from undue pressure from without; and it would maintain the work in an environment traditionally best adapted for its health and strength.

It is clear that the success of any such plans rests, in the end, squarely upon the administration of the supporting agency and in particular upon the capability of the scientific staff which it can secure. In addition to scientific qualifications, the scientific staff should possess administrative ability and preferably experience in some government agency. They will have little opportunity for doing research, but will have the compensation of dealing closely with their colleagues in the same research field to an extent hardly possible in a normal research position. They should not, in my opinion, remain too long at this research administration, if it may be so called, but have opportunity, by leave of absence, or by a system of rotation in employment, to return to research every few years, else they lose immediate touch with, and confidence in their specialty.

However, no matter how excellent the motives and the setup of a supporting agency, it is highly necessary to have full cooperation from the institutions concerned and, in fact, the entire scientific fraternity who can at all times be of real assistance as expert consultants in all matters of research and its handling. This cooperation is especially essential, I believe, in the form of making scientists available on leave for active participation in the government agency. In fact, if government undertakes a major program such as recommended by the Bush and the Steelman reports, it is highly necessary to acquire an experienced group of scientists with the right research and administrative experience to handle the job.

You will note that I have avoided, in so far as possible, reference to any particular government agency as sole sponsor of basic research. This is done in the conviction that the support of basic research should never become a monopoly; such an idea is antagonistic to its principles. In my opinion, every agency should have authority and limited funds which may be placed in support of the research, including basic research, which it deems desirable. It would surely be expected, however, that the major portion of federal support to basic research should come from as highly impartial an agency as possible, such as a proposed National Science Foundation. At our present stage of affairs, it seems clear that only by this means can basic research be given adequate general support. Unless, however, each agency be permitted to conduct and support such research as it feels desirable, we may never expect from it the degree of accomplishment and up-to-date progress of which it is capable. It is only by responsibility that one achieves and maintains full measure of productive effort. The same is true of cooperation in research: it is only by sharing responsibility that full measure of cooperative effort is achieved and maintained.

Fundamental and Applied Research

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The subject of "Fundamental and Applied Research" is difficult to discuss in two parts as both are part of a whole pattern. They are interrelated and interdependent upon each other and to treat this subject properly, it will be necessary to include other subjects.

In medicine, for example, there is more and more of a realization that you can't just treat a liver or a spleen or a heart. There are various interrelations of the separate organs and, in addition, these interrelations must be considered in conjunction with the mental and physiological make-up of the patient. The realization of these interdependent factors has led to increasing interest in the psychosomatic approach to human ailments. I am not, of course, going to talk about human ailments, but I think it is equally necessary in discussing fundamental and applied research to attempt to see in over-all perspective what we are talking about, where we are going, and how we are going to get there. In doing this I will probably cover some of the same ground that previous speakers have traversed and, in addition, I may anticipate the remarks of some of the speakers yet to come. Then, too, my remarks may stir up some disagreement. If everyone agreed on everything there would be no use in having meetings like this one, so there is no need for regret if we find we have different points of view among us here.

I wish to speak with particular emphasis on the role of universities in this whole field of research, and to confine my remarks to the type of research which is ultimately for the purpose of turning out something which can be of use to someone. I want to emphasize, however, that I do not decry in the least the virtues and values of knowledge for knowledge's sake. In this research group here, however, we are primarily interested in those things that are going to be used. The thing which is probably most distinctive about mankind is the fact that he has been a researching animal from the very first. We have evolved into a pattern which we may at least consider reasonably intelligent because people for at least a thousand generations have been interested and willing to try something new. That in essence is what research is—going out into something new.

A culmination or at least a very high point of the efficacy of research on a cooperative basis was exhibited during the last war, whether it was planned or not. The three most distinctive scientific developments that came out during the last war, the things that may have made the difference between victory and defeat were: (1) the proximity fuse, (2) the effective use of radar, and (3) the atomic bomb. It is worth pointing out that there was no single master mind in back of any one of these, not even one organization.

These were truly cooperative ventures. There were a multitude of other things under the general activities of the National Defense Research Committee and the Office of Scientific Research and Development during the war which were very important, but these three—the proximity fuse, radar, and the atomic bomb—stand out as prime and very important examples. It should be noted that none of these developments would have been successful had it not been for the wholehearted participation of universities in the entire program of research and development during the war. This participation is an extremely significant social aspect of a new situation in which universities have been thrust into the position of applying their talents to produce immediate results.

In order to discuss the cooperative nature of research it is necessary to have a reasonable meeting of the minds on the definitions of the different segments of activity. In discussing research, I am speaking of its meaning, that is, the whole process from the time an idea is a gleam in somebody's eye until the ultimate use of a discovery, and between those two points there are a good many steps through which you have to go. The first step—and this is the sort of thing that a cave man probably did, that Edison did, and that most research men do now—is to explore the problem. This means searching around to see in a brief tentative sort of way what is to be done. It may mean putting two things together to see whether they will explode or trying a new electronic circuit. The procedures may be developed from a background of rather sophisticated science or perhaps purely from guesses, but in either case there is usually a great deal of preliminary exploration before a new research project gets under way.

An indispensable background for making research progress in our modern, complicated world is the great field of fundamental research, which is the soundest basis for the long term advances and discoveries. Fundamental research is the investigation of the fundamental laws and phenomena of nature and the compilation and the interpretation of information on their operation. The next step in the chain of events is applied research, which means research which has some particular objective. The objective may be a process, a new gadget, or a new product. The fact that there is a definite end objective in your work is the distinctive characteristic of applied research. The important thing about the general pattern of research is that there is a flow from one type of activity to another. Applied research is not sufficient unto itself. It is a reservoir which is fed by two springs—exploratory research and fundamental research. Anyone who imagines that applied research can stand completely on its own is headed for disillusionment.

After you have completed the applied research stage with your new device or discovery, you still are a long way from finishing the job of ultimate application. The stages through which an invention must go can be compared to the growing from fetal existence to maturity. After birth there is a period of childhood where the individual develops and begins to discover his powers and limitations. This period can be compared to the gradual development of the new idea through the applied research phase. It is a phase which is crucial in that it is usually the period in which the practicality or lack of practicality of the idea is demonstrated. The idea has not yet developed into a usable device. It has reached the stage comparable to that of an adolescent boy who has proved his merit but has not yet earned a net income. Only after the period of post-research development is the idea ready for its final stage—production. It is production which is the ultimate objective of getting something to be useful. Hence, development, wherein that which has been possible is demonstrated to be feasible, is a necessary adjunct to applied research. Thus, there are three levels of activity in the process of carrying an idea through to application: (1) exploratory and fundamental research, (2) applied research, and (3) development.

There are various agencies for carrying on the activities of these different stages of research and development, and these all require distinctive talents and psychological approaches. It takes a different breed of cat to do a good job of fundamental research from one that does applied research. Some people who are quite versatile and brilliant can handle more than one of these fields reasonably well, but the world is almost out of supermen so there is no one who is really superb in every field.

What are the organizations or agencies which are available for carrying on these types of research and development? They nearly all fall into one of four categories. The four types of agencies under which research is done are: (1) universities, (2) industries, (3) government, and (4) research institutes. Research institutes are usually of three kinds. There is the research institute closely associated with universities—"university linked," if you want to use the biological term. There is the independent non-profit research organization, for instance, the Mellon Institute of Industrial Research. There is the commercial research institute—that is, those institutes operated as a business, as A. D. Little, Inc., of Cambridge, Forest D. Snell, Inc., and others.

When you consider that these four agencies may be variously involved in all of the aforementioned, you can readily imagine that the number of combinations of functions is large. With four agencies and three levels, the number of variants is probably factorial seven. This produces a possibility of several thousand permutations and combinations in terms of grouping and of time sequence which can be involved in the process of making something useful. It is apparent that it would be rather silly to think we can set up a few rigid categories like nice little flower beds, one for each area, and expect everybody to stay out of the other's flower bed. It just does not work out that way. The process is more or less of a continuant—a flow—and it has the same degree of complexity as some biological phenomena. However, when we examine the interlocking activities of these groups, we discover a pattern which spreads over a broad spectrum with a great deal of overlapping. The universities are primarily interested in fundamental exploratory research, but they also have a certain interest in applied research. The research institutes are primarily interested in applied research, but, of course, applied research is basically dependent upon fundamental research. Without fundamental research, applied research soon runs dry. Industry being closest to production has its center of interest in the field of development. There is a great deal that goes on in industrial research laboratories that is called research which is actually development, though I am happy to say that the industrial research interest in fundamental research is growing. Government activities in research fairly well cover the whole picture. Since government presumably has the national interest in mind, it covers very broad areas in all phases of research and development.

In this interplay of types of functions and the role of various agencies, universities frequently find themselves in somewhat of a dilemma. I am somewhat embarrassed at this point, feeling as if I were at a convention of parents and holding forth on the characteristics of my own child. I have tried to emphasize that different agencies of research have areas of major interest, but that these areas of interest tend more and more to overlap. The primary research interest of the university has traditionally been in basic and fundamental research. During the war the universities were thrown very vigorously into the field of applied research. They performed beautifully—so beautifully, perhaps, they cannot very well let go of it now. If you examine the interest of industry and particularly of government in the applied research field, you will discover that this interest leads to a strong effort to utilize the talents and accomplishments found in the universities.

This very natural process now poses some embarrassing situations for some universities, perhaps including this one. One of the best examples of the efficacy of universities in the field of applied research was at the Radiation Laboratories at the Massachusetts Institute of Technology—a tremendous project for a university. During the war the universities that were largely engaged in applied research were able to carry on only by losing something of their academic excellence. Since the war, many of the universities have been trying to continue the applied research as well as the academic activities, and, hence, ride two horses. In some cases, there is, I think, serious danger of the universities developing schizophrenia. They are trying to ride the academic horse and the applied research horse at the same time. It is not only that one horse is black and the other is white, they are not the same size and, in addition, they tend to run in different directions. This horse straddling will eventually lead to a large split.

We might ask ourselves how this split operates. Well, Professor X of Zed University has an important position on the academic staff. In addition, he is particularly good at research and is an excellent business manager. His department is loaded with research contracts. All is very lovely at the end of September, but comes the middle of the academic year and the research gets behind. There are certain schedules to be met. Professor X suddenly finds himself confronted with two full-time jobs, namely, an academic job and a research job. One of these jobs is going to suffer and you can guess which one it will be. It is usually the academic job. For this reason, I think that this riding of two horses is something the universities should look at closely.

There is, however, a serious gap to be bridged between exploratory research, on the one hand, and development in industry on the other. Universities have demonstrated that they can, if given opportunity, most effectively bridge this gap. It should be bridged and universities should assume a major role. One way to do it without compromising the academic activity is through research institutes at universities. If such institutes are set up realistically, as separate entities—wholly owned subsidiaries, if you choose—with full-time research staffs, then the universities can effectively and successfully fulfill their endangered research function in the modern world.

The general topic of the symposium for today was to be examples of the type of work projects in which cooperative work is applicable. I should like to suggest some examples of general fields in which cooperative research among the various types of institutions might well be stimulated. National defense is a prime example. Here cooperation is not simply desirable—it is essential. Otherwise, we shall run the risk of outsmarting ourselves one of these days. Life has become so complicated that everyone has to help if we are to develop an efficient defense system, that is, one with a minimum of random motion and maximum of unidirectional action. Collaboration is of prime importance, but it must be based on a mutual understanding of the objectives. In this country much of our thinking about national defense has been by the trial and error method. We have been fairly successful. We have succeeded in getting a certain amount of forward motion from the cooperation of all the different agencies working on a large variety of problems. But I think we will all admit that we still do not have a very efficient setup. How much more we can plan and direct without planning to death I do not know, but I think that through meetings such as this one and through a developing understanding of the problems involved, such planning will be extremely worth while. In this area, particularly, universities can be uniquely objective and helpful.

With relation to national defense, the aircraft industry is an area where cooperative research is especially desirable. You will accuse me of beating the drums for my own particular field, but there is a special reason for the necessity of cooperation here. The aircraft industry is and always has been quite unique in one sense. It has always looked to Santa Claus. Of course, most aircraft industries have been built up by rugged individualists, but they have ultimately depended primarily upon Santa Claus, that is, the government, for financial support. I suppose that such dependence is necessary, but the point is that it has led to rather peculiar situations in years past. It has made the aircraft industry quite helpless—in terms of just its own efforts—to keep up with the inherent research and development work which has to be done. They have looked to the National Advisory Committee for Aeronautics, which was set up in 1917, for fundamental and basic information. In the past they also looked to those universities which set up under the Guggenheim Foundation, a number of laboratories such as the California Institute of Technology and Massachusetts Institute of Technology. This research represents fundamental exploratory work which has merged into the applied and development work. The aircraft industries have never supplied this kind of work and they are not doing a very good job of it yet. There seems to be but little realization of this paramount significance of such university activities in the successful aeronautical activities of World War II.

I might point out that here at the University of Minnesota you have a very excellent unit for aircraft research, one which is participating in the over-all program to a remarkable degree. I hope that the top-level work here for the aircraft industry and for the government will increase in the future.

Another field in which I feel there should be general cooperation is that of the conservation of natural resources. Industry, research institutes, universities, and the government all should join hands in this urgent task. The pattern of cooperation is not particularly well worked out yet. There is the Bureau of Mines and various other agencies in the Department of Interior working in the general field of conservation, but this problem is going to become more and more critical, and, in some areas, the situation is already urgent. The universities and applied research institutes can contribute a great deal in this field. One thing that might be done is the development of new methods of waste disposal, both of organic and inorganic materials. There is, probably, no prospect of profit for individual units by such research, but for the community and for the nation at large they are of extreme importance. The general field of public health is a similar example of an area needing full integration and collaboration. Again, the universities and research foundations can contribute a great deal more than they have in the past. Probably that sort of program will always need a substantial amount of government support and planning.

All of the agencies of research have an important function in the advancement of the common cause against the complex problems which await an ultimate solution. Though cooperative research will not by itself cure all the ills of civilization, it is, as I see it, the only avenue down which we can go to set up the basis for a prosperous and—we all hope—a peaceful world.

Industrial Projects Applicable to Cooperative Research

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Cooperative industrial research may be defined as industrial research which is supported by a group of companies for the common benefit of each company or for the benefit of the industry they represent. About one third of the research sponsored by industry at Battelle Memorial Institute meets this definition. Almost every type of research project is included in this program. The reasons for setting up any one project vary according to what objectives are to be met and according to the group which is interested in supporting the work. These differences may be illustrated by a few case histories taken from Battelle experience with this type of research.

One of the more common reasons for establishing cooperative industrial research programs is the necessity for meeting inter-industrial competition. The cement, brick, and lumber industries maintain broad programs which are designed to secure a share of the building materials market for each of these competing industries. The oil, gas, and coal producers are in somewhat the same position, although their fields overlap and may not be directly competitive throughout. The oil industry, through the American Petroleum Institute, has conducted cooperative research for many years. Much of this work is quite fundamental in nature. Our neighbor, Ohio State University, has had for many years a fundamental project to produce and to investigate the properties of a series of pure hydrocarbon. The data resulting from this work have been of great value to both the producers and the consumers of gasoline. The gas industry, through the American Gas Association, conducts a very broad and a very successful program which deals with production and distribution of gas as well as its consumption. This program has supported some two hundred different projects in the past fifteen years. The individual projects are set up in two laboratories maintained by the association, in the laboratories and plants of the gas companies, and in university and research institutes. At Battelle we have been working on one problem for the American Gas Association in this present category, that is, how to help the gas industry to meet competition from other fuels. This particular project is an investigation of the surface hardening of steel parts by gas heat. The process competes with the induction hardening of steel which has become so widely known in the past few years. The objectives of the work are in part technologic and in part economic. In order to compete, the results of gas heating must at least equal those secured by induction heating and it is necessary to demonstrate that the costs are at least of the same order, preferably less.

The bituminous coal industry is another interesting field of cooperative research. Soft coal has been losing many of its markets to the newer fuels. Forward-looking units in the industry recognized this trend almost twenty years ago, but the industry is spread thinly over a large part of the country. It is not a manufacturing industry. The fact that mining interests ultimately exhaust their properties has always been a cloud on planning for the future.

In 1930 Battelle recognized the need for intensive research in this industry if soft coal was not to lose out. It took the initiative and by gaining the support of a few of the larger coal producers, we were able to start a modest program in 1934 after three years of promotional effort. In 1937 work had gone far enough so that it was evident that research could be made a paying proposition. A definite campaign to raise and maintain a budget for research was started in 1940. It was decided that in order to provide reasonable continuity of effort, the program would be set up for a five-year period. A goal of $500,000 was established and this was met by contributions from the coal companies amounting to about ¼ cent per ton of coal shipped. In order to simplify the task of collecting and accounting for funds, the coal associations were approached rather than the individual small producers. This means that the research program is cooperative in more than one respect. The individual companies are banded together in relatively small associations. The associations in turn are banded together to support their research programs.

Interest in this research has grown so that now Bituminous Coal Research, Inc., is a stable organization with its own research director and a staff to conduct the work of the institute. Its program is very broad. Fundamental work is supported at several universities and utilization work is supported at Battelle. Part of this work has to do with the domestic use of soft coal and part of it with the industrial use of soft coal. The smokeless stove is one of the results of this program. The fundamental work was supported by Bituminous Coal Research, Inc. Twenty-eight stove manufacturers joined with BCR to support the development program. A further example of cooperative research in this industry is the participation of BCR in a large program to develop a coal-fired turbine-driven steam locomotive for the railroads. The cost of this work is shared by the railroads, the locomotive builders, and the BCR industry working through the Locomotive Development Committee.

A second reason for establishing cooperative research is to be of service to an industry's customers. The American Iron and Steel Institute, for example, maintains a cooperative research program which, among other things, supports projects which have to do with the compilation of data of various types of steel, the development of standards for fabricating steel structures, and the collection of information on the performance of steel structures, particularly with regard to corrosion. Information and data of this type can be published and broadcast to the industry. No one company can be expected to bear the cost of the work if it is of benefit to every steel producing company. On a much smaller scale, the same type of thing is done by such organizations as the Alloy Casting Institute, producers of heat and corrosion resistant castings, and by the Nonferrous Ingot Manufacturers Association, members of which deal with secondary metals. The Alloy Casting Institute has maintained a program at Battelle for about fifteen years. Part of this work has been to collect data on the high-temperature performance of the products of the manufacturers and part of it has had to do with the corrosion resistance of these materials.

Another and very interesting reason for cooperative industrial research is the occasional need of an industry to find and to develop new uses for its products. This incentive for research is especially typical of the metal mining companies which sometimes have by-product problems on their hands. For example, selenium is produced as a by-product in copper and nickel mining. Some years ago, the mining people formed an informal group known as the Selenium Development Committee. A survey project was set up at Battelle to make a study of possible markets for selenium. This study indicated that the already existing market for selenium in the production of red glass might be expanded. There was a possibility that selenium additions to stainless steel might improve its machinability. There were indications that the selenium rectifiers, if properly developed, would compete with the copper rectifiers then in use, and, finally, the possibility of selenium chemical additions to lubricating oils for use in extreme pressure types of applications seemed to be important. Five projects were set up at Battelle to investigate these possibilities. Neither the glass nor metallurgical applications worked out. The selenium rectifier, under the impetus of war, assumed such importance that for a time it took all of the available selenium. This necessary interruption held back the chemical uses of selenium, but laboratory work indicates that there may be a very good market in this field.

An interesting by-product of the chemical use of selenium is its use in connection with ornamental plants to control insect attack. This procedure takes advantage of the well known fact that selenium is readily taken up by plants and that it is highly toxic. Some soils in the west which contain appreciable amounts of selenium cannot be grazed by cattle because of its poisonous effects. In the greenhouse growing of chrysanthemums and other ornamental plants, however, the toxic effect of selenium is not important to animals or to people. The selenium is taken up by the plant and the plant becomes toxic to insects. This is a matter of the plant biting the bug rather than the bug biting the plant.

Ordinarily, in most industries it is not practical to undertake cooperative work on problems involving costs of the product or the improvement of products because even in a cooperative program we are, in the last analysis, dealing with a group of competitors. There are certain industries, however, in which the individual plants are noncompetitive by reason of geography or differences in the product they manufacture. The gray iron industry is a notable example of this situation. Most foundries recognize a shipping limit of only a few hundred miles. Then, too, the industry is divided quite sharply into the so-called light foundries which make such things as automobile and farm implement castings on a production basis and the heavy foundries which make such things as machine tool castings on an individual or job lot basis.

About ten years ago we were approached by several of the gray iron foundries and requested to organize a cooperative research program for them. Fifteen foundries were selected to make up this group. None of the foundries is directly competitive, but each one of them makes castings and operates a cupola. The research has been an intensive study of the operation of the cupola. It has resulted in a number of technological improvements which have put the foundries which are members of the cooperative research program in a better competitive position than those foundries which have not undertaken similar research projects.

Some of the major industries of the country are divided into a large number of small producing units. This situation is particularly true in the graphic arts industry. There are literally hundreds of electrotypers, for example, whose annual business is less than $100,000. The cost of operating research would be intolerable to these small companies. An organization formed some years ago called Printing Plates Research, Inc., overcomes this difficulty. Some sixty electrotypers by banding together were able to operate a productive research program at a cost of $300 each per year. A plastic printing plate was developed for this group which is being used under license throughout the industry. License fees are being used to support additional research so that the industry now has a substantial budget for its research activities which are maintained on a continuing basis. An interesting example of cooperative research in this field is the combination of a manufacturer of playing cards and a manufacturer of Bibles to develop an improved method of edge gilding. Here is an example where it might be said that the interests of the Lord and the devil coincide as far as research is concerned.

There are other reasons for establishing cooperative research programs. Among these is to provide common research facilities, to provide educational facilities, and to improve public relations of the industry concerned. The Institute of Paper Chemistry is a noteworthy example of an institution which provides excellent research facilities and, at the same time, turns out particularly well-qualified men for technical responsibilities in the paper industry through its affiliation with Lawrence College.

The Institute of Gas Technology, which is patterned on the Institute of Paper Chemistry and which is associated with Armour Institute, does the same thing in the gas industry. The work of the American Iron and Steel Institute at Mellon Institute on the cleaning of steel and the subsequent stream pollution is a good example of cooperative effort on a public problem.

I have tried to illustrate by example that almost every type of research project can be supported by cooperative effort. There are a few real disadvantages in cooperative research, however, which must be recognized in advance if the program is to be successful. In the first place, the program must be defined to meet the needs of each and every company which participates in it. It is preferable for each company to have the same voice in the management of the research program as every other company. This equality can be obtained by having each company make the same contribution in both men and money, or if contributions are based on annual volume by showing the larger companies that it is to their interest and to the interests of the industry to share control of the program with the smaller companies. It is not hard to convince companies of the truth of this argument in these days of trust-busting and anti-monopolistic thinking. The real curse of cooperative effort is the committee setup. Committees very seldom are able to exercise executive control to the same degree as an individual. In most of the large cooperative research programs a full-time research director and possibly a staff of research coordinators are employed. Company interests are represented by project committees made up of technical men who serve pretty much in an advisory capacity. Financial affairs are handled by committees of company executives to whom the research directors and the project committees report in one way or another. If a research director cannot be made available, there might very well be two research committees: one to bring together the interests of most of the companies, and a second executive committee—which should not be made up of more than five people at most—to act as the directing agency. In the interest of harmony, the chairman of these committees must be rotated rather frequently.

Industrial research may result in valuable discoveries or inventions. This introduces another problem that may be difficult to handle. If an informal group has been organized to handle the research project, definite arrangements to provide for possible patents should be made in advance. Usually it is desirable to arrange for a trustee to hold the patents subject to a formalized licensing deal. In a formally organized group, such as an already existing trade association or a nonprofit corporation made up of the cooperating companies, patents become the property of the corporation and the rights of the individual members are clearly defined. Sometimes a problem arises when some of the members believe an invention to be valuable and others do not. This situation can be met by making it optional with each member to contribute to the expense of securing patents. Only those who so contribute share in the patent in this case.

If the problems are well stated and the projects properly planned, the research will probably be successful, but only to the extent that the information reaches the right people in the supporting companies. This is a second real problem in cooperative research. In many instances the program is so far away from management that knowledge of the work and knowledge of the conclusions may not reach a point where something can be done to utilize them. If these difficulties I have mentioned are recognized and steps are taken to meet them, there is every reason to believe that almost any type of worth-while research can be handled successfully on a cooperative basis.

Governmental Projects Applicable to Cooperative Research

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Government, in the research field, is not new. It is an infant of many years who has suddenly grown into an adolescent, clumsy giant. At the moment, it is noisy, aggressive, overbearing, and obnoxious. Universities fear it, although fathered by them. Industry views with alarm, but is itself forced to indulge in more cooperative research, sometimes as an unwilling "middle man."

The process of determining the proper type of project for cooperative research is far from complete. The war years have served to educate us in the government to the necessity of university research, and you in industry and universities, to the necessity for engaging in more research, if our scientific potential is to increase, rather than decrease.

The services have arrived at a peacetime level of expenditure which requires a careful survey of all projects, and an evaluation of their return to the military establishment. We can no longer say "me too," and parallel another organization's effort. We cannot use military funds for the support of research that could be better handled by the Proposed National Research Foundation, or one of the civilian government agencies, such as the NACA, or the Bureau of Standards. There are very limited areas of applied research where no interest is evinced by any other agency—these should be done within the national military establishment. With these general policies in mind, we can now consider a few typical classes of projects suitable for future cooperative research efforts. The classes are as follows:

1. The long range basic research problem.
2. The short range research problem.
3. The applied research problem with an equipment objective.
4. The development problem.

It is assumed that the Research and Development Board's definitions of the above terms are familiar to all of you.

The long range basic research problem is naturally assumed to be entirely within the scope of the university, and we expected a ready acceptance of this type. This has not been the case. Three years ago, we invited the universities and industry to undertake a major problem of this kind—there have been no takers. The problem is in the field of electronics and does not involve anything but advanced theoretical studies, and does not lend itself to parceling out among graduate students, nor does it have glamour. It is, however, a long, hard, necessary job which can be done by a small talented group. Many of you know the problem well. In the past, this type of problem was well done by European scientists in universities. We need to develop the same approach here in all major centers of learning.

The second type of the long range basic research problem is one that requires a "team" to solve it. That is, a group from *all* the physical sciences and allied with the engineering professions to produce new patterns of procedure and design criteria. Specifically, the field of metallurgy, a group effort by a mathematician, physicist, thermo-dynamicist, metallurgist, chemist, and mechanical engineer, is needed.

The urgent need now of eliminating critical materials, producing high temperature resistance alloys, reducing weight and increasing strength, cannot wait on the old, wasteful, empirical method to produce results. This type of cooperative research cannot be launched yet because of the compartmental isolationism within the university and the lack of cooperation between university and industry. As a nation, we cannot afford this wasteful prodigality of our natural resources. The "team" method developed by the National Defense Research Council during the war was a start in this direction, but did not quite succeed in breaking down the intramural prejudices.

I have mentioned only two problems of this class. There are many more which you can discover for yourselves. There isn't much money involved from any viewpoint—perhaps this helps to make them unattractive. We agree with the Steelman Report that four times as much long range basic research effort is needed as is now available.

The short range research problem is much more popular. It is easier to describe and finds customers more readily. It fits into graduate work readily and can be solved with less "frictional" effort because by its nature, it has very limited objectives. The care in selecting a matched "team" is not required to the same degree. Examples are many—to name a few:

1. Magneto striction oscillators as substitutes for crystals.
2. Radiation characteristics of lot and flush antennas.
3. Glass fabricated laminates.
4. Psychological study of flight control requirements for prone position operation.

The average duration of these projects is two and one-half to three years. The participation group is small and within the capabilities of a single organization. In general, they involve the development of some gadgets. The university or nonprofit institution can readily obtain help to augment its own facilities within the community. The end result of the work is publishable in technical society journals, and does not become involved in the question of patents. Since the objective is quite limited, it is relatively easy to evaluate this type of project and to compare relative performance between institutions. From a budgetary viewpoint, this type of project can be quite easily justified and fits quite well into an advanced development program for equipment. Similar contracts, perhaps somewhat more specific with respect to equipment, are given to industry. Industrial laboratories are generally in the same field of endeavor and may be able to use the results in their own business.

Again, there are limited numbers in this category which would never be undertaken without governmental support because they do not fit into either a university or industrial research program.

The third step, strictly applied research with an ultimate equipment objective, forms a still larger proportion of governmental research programs of this general type. We can take as examples, production methods for hydrazine, ceramic coatings for turbine blades, special purpose magnetrons, and solid delay line. The average period of time is one to two years. The end objective is a piece of equipment which is a component of a major equipment. This does not mean that the research group is required to meet specific military characteristics or standards, but that it does produce "hardware" directly applicable to either commercial or governmental development. This class of projects would lend itself best to a three-way cooperative research, provided the question of proprietary rights and patents were not involved. Since the laboratory techniques are not directly translatable into production methods, proprietary rights should be a minor consideration. There is another drawback to this type of research problem in that it is more often than not, classified, with the usual restrictions on publication and security. It is this last element to which the universities object most. It is this same requirement which is, perhaps, too often unnecessarily invoked by the governmental agency.

It was this area of research that was so rapidly and efficiently exploited by the National Defense Research Council during the war. There is a purely personal incentive that the first two classes do not have, namely, the pride of authorship which can be satisfied by pointing to an equipment in use, and saying, "I contributed that."

The development problem does not involve anything materially new, either in theory or practice, but does involve a modification in scale, in extension of limits, or an improvement in operation of well-established equipments. This is also a short duration problem. It can be done by the so-called "slave labor" in universities and can utilize both undergraduate and graduate instructors and students. The graduate student can demonstrate proficiency which will make him available as a project engineer to industry or government. This kind of project does not require highly skilled, creative scientists. It is the type of research which can be done equally well by other organizations. The postwar trend should, in fact, be away from this type of problem in the university, which, perhaps, belongs in the field of profit-making industrial laboratories. This is not the time or the place to go into the "knotty" problem of unfair competition between university, industry, and nonprofit institution.

There is one general point which I would like to clarify. Government is not trying to dictate in an autocratic way, the trends of research. Too often, the university and industry have been unwilling to propose a more effective way of handling the problem, or have been reluctant to originate proposals for research. There has been justifiable criticism of government in certain limited numbers of cases of being unreceptive to suggestions. I think you will find that this is no longer true, or if it is, correction can be rapidly obtained by discussing the matter with others in the same area in research.

The government is also interested that its personnel, either military or civilian, doing graduate work in a university, should have assigned as thesis projects, problems that will, in fact, demonstrate initiative and creative ability of the individual. Assistance can be obtained from the training activity within the service, and the research and development organization, in the selection of a series of thesis assignments which may fit into an intermediate or long range problem. Whether that problem has originated with the government is immaterial.

Organization and Facilities for Engineering Research at the University of Minnesota

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Research is not an elemental act or process which stands apart by itself. It applies more to the method or methods used in approaching or solving problems. It is defined by Webster as "diligent, protracted investigation." In the highest sense, it may be considered a process within the mind. Thus, when we discuss organization and facilities, we must take a broader view than that required for the organization of some simple, mechanical process.

Research is an essential tool for any progressive educational system, and the organization through which it channels must be flexible and capable of meeting the changing requirements for research. The University of Minnesota is nearly one hundred years old, and from the very beginning, research has played an important part in its development and growth. The processes of research have been applied in thousands of educational and other problems, and in their application it has been necessary to build up research organization and facilities and establish policies for the various areas.

My remarks will be directed to the research organization and facilities as they exist in the Institute of Technology. The over-all university policy which governs the operation of these various units will be discussed by Vice President William T. Middlebrook. I do, however, want to call attention to the fact that a great deal of study has been given by the administration in recent years to the over-all organization of research at the University of Minnesota. In April, 1944, President Coffey appointed a committee, consisting of sixteen faculty members and representing every major research division in the University, to advise with him on the organization of research. This committee made a very careful study, and after about one year submitted a majority and a minority report. The difference between the two reports was largely in the degree to which the management of research should be centralized. Both groups were unanimous on several points, one being the desirability for close correlation between the University and outside research, and the need for both basic and applied research in the University.

I believe that the present policy may be best stated as the decentralized research units governed by an over-all university administrative policy. In the engineering and technical fields in which we are primarily concerned, there are at least a dozen established laboratories or research units ranging all the way from a single laboratory room to an extensive research organization. It is, therefore, difficult to point to a single industrial or technical research laboratory at the University of Minnesota in which cooperative research work may be conducted. This type of work is acceptable and practiced to a greater or lesser degree in nearly every one of the established units.

The research, both basic and applied, in a given field is usually closely associated with the leading faculty members, graduate work, and the growth of that division. The laboratory equipment, the experts, and the trained research personnel are all assembled in a group, and there are many engineering and research problems which fit perfectly into that organization. In some instances, both basic and applied research work are carried on by the same staff members and equipment. In other cases, certain staff members are assigned to specific applied research, and in some instances, complete individual laboratory units are established which may be operated within a division and yet independent of the instruction and graduate work of that division. The organization is, for the most part, flexible and appears to work satisfactorily. The system does, however, present some problems when it comes to defining in words the organization and facilities for cooperative engineering research at Minnesota. I will cover, in the time allotted, a brief description of the various laboratories together with their personnel, specialized equipment, and something as to the type of work they are equipped to undertake, or in many cases are already doing.

Research in agricultural engineering and farm machinery is largely conducted in the Agricultural Engineering Laboratories. There are four major divisions of research in these laboratories: farm power machinery, soil and water conservation, farm structures, and rural electrification. Laboratory equipment is available for testing drain tile and silo staves. Farm power units and farm machinery testing apparatus is also available. One of the major problems at present under way is in cooperation with the Department of Chemical Engineering. It is to design and perfect machinery and processes for harvesting flax straw such that the fibers may be made available for a new linen manufacturing process which has been developed by the Department of Chemical Engineering. A productive research program for several years past has been that of the design and construction of locker plants and low temperature storage units for farm use.

There is a group of five distinct laboratories in the Department of Civil Engineering. Four of these, highway engineering, soils and soils mechanics, sanitary engineering, and structural engineering, are closely correlated with the instructional work in the department. The fifth, the St. Anthony Falls Hydraulic Laboratory, is a separate unit and will be discussed later. The highway laboratory cooperates very closely with the State Highway Department. It is well equipped and extensive research has been carried on relative to highway problems in Minnesota. The soils and soils mechanics laboratory and the structural laboratory, recently installed in limited quarters in the Oak Street Laboratories, are reasonably well equipped for undergraduate and graduate work as well as cooperative work in their respective fields. The structural concrete laboratory, established about ten years ago, has a complete line of concrete testing apparatus, moist rooms, etc. An outstanding feature is the temperature control room which in the past has been used extensively for freezing and thawing tests on concrete. Cooperative engineering research has been and, in several cases, is now being conducted in all of the Civil Engineering Laboratories.

A new modern laboratory is in the process of construction for the Department of Chemical Engineering. Even in its present crowded condition, this department has laboratories equipped for such problems as drying studies of food, heat and mass transfer, industrial electrochemistry, crushing and grinding, measurement of surface areas of fine particles, high pressure reaction vessels, and pilot plant operation. The department has a large number of research problems now under way such as organic inhibitors of corrosion, reduction of iron ore with peat, determination of mass transfer coefficients in a falling film, studies in ion exchange, theory of crushing, studies in crystallization, heat transfer in natural circulation evaporators, fusion and reaction in kinetics, heat mass transfer rates at subatmospheric pressures.

There are several laboratory units covering the principal fields of interest in electrical engineering. Omitting those that are principally for instructional work, the major units devoted largely to research are: (1) vacuum tube laboratories which are equipped with vacuum systems, receiving apparatus, dessiccator, power supplies, welding apparatus, etc.; (2) electro-acoustic laboratory, equipped with oscillators, microphones, electric amplifier systems, filter circuits, acoustic impedance measuring devices, standing wave ratio apparatus, acoustic chambers, etc.; (3) magnetic-tape research laboratory equipped with electric turntables, electronic wave analyzer and the usual pick-up transducers, amplifiers, discriminating circuits, etc.; (4) iron ore magnetic research laboratory (this laboratory is equipped with specialized equipment such as variable frequency power supplies of five kilowatt capacity, high frequency, high power magnetizing coils, V-H curve tracing apparatus, microscopes, etc.); (5) high voltage research laboratory equipped with a Marx generator, high voltage Tesla coil, 300,000 volt, 60 cycle transformer, standard spark gaps, etc. In addition to the above there are several laboratories for graduate research in which individual projects are being worked upon. Some of these projects are: VHF wide band amplifier research, ultra-high frequency research, transister research, automatic voltage control of synchronous generator research, single phase motor starting research, pulse generator research, low voltage silver contact research, analogue computer research, etc. There is a cooperative research project under way with the Department of Physics for the development and construction of a linear proton accelerator. This is essentially the development of a research tool for nuclear research.

The Department of Geology and Mineralogy has facilities and staff for research along such lines as chemical analyses, microscopic analyses or x-ray analyses, ultraviolet study of minerals and rocks. There is special equipment for analyses at temperatures of 1400 C and pressures of 10,000 psi.

The metallograhic laboratories are equipped for sampling, polishing, photographing and testing all metals and alloys. Some of the typical research problems under way are fundamental research on alloy equilibrium at various temperatures, nonpoisonous alloy shot, high strength alloys of aluminum, impact toughness of metals and resistance of high strength aluminum alloys as affected by gauging treatment, hydrogen embrittlement of carbon steels, crystal structures of metals and alloys, etc. Several cooperative research projects have been completed and many are in progress. The process metallurgic laboratory is equipped with high temperature resistance and induction furnaces for what is essentially high temperature physical chemistry. Typical research projects under way are studies on rates and mechanism of iron ore reduction, calcination of limestone, slag metal equilibrium, slag constitution, etc.

The major research laboratories in the Department of Mechanical Engineering are the internal combustion engine laboratory, refrigeration laboratory, instrumentation and automatic control laboratory, machine design and dynamic instruments laboratory, and industrial laboratories. The internal combustion engine laboratories are exceptionally well equipped for research in all types of internal combustion engines. There are within these laboratories several variable speed dynamometers, four airplane engine test cells, an oil laboratory, and numerous other facilities. Some of the latest research is in the field of turbojet engines, Diesel engines, and two-cycle motors. The dynamic instruments laboratory was specifically set up for the development of recording gyroscopes with extreme accuracy and other recording instruments such as altimeters, tensiometers, and accelerometers to be used in aircraft flight analyses.

The Northwest Research Foundation incorporated as a nonprofit organization in the middle 1930's for the purpose of raising funds to support industrial development research at the University of Minnesota. There was an elected board of twenty-five trustees which managed the affairs of the Foundation. The Foundation entered into an agreement with the Board of Regents and a Northwest Research Institute was established on campus and charged with the responsibility of directing the research activities sponsored by the Foundation. Under this sponsorship two major research programs were carried out at the University of Minnesota. The first con cerned itself with the production of alpha cellulose from the second growth poplar (aspen) of the north country. The second was devoted to the gasification and better utilization of the vast deposits of lignite to the west of Minnesota. The first project resulted in a successful process which has not yet been reduced to a commercial scale. The second process was pursued through the first pilot plant stage in such a successful manner that the U. S. Bureau of Mines took over the commercial scale development of the process. The final expanded work in this field will be carried on in a newly established lignite station of the U. S. Bureau of Mines at Grand Forks, North Dakota.

The Mines Experiment Station was established to advance the mining activities of the State of Minnesota. It is supported entirely by funds appropriated to the University through the State Legislature, and the work is divided into the divisions of state service and research. In the service division any mineral from the state may be examined and tested free provided that the party submitting the sample indicates the approximate location in the state from which it was taken. Samples are often examined for gold, silver, copper, and even uranium, but the major work in the department relates to iron and manganese. Mining companies usually send carload samples of their off-grade ore for study, the idea being that by some processing method good ore may be made from the low-grade material. The Station is equipped to carry iron and manganese ore through the various processes of concentration at the rate of about one ton per hour. The research staff works on the development of new information, processes, and equipment relative to treatment and utilization of iron and manganese ore and their products. Since a major part of the results are of interest primarily to the companies submitting the material, few general reports are published. The laboratories are well equipped for research and pilot plant operation and special apparatus is constantly under construction. Major investigations under way at present are the magnetic characteristics of oxide of iron, agglomeration with and without binders, electronic controls for accurate proportions of fuel or mixtures, etc.

The Engineering Experiment Station is open to all divisions of the Institute of Technology and the research in the various fields may be directed by any one of the divisions. A part of the laboratories is in the Experimental Engineering building, but the major portion is in the Oak Street laboratories building. These laboratories contain a completely equipped concrete research laboratory with special facilities for both freezing and thawing of concrete and other materials, a soils laboratory, a sanitary engineering laboratory, and a structural engineering laboratory, the research work in these fields being directed by members of the Department of Civil Engineering. An extensive study has just been completed on the thermal properties of Alaskan soil. There are two wind tunnels, one with a 4-foot square throat and the other a 7 by 10 foot throat under the direction of the Department of Aeronautical Engineering. The Experiment Station laboratories are exceptionally well equipped for experiments in the field of low temperature work, for heat transmission, and vapor permeability problems. There is a railroad test room 90 feet long, 20 feet high, and 20 feet wide equipped for temperature control from 0 to 150° F. This is served with railroad tracks so that a full-sized refrigerator or passenger car may be tested. There is also a temperature control room 30 feet square and 25 feet high which may be cooled to -25° F. This has been used very extensively for the study of insulated walls and vapor permeability problems. Moderate-size bungalows have been constructed and tested in the test room, and the results have served as a guide to solutions of vapor permeability and condensation problems in buildings. The laboratories are equipped with complete heat transmission apparatus for full-scale building walls and for all types of insulating materials. There are also well-equipped shops for the construction of practically any type of apparatus.

The St. Anthony Falls Hydraulic Laboratory of the University of Minnesota is located on Hennepin Island at the head of the St. Anthony Falls about one mile from the Minneapolis Campus. In 1936, the City of Minneapolis transferred the water rights and a certain amount of land on Hennepin Island to the University, and the Northern States Power Company granted easements on adjoining property for the use and development of the project. Funds were supplied for the construction by the WPA under the sponsorship of the University at a total cost of approximately $500,000. The structure has six floor levels and has a very accurate controllable water supply of as much as 150,000 gallons per minute at a 50-foot head. In the laboratory there is a main test channel 9 feet deep and 60 feet wide by 300 feet long, a hydraulic machinery and pump laboratory, a water turbine test laboratory, sedimentation tank for water treatment, etc. In addition to those main features of the building there are many demonstration models such as a 1-foot sediment channel, portable demonstration model, 3-foot tilting flue, 20-inch glass channel, 1-foot recirculating sediment channel, glass wall tank, etc. The magnitude and scope of the program at the St. Anthony Falls Hydraulic Laboratory is far greater than would warrant the sole support of the State of Minnesota. The policy is, therefore, cooperative research with outside enterprises as well as studies with and for state agencies. In general, the laboratory is conceived as having three other closely related functions: (1) instruction and training of graduate students in hydraulics and fluid mechanics; (2) fundamental research, a broad field of fluid mechanics; (3) applied research involving largely experimental design and analysis of specific hydraulic structures. There are a large number of graduate students in the laboratory and a variety of research projects, many of which are sponsored by outside agencies and entirely self-supporting. Among the sponsors and collaborators in work during the past year are Minnesota Department of Conservation, Minnesota Department of Health, State Highway Department, U. S. Soils Conservation Service, Corps of Engineers, War Department, City of Houston, Texas, Elk River Concrete Company, Northern States Power, Standard Oil Company of Indiana, American Concrete and Pipe Association, Engineering Foundation of New York, American Society of Civil Engineers, and other private enterprises of miscellaneous projects. The laboratory is unique in the volume of water at high head and the design which accommodates a great variety of hydraulic problems.

The Rosemount Research Center consists of a group of buildings that were erected during the war for the manufacture of powder and explosives. The tract contains more than 8,000 acres with 172 buildings. There is a steam plant capable of generating one million pounds of steam per hour at 450 pounds per square inch and 700° F superheat. There is one 1,000 horsepower electric Chicago pneumatic compressor with 5,000 cfm free air capacity and four 700 horsepower electric Ingersoll-Rand compressors with 3,250 cfm free air capacity each, giving a total capacity of 18,000 cfm. There are office buildings, storage buildings, and well-equipped shops at the center. The area is well supplied with high and low voltage electricity, water, and a complete sewage and drainage system. It is covered by 26 miles of standard gauge railway connected to three major railroads. The plant is exceptionally well equipped for many lines of large-scale research work. These facilities are available for any department or division of the University. However, the major research projects at present under way are those in the Departments of Aeronautical Engineering, Medical Research, and Agriculture. The Aeronautical Division has constructed and is now operating three wind tunnels, a transonic, a supersonic, and a hypersonic tunnel, physiological laboratory, a landing gear laboratory, and other special laboratories in connection with aeronautics. The Medical School has recently operated a 100-bed hospital unit for polio patients and various members of the staff have, or are now conducting research in the fields of physiology, bacteriology, etc. The Department of Agriculture is using over 1,500 acres for experimental work in animal and poultry breeding, dairy production, soils research, etc. The Department of Civil Engineering of the Institute of Technology takes advantage of the area as a summer surveying camp.

The above list does not cover in detail all of the laboratory facilities of the Institute of Technology. No attempt has been made to include the numerous laboratories outside the Institute such as physics, biology, botany, agriculture, medicine, etc. There is, however, a close correlation between the laboratory organization within the Institute and many of those not described. Research staff and facilities are available within the University for practically every type of research, and it is the purpose of the University to use these facilities to the fullest extent possible for the advancement of science and the betterment of mankind.

The Function of University Personnel in Cooperative Research

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The holding of a Symposium on Cooperative Engineering Research is an acknowledgment of the close relationship which exists in our present age among universities, industry, and the government and their mutual and interdependent responsibilities for the advancement of engineering and other sciences, including the training of better men for work in these fields, and the development of basic information and techniques which will be of benefit to these three units and through them to the public. It is likewise an acknowledgment of the responsibility of universities for the activities, in addition to classroom instruction, which have existed through the years but have been brought to a recent state of development probably not even dreamed of until the last decade or so.

We think it is generally agreed that the primary functions of a great university are the training and education of students, and the gaining and dissemination of new knowledge. This knowledge is obtained through research, and its dissemination to both the students through the faculty and to the public at large through appropriate publications must be considered the final stage of the research. However, to completely fulfill its responsibilities, a university, and especially a state university, must also use its facilities to serve the people beyond the bounds of the campus. In this discussion, we are primarily concerned with the research and public service activities, and particularly we are concerned with sponsored research generally carried out under contract by a group maintaining rather close liaison with technical representatives of the sponsoring agency and perhaps with similar groups located at other research centers, as distinguished from the independent research activities which have been carried out in the great universities for many years.

Since the topic of "Personnel" is placed under the heading of "The Universities' Function in Cooperative Research" we will limit this discussion to personnel engaged in research in universities, and not in industrial laboratories or in private research institutes, and specifically we will be concerned with the personnel engaged in sponsored research carried out under contract primarily with industry and government. Some phases of the personnel factor in research naturally have been and will be further treated in other parts of this program and we will try not to overlap those discussions too much, although there may be some unavoidable duplication.

This treatment of the subject of personnel is based on the principles that the sponsored research is carried out within the university departments but not necessarily in only one department, under the direction of a faculty member, and is integrated with the university research program so that it will forward educational objectives, contribute to the training of research personnel, broaden the university research program, and at the same time benefit the sponsor.

Research is built around the people doing it; consequently the most important factor in research is the quality of the personnel because the people doing the work determine its character and excellence. This principle does not beg the question of the necessity for adequate facilities of space and equipment; no research, however, can be successful unless it is conducted by and through the sincere efforts of technically competent and efficient staff.

Another basic principle is that competent scientific direction is the core of successful research. The director must have an adequate supporting staff consisting of technical personnel with sufficient training and experience, graduate students, and nontechnical personnel. The whole staff must work as a team toward the common goal for best results.

Just as in any research organization, universities should have proper personnel policies with respect to the staff to assure not only the efficient conduct of the research but also its proper coordination with education. The university must take both the authority and responsibility for the formulation and execution of these policies.

The supervisor, or director, or leader, of the research should be a member of the university faculty. He will then be in position to act as an adviser of graduate students engaged on the project, to assure the proper educational emphasis of the research and its integration into the departmental or over-all university research program. Furthermore, the faculty members will obtain definite benefits from their supervisory work, as will be mentioned a little later.

The supervisor should be technically qualified in the field of the research project and should be definitely interested in the scientific and technical aspects of the problem, and not alone in any financial considerations involved. It is a truism that the faculty member should accept such supervisory work voluntarily and not be assigned to it. In general, he will be engaged only part-time on the project and must not permit his research supervisory duties to cause any neglect of his teaching duties.

While the primary responsibility of the supervisor is the scientific and technical direction of the research, the successful supervisor must also be cognizant of and sympathetic to the administrative responsibilities inherent in the direction of research. Although the research administrative organization set up in most of the educational institutions which are carrying out cooperative research on an appreciable scale has the responsibility for the general administration of the work, including the contractual matters, accounting, receipt and disbursement of funds, seeing that the research results are formally reported on a satisfactory basis to the sponsor, and general sponsor relationships, nevertheless a certain amount of administrative responsibility falls upon the supervisor in that he is the executive agent for the project who has to see that the institution's policies are carried out in so far as they relate to the conduct of the research. Consequently, not only the supervisor but every member of the research staff should feel a responsibility for observing the rules involved with respect to the institution's policies on sponsored research. Such observance of the rules will not only save a great deal of time of both the research and administrative staffs but will also expedite the progress of the research. Experiences are not unknown wherein a most brilliant technical performer may not arrive anywhere because of needless neglect of good business practice.

For the sake of emphasis, let it be repeated that while the most important characteristics of the supervisor are his scientific ability and his capacity to lead and stimulate the members of his staff, nevertheless, the supervisor who has an entire lack of appreciation of general executive functions should be avoided on any research project involving the teamwork of a group. Briefly, the executive duties of the supervisor would embrace the need to see that the policies of the institution are followed in so far as they relate to the conduct of the project with respect to good accounting, report writing, publications, patents, etc., in addition to carrying out the scientific objectives stipulated in the contract.

The direction of sponsored research which is of suitable character to be carried out within the university provides a number of advantages to faculty members. In the first place it enlarges the services that faculty scientists may take to the national welfare. The professional stimulation provided by association with competent men in other scientific fields through group research, the intellectual exchange between faculty members and industrial research men, and the knowledge of broader, technical problems all contribute to enlarging his horizon and increasing his capacity. The resulting cross-fertilization of ideas by contact with men outside of the university will in many cases expedite progress in the securing of new knowledge.

Such research also informs the faculty of and permits them to transmit to their students current engineering practice which is not yet in textbooks, and consequently increases their teaching capacity. Not the least of the benefits is the "education" of the faculty by association with the fresh, uninhibited brains of good students on challenging problems and the association with other men who have competency in special fields outside that of the faculty member. Work on problems of this type also provides both the faculty and students with better "clinical experience" than do many of the previous problems selected solely out of the faculty member's experience and knowledge.

Such research also helps the university to provide its research staff with more and better research equipment and permits time to be spent on actual research rather than on apparatus construction. It gives the faculty enlarged opportunity to make significant scientific discoveries and publications of wider scope. In many cases it permits the faculty member to be employed on a twelve-month basis and thus permits better staff members to be obtained, especially in times of shortage of competent technical personnel, when it is perhaps even more important than otherwise that the universities have their share of such persons, to train more students to relieve the shortage. Significantly, it gives the faculty better knowledge of the point of view of industry so that they may know better how to train men for industry.

While it is probable that, from the point of view of the attainment of educational objectives, the project research staff should be filled primarily with faculty members and graduate students, full-time research personnel are required to conduct adequately any group research project of appreciable magnitude. Such full-time personnel are needed to provide the necessary continuity and coordination, to expedite the progress, and in some cases to preserve the ability to work toward the agreed upon objectives of the research. Such personnel also may well serve as group leaders on individual phases of the project. They should have the same general and technical qualifications as the faculty and may be quite analagous in competence to the full-time research professors frequently found in universities, notably in the engineering experiment stations.

Moreover, the employment of full-time research personnel, especially younger men, has a direct relation to the educational program in that it gives them more experience under mature direction, further develops their research ability, and thus provides essentially a special kind of adult scientific education.

While it may not always be possible to do so, it would seem desirable that, where feasible, the professional personnel have limited teaching duties in order to integrate them better into the department in which the research is being conducted, give them that kind of association with students, and generally tie them closer with the university objectives. This will insure within the university better coordination of the research and public service functions with the educational program.

Some research projects, especially those which involve more than one scientific field, require for their best progress consultants on specific phases of the work. These consultants are ordinarily other faculty members of the institution or of other institutions. The formally appointed consultants are usually few in number since the university environment provides a great deal of informal, very helpful consultation with other faculty members.

In addition to the supervisor and possible consultants, other faculty members may participate in the research project, particularly if it is a group research program which involves the fields of several related university departments. These men may serve effectively as leaders of associated phases of the project, in which case they would be essentially "phase supervisors," or they may take part directly in the research work.

The advantages of the participation of faculty members as consultants and investigators are essentially the same as those cited above for the faculty supervisor. It may also be mentioned that association of the faculty with the research program is beneficial in that it will open up new vistas even in a subject in which the mature investigator is highly experienced.

In these days of tremendous university enrolments, sponsored research has increased the capacity of universities to train graduate students and has also frequently improved the quality of their education. The support of graduate instruction through the part-time participation of graduate students on research projects constitutes a primary objective of sponsored research in a university. Such students will normally not be employed on more than a half-time basis during the academic year, based on the principle that the other educational factors in obtaining a graduate degree should be given at least half of their time. The employment on research is taken into account in their registration for classroom work, and such employment also takes into account their responsibility for maintaining a high level of performance in their academic subjects. These men will generally constitute the rank and file of the more highly qualified junior level staff.

Not only does such participation in research projects provide financial support for the students but it also furnishes valuable supplementary training and practical experience in industrial research while they are still in school. The advantages to the students are considerable. Valuable assistance is given in deepening and broadening the students' ability to apply the scientific method to the organization and solution of problems. They are particularly fortunate in having the facilities for "learning by doing" the methods actually used in research since research skills and point of view cannot be effectively taught by precept only; they must be learned by really doing.

Sponsored research likewise permits the training of students, as well as the younger professional research personnel, in group, teamwork research, in which broad problems are attacked in parts, the total of which make up integrated investigations frequently cutting across departmental lines. Thus, students are enabled to acquire research techniques which are only possible by participation in organized team research. Such group research also furnishes stimulation to the students by association with not just their advisers, but also with other mature, experienced scientists and engineers who lead the research and with competent technical representatives of the sponsoring organizations.

The use of project research for thesis purposes, when properly handled, also furnishes several distinct advantages. Live industrial projects may provide excellent research problems for the students. In using project research for thesis credit, due regard must be given to the relationship between the nature of the project research and the requirements for theses. Most desirably, the project research is correlated with the student's thesis work so that each contributes to the other. An added advantage generally resides in the fact that the student's time and interest are not divided between outside, unrelated work for a living and thesis research. His whole time, except for classroom work, can be devoted to one area of research. This unity of purpose permits not only his thesis research to be better, more fully developed work, but the project results are likewise enhanced.

Participation in sponsored research while in school not only may well improve the student's graduate training and his capacity for research work upon graduation, but it also frequently leads to a definite avenue for employment following graduation. This is true because the advanced student has an opportunity to test his inclination and aptitude for a given field of work while in school, and his work, if good, will acquaint the sponsor with the availability of an attractive prospect for employment.

In addition to the research personnel, supporting personnel of technician grade, such as laboratory assistants, draftsmen, machinists, instrument makers, clerical personnel, etc., are required in projects of any appreciable magnitude. Regular university facilities may be sufficient in some cases. In other cases, service personnel must be obtained for specific projects or groups of projects. These persons should be employed on the same basis as other comparable employees of the university.

Undergraduate students on a part-time or hourly basis are also useful for subprofessional assistance. Many of the advantages named for the graduate students also hold true for the undergraduate, since his project work gives him an initial experience in research laboratory techniques and at the same time helps to finance his education.

The policies with respect to the remuneration of faculty members for participation in research projects differ among the different educational institutions. In some institutions, the faculty members who serve as supervisors, consultants, or investigators do not ordinarily receive any additional compensation during the academic year for their work on research projects. This is particularly true in those institutions in which the faculty is appointed on a twelve-month basis. This procedure is based upon the principle that no additional obligations will be imposed upon a faculty member by reason of his participation in a research project and that his teaching or other university duties may be correspondingly decreased. If such duties are decreased sufficiently, any money paid by the sponsor for the services of the faculty member may be used to contribute to the salary of a substitute employed to take over that part of his academic duties, or it may conceivably go directly to the institution. But if he gives up consulting opportunities, he should be paid for his sponsored research work.

In other institutions, the faculty members who participate in research projects receive a reasonable stipend (the maximum of which may or may not be fixed by the institution) for their services in proportion to the time required and to their normal salaries. As was mentioned above, participation of faculty members on research projects should be entirely voluntary on their part and should not be governed primarily by finanical considerations. Consequently, due care must be taken to insure that while the faculty member is properly reimbursed for his services, such compensation does not become the deciding factor in his acceptance of this type of work. It seems to us that compensation to a faculty member for participation in a research project which has decided advantages to the educational institution, as well as to the sponsor, is just as reasonable and proper as the opportunity granted faculty members to earn extra compensation by industrial consulting work.

Additional compensation on a reasonable basis to faculty members for their participation in research projects may, as mentioned before, well help the institution to obtain and hold competent personnel in competition with industry.

The remuneration for consultants and part-time investigators who are members of the faculty will ordinarily be governed by the same general principles as those outlined for supervisors. In those cases in which the consultants are compensated (whether they be faculty members or outside consultants) remuneration is usually adjusted on an individual basis, as is the practice in industry. Ordinarily, however, these fees are at a substantially lower rate than is the custom with the general scale in industrial consulting work.

It is believed that the primary considerations underlying the interest of professional personnel for full-time employment on research projects in universities include the desire to work in specific research areas, to gain additional experience under qualified scientific leaders in their fields of interest, to have greater publication privileges, and perhaps in addition to work in a university atmosphere, but remuneration must also be taken into account. The positions established for the research personnel who are neither members of the faculty nor graduate students should be commensurate in salary scale and responsibilities with the latter two categories in order to avoid discrepancies that would lead to dissatisfaction or to lowering of morale. The local conditions in the institution and in the community are pertinent here.

In view of the lack of permanence of the research positions and of opportunity to engage in consulting practice, the professional personnel may in some instances be given a slight premium over the academic salary scale, but their salaries should be kept essentially in line with those of faculty members of comparable ability, and competition with industry on a straight salary basis should not and does not ordinarily occur.

Graduate students are ordinarily employed one-half time, as is the academic practice for the teaching staff grade of "graduate assistants." In some few institutions, the practice is followed of paying the graduate students somewhat more if they receive no academic residence or thesis credit from their project research. In general, however, the remuneration of the graduate students participating in research projects is consistent with that of teaching assistants and university fellows with the same general experience and other qualifications and for corresponding hours of work. We believe that these principles have proven satisfactory to all concerned and should be followed.

In the case of the subprofessional personnel, the hours of work and rates of pay are controlled by the local practices in the institution and in the community. While the salary scales for the nonfaculty, professional personnel should be generally consistent with the scales for other comparable employees of the university, it is recognized that the element of lack of "tenure" must be kept in mind in establishing the pay scales in any bracket. By that is meant that when a regular university faculty member is employed, it is traditional that we hope the period of employment will be indefinitely permanent; that is, the selection is made on such a careful basis that it is hoped our search is ended with a satisfactory employment consummated. On the other hand, while we hope that the employment of research personnel will be equally satisfactory from the standpoints of character, competence, and compatibility within the institution, it must nevertheless be borne in mind that the contracts for the research projects are subject, in some instances, to cancellation upon due notice and will all eventually come to a termination date. This factor may make some adjustment in the pay scales desirable and obviously will be more accented in times of a competitive market for staff.

In addition to the points which have been discussed, there are a number of other factors which must be considered by the institution in establishing the policies under which personnel will be employed and will participate in research projects.

Should the research personnel, including the faculty participants, professional personnel, graduate students, and subprofessional personnel, be staff members of the university appointed by the Board of Trustees, or should they be employees only of the Research Institute if it is legally distinct from but affiliated with the university?

Should faculty status be given to the full-time professional personnel who are qualified by training and experience for faculty membership? If so, what faculty rank should they be given? We think it will be generally agreed that, in any case, such professional personnel should have all of the social privileges of faculty membership.

What degree of tenure, if any, should be given to the full-time research personnel? In some institutions such personnel is hired for the duration of the project; in others, it is employed on an indefinite, "until further notice" basis. Some degree of permanence of the research project (such as a project definitely planned for several years' duration) helps decidedly not only to plan a better coordinated research program but also to attract more competent personnel.

If the university research program is large and well established, perhaps some semblance of tenure might be provided for all, or at least the more significant portion, of the full-time research staff. It would seem, however, that any such understanding would need to be entirely tacit, since while education is permanent, sponsored research is not, at least as far as any individual project is concerned. Consequently, the educational income of the institution cannot bear the liability for tenure and the corollary factors, such as retirement, for full-time research employees. This is a difficult problem to which no unique solution has been reached.

Other employment policies, including length of vacation, sick leave, group insurance, hospitalization, retirement benefits, etc., also come into account. In general, vacation and sick leave policies with respect to research personnel correspond with those of other comparable employees of the university. The question of retirement is more difficult since it involves to some extent the questions of permanence of employment and tenure mentioned above. Since the majority of the full-time research personnel, to whom the retirement benefits would appear to be applicable, may not spend the major portion of their career on the research projects in the institution, it seems that, in the last analysis, such retirement benefits would be in effect chiefly a form of forced saving. The questions of group insurance and hospitalization, particularly if paid for by the employee, can follow the practice of the institution.

Since the full-time professional personnel are employed on the research projects in the fields of their greatest competence and since any consulting which they might be requested to undertake would normally lie in the same fields, it appears preferable that they not be allowed to do such consulting work, in view of possible conflict of interest or violation of trust with respect to the work of the project, unless specifically permitted in individual cases to do so by proper institutional authority.

The possibility of full-time personnel taking formal course work on a limited basis deserves consideration. Such a practice has the advantage of furthering the education and development of the person and making him a better research worker. It is believed that this practice should be encouraged with proper safeguards to insure that the project work does not suffer.

While the general question of the degree of freedom for publication cannot be covered specifically by fixed rules, it is desirable that, in so far as possible, the basic fundamental information obtained be published. This is desirable not only because such publication expedites scientific progress and increases the pool of fundamental knowledge available in our country but also because the research worker's reputation depends to a large extent upon his publications, and the incentive to do a good research and to prepare clear reports on it is largely dependent upon the recognition which these will give the author and his institution. Consequently, freedom of publication, within proper limits agreed upon in the contract, will be very helpful in the securing of competent research personnel. Subject to reasonable restrictions in the research contract, it is generally the academic pattern to safeguard the right of publication to the researcher.

With regard to patents, the policies vary greatly among the different institutions. The disposition of the inventions and of the patents issuing on them is governed by the provisions in the research contract between the institution and the sponsor, but the participation of the inventor in any patent income varies among the institutions, and even in individual institutions, according to the equities which may be present in the invention. In some institutions the inventor does not participate in any income from patents developed on sponsored research projects; in others, he receives a stipulated percentage of this income.

While the attendance of certain of the research personnel at scientific meetings which will be of direct benefit to the projects on which they are engaged presents no great problems, since the expenses of such attendance are ordinarily a direct charge to the project, one problem which deserves some consideration is the freedom to attend and frequency of attendance at scientific meetings, principally for the man's own professional growth and development, with a portion or all of the expenses paid by other than the person himself.

The administrative problems exemplified in those mentioned above have been cited since they are believed to be general in their applicability; there is no general solution to any one of them, since the solutions must be consistent with the policies of the individual institutions. However, they are subject to much administrative consideration, as every administrator of research knows.

We have left the most obvious and the most important matter of personnel to the last, with the realization that it may be considered trite, but nevertheless it is thought that its absence might be noted. It is this: The most important factor in the selection of personnel is the requirement of character. This is a truism in all matters of employment, but it is particularly true in connection with research employment. Another important factor is the competence of the individual in the field of research for which he is being considered. Another characteristic which is particularly important in modern group research is that of compatibility with his fellows and the ability to get along with them and to be a unit of a smooth working team.

In conclusion, the matter of personnel may be summarized by reiterating that, in any research, the problem of personnel is of paramount importance because the personnel determines the character and merit of the work. From the university point of view, the type of projects accepted and the attitude and group relationship of the research personnel and of the departmental staffs largely determine the degree to which the sponsored research may be integrated into the university research program. This is important since sponsored research projects should operate within the university structure, be directed by members of the faculty, and be staffed largely by regular members of the university, including graduate students; they should be directly related to the educational program of the institution, which includes both instruction and research; and they should be of sufficient importance and interest to be undertaken and carried out enthusiastically within the policies of the institution.

Upon the matter of personnel policies, the experience and judgment of the several institutions now conducting sponsored research on a considerable scale have not reached entirely the same conclusion, nor in any one institution may there be a complete unanimity of thinking on the best policies to follow. Probably, the only safe rule is that the educational objectives of the institution must be kept paramount. Sponsored research conducted on this principle will be of greatest mutual benefit to the sponsor and to the university, and in this way the university can most effectively serve the public as represented by the citizens, industry, and government.

University Policies on Contracts, Patents, and Publications

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University policies on contracts, patents, and publications necessarily have a broader base than cooperative engineering research. They reach back to the broad basic purposes of the institution. Universities' basic purposes are to train people from the accumulated reservoir of knowledge and to add to that reservoir more knowledge without regard to its immediate usefulness. Other social agencies may further intensify and specialize that training and direct new knowledge to more immediate usefulness, but no other agency is charged with the basic responsibility for instruction and for fundamental or basic research.

This does not mean that a university should not serve otherwise if it is in the public interest to do so, but it does mean that other services must be undertaken only to the extent that its primary purposes can still be achieved with reasonable adequacy. Yet universities, government, and industry are under contract with the people to serve the common public interest. The charter of the university, the constitution of the government, and the articles of incorporation of industry clearly carry a mandate to serve, and when possible, to serve cooperatively the people and their interests. But there is no mandate on universities to serve business and government except that it be in the public interest to do so, and except that it be not prejudicial to the primary purposes for which the university was established. These are, of course, broad generalizations but they are nevertheless the starting points of policy.

Policy stems from attitudes—the attitudes of people, not of corporations nor of universities as such. It is this fact which complicates university policy and particularly state university policy. University administration may guide, influence, and, in case of disagreement, determine the institutional attitudes and policies; but generally speaking university policies reflect the attitudes of its staff members and of the public which it serves. Private universities do not differ from the public universities in this respect as much as might be supposed. Private universities have their particular publics and they must also be responsive in some degree to the general public as well. To be sure, private universities may depart more readily and with less disturbance from the primary purposes since the responsibility is assumed voluntarily and is not assigned. But even in private universities there are limits beyond which it is not safe to go for it must be kept constantly in mind that research talent has a ready market.

What are some of these attitudes which determine policy and find their way into our research and license agreements? One generalization is entirely safe. There is no uniformity between universities or even within a single university. Attitudes differ from college to college and from department to department. This, of course, is because people, not organization units, have attitudes. To me this is highly desirable. I am no advocate of uniformity. There is no uniformity in individuals. We do not look alike, think alike, talk alike, dress too much alike, eat alike, sleep or otherwise act alike. To be sure, there is a general pattern but the details vary widely. Probably it is the interplay of differences which spells progress. It is not essential, or perhaps even desirable, that our universities all be alike except in some general way.

Let us now examine some university attitudes and policies in the area of basic and applied research. I shall try to generalize for universities as a whole and particularize for the University of Minnesota.

Aid in the form of fellowships and grants-in-aid for basic research is eagerly sought and welcomed with enthusiasm. "Business and government should do more" is a comman comment. They—business and government—should help us more with basic research aid so that we may improve and extend our training of scientists and technologists for ultimate use by them. They have a stake in our training programs and they need our basic research upon which to build their applied research. There are no fundamental problems of whether it should be done, who should do it, and where it should be done. The right to publish results causes little disagreement. The results of research in the form of patentable discoveries do not loom large. That, however, is changing, and before long may assume greater importance in negotiations as the line between basic and applied research becomes less distinct. Frequently the meeting of minds is so clear that an exchange of letters outlining the project, the leader, the amount involved, and its accounting is deemed sufficient.

The situation with cooperative research, presumably of an applied character, is quite different. Multitudinous questions are involved and carefully prepared agreements are required. The questions with which agreements are principally concerned are these: Should the research be undertaken? Will it interfere with the program of basic research? Will it help train our graduate students? Should it be done in our regularly established laboratories, by our regularly appointed staff? Or should there be special, separate laboratories with special staffs, and the regular staff involved only in supervision and general direction? Who should decide to take it or not to take it? What additional compensation, if any, should be given regular staff members who direct it? Should patentable discoveries be kept by the university, left to the inventor, or assigned to the cooperator? Should the inventor share in royalties; should the university control or share; should results be dedicated to the public? What charges should be made beyond direct costs and for what? The possible answers to these questions are as many as the people involved. Fortunately, however, a large number of the universities which are principally concerned have through the years resolved these conflicting attitudes into a general pattern of policy.

From this welter of university attitudes and policies there has emerged agreement on some questions. I think it is safe to say that the value of cooperative applied research in the training program is generally recognized and that making university facilities and staff available for this purpose is deemed to be in the public interest provided, of course, that the basic purposes of the university can at the same time be reasonably accomplished. There is common recognition that applied research, like basic research, flows in most instances to individual members of staff rather than to the institution itself. Consequently the staff member or staff members involved should have a major voice in determining whether or not any proposed research project should be undertaken, having in mind such considerations as facilities, staff, and probable interference with, or aid to, existing training and research programs. There is common acceptance of these points:

1. That a covering agreement is desirable.

2. That the agreement should be negotiated by business-trained people within the university or in an affiliated organization.

3. That the agreement should embrace standard provisions covering (a) a description of the work to be undertaken, (b) the leader or leaders of the work, (c) the period covered, (d) accounting to the cooperator for the funds to be provided, and (e) the right of the university to publish with appropriate recognition and acknowledgment of the cooperative nature of the project.

There is not as yet, and perhaps never will be, uniform practice or common agreement on whether the research should be undertaken with regular staff in the regularly established laboratories or whether the research should be segregated in other buildings, separately staffed and equipped, and only supervised by the regular staff. To some cooperators this may appear as a matter of interest only to the university. This is not necessarily the case. It is possible that coöperative research incorporated into the main stream of training and basic research might be more productive. Even in specialized laboratories, like the Paper Research Institute at Lawrence College, the comingling of cooperative research with graduate training and basic research, with accompanying free interchange of ideas, could be of advantage to the cooperator. In some universities the departmental and college fences are still high. The ramification of science itself has tended to lower these fences, and many instances of significant results could be cited where the staff of separate departments and colleges have cooperated on a single project. Actually is it not the presence and availability of talent in many fields which gives the university its chief advantage in the handling of research projects? The searchlight of these many and diverse talents can be focused on the problem. However, there are many staff members in our own university who are strong advocates of segregation. They argue that the interest and attention of the staff will be focused too strongly on applied research with its rewards, to the detriment of teaching and basic research. They believe that the internal relationships should approximate those of outside consultantships.

There is likewise no uniformity on the problem of costs. The attitudes range from direct added costs, with no interest or participation in results beyond publication, to all direct costs plus 100 per cent additional if results are to be carried away by the cooperator. There are many arrangements falling between these extremes, all of which are more or less related to the disposition of discoveries. Provision is often made for a nonexclusive license upon payment of direct costs plus a fixed percentage for operating overhead.

The major controversy today centers around the disposition of discoveries of a patentable nature. There is, as might be expected, a wide variety of practice. Some universities have adopted a complete "hands off" policy. They want nothing to do with the commercialism of any discovery emanating from their scientific laboratories. They honestly feel that their staffs will be infected by the commercial virus, slight their regular duties, and lose caste with their fellow professional workers. Other universities are willing to apply for patents and if they are received to dedicate them to the public. Still others leave the disposition entirely in the hands of the staff member or members involved. To me none of these courses recognizes the social responsibilities imposed upon a university because of its relationships with the people. Many universities are willing to assume full responsibility. They patent directly or through an outside organization, enter into licensing agreements, recognize the cooperator with a nonexclusive license or provide for any needed developmental work through an exclusive license for a limited or the full period. The public nature of state universities has tended to place them in this group. Government research has influenced many others to follow this course of action. Incidentally, the universities have made significant progress toward uniformity in agreements with the federal departments of the Army and Navy. University committees of business officers have met with representatives of the Army and Navy and have worked out mutually accepted principles for the determination of direct and indirect costs. Perhaps before too long we can do something like this with industry. It would place them in this group. Government research has influenced many others to follow this course of action. Incidentally, the universities have made significant progress toward uniformity in agreements with the federal departments of the Army and Navy. University committees of business officers have met with representatives of the Army and Navy and have worked out mutually accepted principles for the determination of direct and indirect costs. Perhaps before too long we can do something like this with industry. It would be helpful to all of us. However, patent provisions in government research contracts follow different patterns and are still in a state of change.

On these controversial points our policies at the University of Minnesota are in large measure resolved. We have established no separate or affiliated organization to undertake research and promote discoveries. We leave to the staff members or members the determination of the acceptance of the project and to the business office the negotiation of the contract. We have recognized that any real assistance on the part of the university in securing and administering patents must flow from an expressed willingness: (1) to establish machinery to aid in determining the novelty and the usefulness of a discovery, (2) to provide funds under stated conditions for the employment of competent patent counsel and for the prosecution of the patent application, (3) to accept assignment from the staff member of the patent application and/or the patent, (4) to undertake, itself, directly or through an allied agency, the licensing and the other responsibilities incident to the administration of patents, and (5) to assume custody and disposition of any royalties arising from patents not dedicated to the public.

To become effective any expressed willingness to assist must take the tangible form of establishing administrative machinery and an over-all policy for general guidance. Effective machinery and a comprehensive policy are not developed overnight. Both require gradual growth on an empirical basis.

After experience extending over nearly two decades the business office of the University recommended, and the Regents approved on November 5, 1938:

1. That the Regents authorize the establishment of a Committee on University Patents to consist of the Comptroller of the University and two members of the staff to be appointed by the President.
2. That the Committee on University Patents so established be charged with the following responsibilities:
   a. To receive and consider applications from staff members desiring to secure patents at university expense and with university participation in profits and control.
   b. To appoint subcommittees of the staff to advise on technical phases of patent applications under consideration.
   c. To consider the business aspects of such applications.
   d. To authorize the patent counsel of the University to make formal applications for patents.
   e. To consider and recommend to the Board of Regents agreements covering licensing under patents secured.
   f. To consider and recommend to the Board agreements with staff members relative to the assignment of patents by the staff members to the University.

This action did not contemplate any outside foundation or agency for patent application or administration. The University of Minnesota is of constitutional origin and its governing board enjoys wide latitude in its powers of management. For this reason it was the judgment of the Regents that the business of patents, like other university business, should be managed directly by them. It will also be observed that there was no provision for compulsory assignment of inventions by staff members. While it was recognized by the Regents that there had been and would be additional special cooperative research under which compulsory assignment of discoveries would be necessary, it was their belief that other discoveries should be assigned on a voluntary basis. In following this plan they were realistic in recognizing that any staff member could evade assignment if he wished to do so.

On December 7, 1938, the Patent Committee, consisting of the comptroller (now vice president, business administration), the dean of the Law School and the head of the Mines Experiment Station agreed:

1. To receive and consider applications from such staff members without regard to whether the patent was developed by the staff member in or outside of his general field of University employment and without regard to whether the patent was developed with or without the use of University facilities and funds.

2. To receive and consider applications from non-staff members only under special circumstances and to authorize the Patent Counsel to make formal application for patents after specific approval by the Board of Regents.

The most perplexing business problems have centered around the form of the license agreement. The main question has been: Shall the license be exclusive or nonexclusive? Each patent has been approached on the basic assumption that the University of Minnesota is a state, publicly-supported institution and that its discoveries should be made available to all companies serving the public, and particularly those companies operating in Minnesota. With few exceptions, however, the difficulty of this approach has been that to make most laboratory discoveries commercially useful and successful has required further "pilot plant" research and the solution of many production problems. It is quite understandable that companies are unwilling to assume the costs of added research and the solution of production problems unless there is some chance for them to recoup. Only an exclusive license, either for the life of the patent or for some lesser period, gives them this chance. We have met this problem in a number of instances by granting an exclusive license for a period of seven instead of seventeen years, the statutory life of a patent.

Our experience with patents to date has indicated that the license agreement should contain some or all of these provisions:

1. For control by the University of discoveries resulting from further research carried on in the University and in the licensee's laboratories (exclusive).
2. For a minimum annual guaranteed royalty where royalties are based upon a percentage of sales (exclusive).
3. For a division of the cost of additional patents (exclusive).
4. For securing foreign patent protection together with a sharing of the cost of such foreign patents (exclusive).
5. For periodic reports of sales and payment of royalties.
6. For the prosecution of infringements and distribution of recoveries (exclusive).
7. For fair and reasonable prices of any products sold under patents.
8. For requiring licensee to refrain from making any unwarranted or extravagant claims in its advertising and from using the name of the University of Minnesota or any of its staff members in connection with sales or advertising except with a prior written approval of the University.
9. For retaining to the University right to publish the results of any further research undertaken, provided that prospective patent rights are not jeopardized by such publication.

To clarify more fully university attitudes and policies, the Board of Regents adopted this resolution on February 19, 1943:

"WHEREAS, The University of Minnesota, a state-supported institution for higher education, has a responsibility and interest in the advancement of scientific knowledge and in the advancement of the economic interest and welfare of the people, particularly the people of the State of Minnesota, and

"WHEREAS, This responsibility and interest can from time to time be advanced by engaging in research, the results of which may have commercial applications which are patentable and which should be patented in the interest of the public and the income from which may be used for the promotion of further scientific research, and

"WHEREAS, Such research in some instances is cooperative in character, financially and otherwise, with outside persons and organizations, and

"WHEREAS, Such research undertaken at the University involves the use of staff and facilities not always accurately measurable in dollars,

"*Now, Therefore*, The Regents of the University of Minnesota in an effort to promote such research for the advancement of science and the economic and social welfare of the people, indicates its willingness to undertake such research in cooperation with outside persons and organizations within the limitations of its staff and facilities under the following general conditions:

1. That unless otherwise provided in the agreement patents shall be controlled by the University.
2. That the University will be willing to consider the granting of a nonexclusive license (shop rights) to the cooperating person or organization which provides funds for the direct and operating overhead costs of the research.
3. That if the research undertaken by the University is a continuation of research already initiated by the cooperating person or organization, if the research results of the University require further development work for commercial application, or if for other reasons the public interest can thus be better served, the University will be willing to consider an exclusive license for a limited period (5 to 7 years of the 17-year patent life) or even for the life of the patent where it is clear that the public interest will be served, provided the University receives full reimbursement for all costs, and a reasonable royalty with a minimum annual amount of such royalties guaranteed to insure that the patent is used by the licensee."

Many of our recent research agreements either include or make reference to this general policy and avoid the inclusion of patent clauses which are so difficult to write in advance of the research and in anticipation of discoveries which may never materialize.

The disposition of royalties is not devoid of problems, particularly in publicly-supported institutions. These are some of the questions which must be faced. Should royalties be merely added to general institutional income? Or, should royalties be shared with the staff member who makes the discovery, and the balance earmarked for special designated institutional purposes? Some institutions have been reluctant to share with the staff member. Undoubtedly these institutions are motivated in their attitude by a fear that the staff member who tastes the fruits of his labor will no longer be willing to devote his time to fundamental research, the fruits of which may be long delayed.

Our Patent Committee took an early stand on this matter. In 1938 they recommended, and the Regents approved, that after deduction for the cost of securing the patent the division of royalties be as follows:

1. That the division of royalties be 25 per cent to the staff member and 75 per cent to the University in those cases where the patent is in the general field of the staff member's employment and university funds and facilities have been used in the development of the patent.
2. That the division of royalties be 50 per cent to the staff member and 50 per cent to the University in those cases where the patent is outside of the general field of the staff member's employment and university funds and facilities are not used in the development of the patent.
3. That in those cases where the patents are outside of the general field of the staff member's employment or university funds and facilities are not used for the development of the patents, the division of royalties be somewhere between 25 per cent and 50 per cent to the staff member and the balance to the University.

While there is no published policy it has been our practice to dedicate the University's share of royalties to research in the same or allied fields.

We feel that our research organization was greatly strengthened when the office of patent adviser was added to Business Administration. This office has been helpful to staff, patent counsel, and industry, in spotting significant discoveries, aiding in securing patent coverage, and in bringing possibilities to the attention of industry.

The Effect of University Policies on Industry

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The primary purpose of a university is to train students for the future. Therefore, we must raise a basic question. What kind of future? Shall it be communism, socialism, or democracy. We know that our form of government has produced the highest standard of living in the world. We live in a country which stands for freedom and decency, and one which gives credit for ability and opportunity to all. If we wish to preserve our form of government we must train both leaders and followers who believe in it. We cannot plant weeds and expect to harvest wheat.

As measured by physical goods, it is impossible to have a high standard of living without being highly dependent upon others. A corollary to this statement is that without cooperation among individuals it is impossible to have a high standard of living within a country, and without cooperation among nations a high world standard of living is likewise impossible.

Today I have been asked to consider from an industrial point of view one small segment of the over-all picture of our national welfare. What is the effect of universities' contract, patent, and publication policies on industries? As industry goes, so goes the prosperity and welfare of our nation. If our university policies are sound, then they must strengthen industry, for in its broadest sense, industry means cooperative efforts directed toward the attainment of physical goods.

Industry cannot survive without well-trained man power and it must rely upon colleges and universities for these individuals. The guidance and training which the student receives is a lasting one. Seldom can industry unmold the finished product and recast it into a vastly different form. In industrial research, men are desired who are filled with enthusiasm for decreasing the horizon of ignorance which is all around us. They must be capable of expressing their findings clearly and concisely so that additional confusion does not result from their pronouncements. They should be capable of recognizing the significance of the part which they are doing in relationship to a broader perspective.

At a recent meeting of the Industrial Research Institute, James Killian listed industry contracts with universities into four general groups: endowed professorships, graduate scholarships and fellowships, grants-in-aid in a general field, and research contracts with prescribed objectives. Endowed professorships are motivated by the desire to keep the professor in university work who has unusual research or teaching ability, where his influence may be felt by many students and disseminated throughout the nation by his pupils. Such grants promise, in the long run, to pay great dividends to our country. Of equal importance are the graduate scholarships and fellowships, for there is little to be gained by having an excellent faculty attempting to train mediocre students. Financial aid is imperative for most graduate students since, in general, educational costs have risen so high that few families can afford the long financial drain necessary for advanced training. Grants-in-aid in a general field are a very desirable type of contractual arrangement between industry and university, providing the university is well-equipped to train students in that field. A typical illustration of an arrangement of this type is that of the Corn Industries Research Foundation. Companies engaged in the wet milling of corn contribute money to the Corn Industries Research Foundation, which in turn awards fellowships in the field of carbohydrate research. The emphasis is placed on freedom of the research worker to explore the unknown realm of starch and carbohydrate chemistry. Thousands of dollars have been spent on such fellowships to learn more about the structure of the starch molecule.

Research contracts with prescribed objectives are, in general, the least desirable and the more highly prescribed, the less desirable. Frequently, with such contracts, the broad aspects of university training are lost in search for the practical and patentable. A university that specializes in such contracts may soon find itself being little more than a consulting laboratory with the donor of the funds obtaining additional information at partial public expense. Broad fields of investigation may be passed by in order to accept funds for research in very narrow specialized ones. The training which the student receives while conducting such research parallels that of an industrial laboratory and, therefore, tends to prematurely narrow the horizon of the individual.

It is recognized that many universities are in poor financial condition. Decreased revenue from endowment funds, higher operating expenses, continued pressure for enlarged services, and the desires of administration to outdo their neighboring institutions are the major contributing factors to this condition. A logical alternative to the "me too" attitude is some good old-fashioned horse trading. For example, suppose that two universities have small forestry and veterinary colleges and operating costs are high. Both gain if one closes its forestry college and the other its veterinary college and each transfers students to the other. The Corn Industries Research Foundation serves as a typical example of how the principle of a cooperative program is applied in industry. It would be foolish for each individual company in the wet milling industry to try to sponsor all of the fundamental research which should be done in its field. It is doubtful whether university contracts motivated by the primary desire of keeping the wolf from the door will do little more than delay the downfall of the institution.

Every contract made involves a certain risk, and having considered some of the hazards, the potential gains should be cited. Industry hopes to gain by obtaining well-trained men for industrial laboratories. This motive far outweighs such lesser objectives as solving of research problems at less expense and availability of equipment.

James Killian has cited the three most important college gains as: financial aid for equipment so that they may maintain independence, intellectual exchange of ideas, and suggestions for more suitable theses topics. The universities must be supported in such a way that they may maintain independence. They should be kept free to seek and teach the truth. World War II has almost completely broken down the barrier between the long-haired college professor dwelling in his ivory tower and the public. The professor has been amazed, and pleased, at the speed with which his findings could be put into use. Furthermore, he has had an opportunity to observe cross-fertilization of ideas and cooperative ventures as never before.

One example of a cooperative contract was that of the fermentation program for the production of penicillin. It was my good fortune to be chosen to serve as coordinator of this program for the War Production Board during the war and thus I had the opportunity to observe the splendid progress which can result from contracts. Advantage was taken of special skills and "know-how" available in the universities to assist in breaking technical bottlenecks in the industrial production program. Plant pathologists, led by Dr. E. C. Stakman at the University of Minnesota, were organized to search for new and better strains of mold which would produce penicillin. Samples of soil from all parts of the world were used in this study. Dr. G. W. Beadle, then at Stanford University, was assigned the problem of producing genetic changes in the mold which might result in greater yields of penicillin. Fermentation problems involving modifications in culture media and other environmental conditions were given to Dr. W. H. Peterson at the University of Wisconsin. The late Dean Frank C. Whitmore of Pennsylvania State College placed a group of chemists and chemical engineers on problems pertaining to the recovery of penicillin from the media. Dr. T. K. Sherwood at Massachusetts Institute of Technology advised on methods of drying and packaging the final products. This project is cited for the success of it is proof of what can be done when there is cooperation among government, universities, and industry. It should be emphasized that in all of these university contracts absolutely no pressure to dictate a procedure of attack was placed on the university staff. The problem was stated as clearly as possible and the university staff was free to approach the problem as desired. Although a practical goal was in sight, in this instance it was fundamental information which was lacking. Some such information is still missing. For example one may ask the fermentation experts whether the mold produces penicillin because it is aggrevated or because it is pleased. Too much emphasis cannot be placed on the potentialities of solving problems by contracts with several universities where specialized knowledge may be utilized with maximum efficiency.

Through its contracts with universities, industry can be of help in suggesting better theses topics for graduate students. The atomic bomb, synthetic rubber, and penicillin developments emphasize that major applications of scientific achievements are the result of cooperative programs. Contracts which assist in enlarging the frontiers of knowledge should improve the quality of theses topics. A research program which aids in the training of the student in research habits and techniques is essential, but it is even more satisfactory to the student, professor, and university if the problem is worth while. Although many industrial programs fail, it is rarely that a field of investigation is selected without considerable justification. Entirely too little time is given to the selection of research problems for university graduate students. All too frequently research topics are selected on the spur of the moment with not much more justification than the fact that some problem must be assigned to the graduate student. Industry finds its most useful men from among those who have been trained to recognize the part which their work plays in the development of a larger program. University contracts which stimulate this point of view should be encouraged. Joint contracts between departments further this type of training. One example of such a contract is that between Corn Industries Research Foundation and Iowa State College. One part of that program is devoted to plant breeding of new types of corn and the other pertains to a study of starch structure. The graduate student becomes familiar with certain aspects of genetics and the results of this work are explained in terms of composition of the new species of corn. Eventually, industry can evaluate the new starches for end uses and consumer needs.

Discoveries may be kept secret or disclosed to the public. Secrecy is difficult to attain and frequently nearly impossible except for short intervals of time. Secrecy in university work, except where military requirements indicate otherwise, should be discouraged. Any university that accepts contracts with clauses which might prevent publication of the data is competing directly with industrial consulting laboratories. At the same time, its student training program is automatically incomplete if it deprives the research student of the right of publication.

The two most important types of technical publications are patents and the scientific journals. Patent aspects will be considered a little later. Many students receive very poor training in writing of notebooks. The evidence of this is to be found in hundreds of places in industrial laboratories. When industry makes a contract with a university, those in charge of experimental work are expected to see that proper records are kept of the work so that the student is trained in recording and reporting data. The outline guide is very simple. What is the problem? What experiments are to be conducted? What happened? What valid conclusions can be drawn? What should be done next? If the problem is real, the experiments well planned, and the work well executed, then some conclusions should be attainable which are worthy of record in the scientific literature. Again, the university is falling down in its contractual relationship if the professor writes up all the record for the literature. Industry wants men who have been trained to express their own observations on the printed page. I do not imply that oral presentation is not important. The industry conference table is a give and take proposition and the individual who cannot express himself is under a handicap. There is the old story of the college professor who in examining a thesis which the student had submitted and wished to publish said, "Son, there is much in this thesis which is true and much which is new; unfortunately, that which is true is not new and that which is new is not true." To reverse the statement is the goal of all university research work.

In 1934, the Committee on Patents, Copyrights, and Trademarks of the American Association for the Advancement of Science listed the following as the most frequent objections to patenting university research:

1. That it is unethical for scientists or professors to patent the results of their work;

2. That patenting will involve scientists in commercial pursuits and leave them little time for research;

3. That publication or dedication to the public is sufficient to give the public the results of the work of scientists;

4. That patenting leads to secrecy;

5. That a patent policy will lead to debasement of research;

6. That patents will place unfortunate strictures on other men who subsequently do fundamentally important work in the same field;

7. That it is debatable whether one man should receive credit for the final result he obtains after a long series of studies has been carried out by others before him;

8. That the policy of obtaining patents will lead to ill feeling and personal jealousies among investigators; and

9. That the act of securing patents is in itself evidence that he (the scientific investigator) desires financial profits from his work."

After studying these objections the committee concluded that patenting of research of industrial importance is desirable and they stated:

1. "Our patent laws have been enacted in accordance with the provision in the Constitution, 'to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries.'

2. "The investigator who takes advantage of our patent laws is therefore perfectly warranted in his act not only for any possible financial returns but also for the good of the public. The obtaining of some remuneration from a patent is no more debasing or tainted with commercialism than the acceptance of copyright royalties from a textbook or even receiving a salary for teaching. We are at present living in an economic structure in which the making of legitimate profit is a fundamental assumption.

3. "The recent economic crisis has reduced the funds available for research to an alarming extent. Scientists are therefore warranted in legitimately obtaining funds from the results of their own work whenever they can do so by patents. In this way they will be able to finance their own work, extend their researches, and at the same time make contributions both to science and industry.

4. "Only by means of patents can the legal right be secured to exclude others from practicing a given process or commercializing a new product.

5. "By having such control of new discoveries the investigator is assured that his results will be used only for proper and meritorious purposes. He can prevent the exploitation of the public by dictating the terms under which his patent should be worked and even control the character of the commercial advertising."

Archie M. Palmer has written several articles during recent years on the subject of university patent policies. It is particularly significant that the word "policies" is used, for no uniform policy has been adopted by the universities. To illustrate some of this lack of uniformity the following contracts are quoted:

1. "At the discretion of the university, the results of this study shall be published, but before publication copy of the manuscript shall be submitted to the company for such comments as they may wish to make. Any invention or improvement arising from this work shall be and become the property of the company. The company shall have the right to file patent applications on any such inventions and to obtain such patent protection as it sees fit. However, if in any instance, the company should elect not to file patent applications, then the university may do so providing it pays the expense of filing and prosecuting the case through the Patent Office and grants thereunder to the company a non-exclusive royalty-free license.

2. "The results of this study and any inventions or discoveries resulting therefrom shall be published in lieu of patenting by either party, but university, prior to publishing any material relating to the subject investigation, shall first submit a copy thereof to the company for its examination.

3. "The university reserves the right to publish the results of the investigation. Before publishing, however, it will give the company an opportunity to review the manuscript and will consider suggested modifications. But the university's decision as to what the publication shall contain shall be final. It is mutually agreed that any and all patent rights arising from research conducted at the university under this agreement shall be the property of and assigned to the university. The university agrees to grant a non-exclusive license to the company on any invention arising from this research. The university agrees that no exclusive license will be granted under any patent rights arising from research conducted at the university under this agreement."

From these three types of contracts one notes that patent agreements range from full rights to the sponsor to full rights to the university. The first contract form differs from the usual contract with nonprofit research institutes in that with the latter, publication may be withheld indefinitely by the sponsor. The nonprofit research institute functions in many ways as does a commercial consulting laboratory.

The second type of contract states that industry is encouraging fundamental research and desires that the results of the investigation be made public property through publication in a technical journal. Such a contract is criticized by some on the basis that if something highly important should result from the investigation it is impossible for the university to obtain any financial reward from the work. An editorial in *Industrial and Engineering Chemistry* has this to say regarding the effect of patents on university and foundation laboratories:

"A generation ago most research workers in the medical field and many of those in our universities felt that it was not quite ethical to patent their discoveries, particularly in matters relating to public health. During the past twenty years, however, there has been a growing recognition of three facts: (1) Failure to patent is more likely to delay than to encourage the development and marketing of new products, especially if any substantial investment or advertising is required to get them started. (2) Failure to patent leaves new remedies open to widespread abuse by unethical manufacturers and promoters, whereas patenting permits a control of quality and marketing practices which is highly desirable in the case of many new drugs. (3) Failure to patent simply throws away a large potential income from those who benefit from new discoveries, which income might better be collected and used to promote further research in related fields. Growing appreciation of these three facts has largely changed the attitude toward patents of the workers in these fields, so that patenting is now the usual practice. Partly due to the outstanding example of the Wisconsin Alumni Research Foundation, millions of dollars a year are today being devoted to pure research in medical and other lines from royalties obtained from the inventions of earlier workers, generally in the same organization. This is a sound and socially desirable method of financing research work which would be lost if the value of patents were to be greatly reduced."

The third contract is typical of the patent-conscious university. Sam Tour in *Chemical and Engineering News*, 1948, has this to say regarding the patent consciousness of academic institutions:

"Our institutions of higher education have not been, are not now, and should not be expected to be the places for research and development for private enterprise. They have been and probably should be a decided minority in the picture of industrial research. Their attempt to enter and enlarge in this field, new to them, is spreading them so thin that they are losing sight of their primary function of teaching and of their secondary function regarding research.

"The bewitching tale of the absent-minded professor so absorbed in his research that he forgets himself, his meals, and his classes is much of a fairy tale today. Too few professors of today are sufficiently imbued with the 'spirit of research' of 'delving in the unknown' of 'research for research's sake'—the great majority are out after the almighty dollar. This situation is not always the fault of the individual professor. The policy of some educational institutions is such that a professor is required to go after outside work for the 'prestige of the institution' whether he likes it or not. He is not permitted to devote himself entirely to the business of teaching nor to fundamental research work of his own choice. He must do something 'to make the headlines.' In some of these publicity hunting institutions of today, the undergraduate student gets rather short shift from the faculty. If he learns anything it is largely because he wants to learn and in spite of the faculty. This low state of affairs is not because of a low caliber or shortage of faculty but because the idea of teaching has been lost sight of in the helter-skelter race for publicity and the dollar."

Archie M. Palmer, *Chemical and Engineering News*, 1948, points out that getting into the patent business is not all a bed of roses. It is usually years from the conception of the idea which should be recorded in the research notebook to issuance of the patent by the Patent Office. The normal university research procedure is relatively simple in that it consists of an idea, experimental work, and publication. If the goal is a patent many additional steps may be required. The idea should be carefully stated and witnessed, research data obtained, preliminary patent memorandum submitted, patent search completed, final patent memorandum prepared, patent application written, and Patent Office actions answered. If a patent is issued, it still may be subject to innumerable legal entanglements. In industrial research it is the rare case when all of the desirable data needed to define the limits of the invention are available when the preliminary patent memorandum is submitted. In industry, continuation of the experimental work is not difficult; in the university, the graduate student may have his diploma and be thousands of miles away. Thus if the university is to obtain good patents, the research must be continuously pointed in that direction.

Patent management is both complicated and expensive. Palmer states that "it requires a high degree of legal competence, administrative astuteness, and promotional zeal—a combination of talent not always readily available in an educational institution." It is for these reasons that universities have adopted such different patent policies. One solution, and until the last few years, the one most commonly adopted was a hands-off policy. Some universities have incorporated patent management corporations and are attempting to make university research pay through royalties obtained from the patents. Other universities have passed the problem on to Research Corporation, a nonprofit patent management foundation which will process patentable discoveries for the universities. Some universities attempt to handle patent work through the regular administrative organization and act on each potentially patentable discovery as an individual case. This policy is capable of producing considerable internal friction particularly when committee decisions are made to attempt to patent the work of one professor and not that of another.

In most instances it is not feasible for the university to carry an idea beyond the patentable stage. Development and evaluation of a process are in most cases far more expensive than the work which led up to the patent. If the process has been developed at partial public expense then exclusive licenses are criticized. Without an exclusive license it is extremely difficult for industry to justify the enormous development expense. Where universities seek to obtain and grant nonexclusive licenses, development work may be the bottleneck to the successful utilization of the idea. For the university or government to partially solve the problem by doing the pilot plant work still does not guarantee use of the patent. To go further and set up a manufacturing group is to deprive industry of the opportunity to succeed.

Perhaps at some future date it may be necessary for industry to create an industrial university for the purpose of training its future employees in a strictly academic atmosphere away from the business pressure of the average university of that time.

In the book, *Research in Industry*, Paul D. V. Manning discusses goals and problems of the future. He lists six important problems, the solution of which may lead to a peaceful world and one with higher standards of living. These problems are:

1. Improved and nutritionally satisfactory foods at lower costs.
2. Increased knowledge of the human mind and sociology.
3. Improvements in the distribution of products from all sources.
4. More conveniences and labor-saving devices in everyday life.
5. Production and distribution of low-cost heat and power.
6. The fullest conservation of material resources.

Several recent books have tended to stress the rate with which the world population is increasing and the national resources are decreasing. One needs only to extrapolate the two curves to the point at which they cross to determine the focal point of lowered standards of health and living. It is my contention that, if people are sufficiently educated, these curves never need to cross. Basic to our future is world peace, for we cannot have mass slaughter of people and destruction of resources and still maintain a high world standard of living. If we are to have world peace we must have a true world desire for it. To achieve peace we must solve the six broad problems outlined by Doctor Manning; and to do this, requires trained manpower.

In conclusion, it is urged that all of us recognize the important problems about us. We must solve them or be swallowed in the catastrophes which will follow. Industry must do its part in creating the materials so vitally needed for our welfare. This it cannot do without both government support and approval, and personnel with the training and desire to succeed. Universities are urged to continue training programs which will meet the future needs of the country. Any contract, publication, or patent policy which interferes with the best in student training should not be adopted.

The Qualifications for Industrial Research Personnel

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The general question of what the young technical man can do to advance himself has been discussed by so many people that it is hard to find something new to say on this subject. It occurred to some of us, however, that useful information might be obtained from a survey of the outstanding technical men in the field; and we therefore sent out a questionnaire to leaders in industrial research. We were less interested in opinions—although we did not discourage them—than we were in actual case histories.

The questionnaire was sent to about 160 people, representing approximately 80 companies. Replies were received from about 85 per cent. It will be noted at once that the size of the sample is small, and that it would be unwise to consider the results in any sense final. On the other hand, the number of people at the top in research organizations is also quite small, so the survey may be more representative than it seems on first glance. The people selected were the company representatives to the Industrial Research Institute, which carefully endeavors to keep its membership representative of modern industrial research in this country. It went to chemical companies, oil companies, mechanical industries, foundries—in all, quite a wide distribution.

The age distribution of the technical men, although most of them are past forty, is quite broad. It may come as a surprise that a very large percentage of the men questioned came from a background of chemistry or chemical engineering. This condition prevailed not merely in oil or chemical companies, where we might expect it, but also in many of the mechanical industries. Physics furnished the next largest percentage, and was followed by mechanical and electrical engineering. Only one of the respondents was trained in civil engineering.

We wanted to discover whether these men attributed their success chiefly to their technical ability or to their executive ability. The question was so worded that they were supposed to choose one or the other, but a great many of them merely remarked that both technical ability and executive ability are important. Probably in their earlier years their success was dependent to a considerable degree upon their technical ability, but as they moved into management positions their executive ability became more important. The relative importance of these factors also may depend upon the kind of company for which a man works.

We have heard a great many times that teaching is a valuable asset to a man who wants to get into the field of industrial research. It developed, however, that only 42 of the responding people had taught and 70 had not taught. The teaching experience, in most cases, was limited to a year or two. Only a few had done any substantial amount of teaching. The figures seem to indicate that teaching is not a prerequisite for success in industrial research.

A question of interest to every young technical man is how long it will take him to gain recognition. While recognition can come in various ways, at least one indication is the attainment of a supervisory position. In asking how many years elapsed between the B.S. degree and the first supervisory position, we found that most of these technical men reached a supervisory position relatively soon. Sixty-two per cent were supervisors within five years of the time their B.S. degrees were awarded. I am not sure just how we should interpret these figures. It may be that many of these men got into industrial research when the field was rapidly expanding. Some of them undoubtedly began their work in supervisory jobs, or perhaps went into a company as an assistant to someone and very shortly took over supervisory responsibilities. In my opinion, the young technical man starting out today would have considerably more difficulty than these men in reaching his first supervisory job.

The questionnaire also asked how soon after the B.S. degree the respondents were awarded their second supervisory jobs. The answers varied considerably, although the time of heaviest concentration was between eight and twelve years.

To a technical man, highly placed in his company, it may be that his second supervisory position does not now seem to him a matter of great importance. We therefore asked the respondents how many years it took them to reach a major position. We did not attempt to define what a major position was, but left its determination entirely up to the respondent. The replies show considerable variation. On an average, it took the men anywhere from five to fifteen years to reach such a position.

Another indication of recognition is salary, although the issue here is complicated by the fact that the men started in different periods, when widely different salary scales prevailed. We decided, therefore, not to ask them what their salaries were in terms of dollars, but how long it took them to double their starting salaries. This method of sampling also had its defects, but we believed it would at least be an improvement over actual salary figures. Many of the men doubled their starting salary relatively early. There is a concentration in the period from two to seven years.

It may be of some interest to compare these figures with those of the last salary survey of the American Chemical Society, which was taken in 1943 and covered approximately 20,000 chemists. It was found that the average chemist at that time took thirteen years to double his starting salary. The time required for the lowest member of the top 10 per cent of the chemists was nine years, a period still substantially longer than the average for all of the technical men in our survey.

We also asked our respondents to indicate how soon after their B.S. degrees they tripled their starting salaries. Here the time broadened out considerably, but most of the men had attained this level in five to twenty years. There was some concentration between eight and twelve years. The American Chemical Society survey indicated that the average chemist took twenty-seven years to triple his starting salary, and the man at the bottom of the top 10 per cent took fifteen years to triple his starting salary.

Carrying this kind of analysis still further, we asked how many years it took these men to quadruple their starting salaries. The answers varied widely, though there was some concentration between ten and fifteen years. One man said that he doubled his starting salary in six months, tripled it in nine months, and quadrupled it in a year. Reading his figures, we almost decided to abandon the survey and concentrate on finding out how he operated. The American Chemical Society figures showed that the average chemist never did quadruple his starting salary, and the man at the bottom of the top 10 per cent took 20 years. Here once again, you will note that the technical men in our survey are substantially ahead.

Frequently young technical men wish to know whether they should change jobs frequently, so as to have a broad and varied experience, or whether they should stay with one company, getting a concentrated experience. In our survey, we found that 40 per cent of the technical men had worked for only one company, 30 per cent had worked for only two companies, and the remainder had worked for three or more. The figures seem to indicate that moving from one company to another is not a prerequisite for success, at least for those men who eventually became heads of technical departments.

In an inquiry about patents we discovered that 50 per cent of these men had taken out from none to five patents and the other 50 per cent had taken out five patents or more. The conclusion seems to be that taking out a large number of patents is not a necessary prerequisite to success in industrial research.

Another question frequently asked is whether the publishing of technical articles advances a man in his career. We were surprised to discover that 15 per cent of the men in our survey had never published anything, and that a large number of them had published only one or two technical articles. A few of the men, however, had published a tremendous number of articles —one as many as 108.

We also found that 45 per cent had never published any semi-technical articles. It can hardly be said that this group writes articles just to get their names in the paper. There is, however, an increasing tendency for the leaders of industrial research as well as for industrial leaders generally to feel more and more responsibility to keep the public informed about the nature of the work which is going on. I should hazard the guess that if a similar survey is taken a few years from now, it will disclose a much larger per cent of the men engaged in writing occasional semi-technical articles.

We also asked how many books the men had written. Here the figure was very low. Apparently, the leaders in industrial research just do not have time for writing books.

Frequently the young technical man is told that he must learn to get up and talk, that making speeches can be a tremendous asset to him. In our survey we found it surprising that most of the men make only a few speeches—though a small minority make a tremendous number of talks. I would have expected to find more men engaged in this kind of activity than our figures indicate. We made a distinction in our question between speeches before technical societies and those before non-technical groups, but we found no significant differences in the figures for either type of speech.

It is interesting to note, however, that 50 per cent of the men had taken courses in public speaking, indicating that they felt seriously enough about speaking ability. In addition, 24 per cent of them indicated that they had found it necessary to take courses in business administration, and 20 per cent had taken courses in personnel management.

The men were asked what school subjects outside of professional courses they considered to be of the most value to them. It is interesting to observe that English was noted by twice as many people as any other one subject. Economics came next. Public speaking and psychology were both rather high on the list. Language, cultural subjects, and history were mentioned by a sizable number.

In addition, the men were asked to name the courses which they did not take but which would have been helpful. Business management was the course most frequently mentioned. Economics and public speaking rated high on this list, as did psychology. Thirteen of the men mentioned English in this connection. I find it difficult to believe that anyone could get through college without taking any English courses, so that presumably this meant additional courses.

We attempted to find out whether the technical men thought the school they attended was an important factor in their success. We asked them to rate their alma maters as among the top quarter, the second quarter, the third quarter, or the fourth quarter of existing institutions. I do not know whether the answers indicate excessive school spirit or not, but 95 per cent thought their school rated in the top quarter.

About 90 per cent of the men paid part or all of their school expenses. There was a sizable percentage, however, who paid no part of their school expenses. It is safe to say that earning your way through school is not necessary in order to get ahead in industrial research. A majority of the men participated in extracurricular activities during their college years, some, of course, much more than others. The indication seems to be that such activities show aggressiveness and breadth of interest.

We also questioned the men concerning their hobbies. I am not sure whether we can learn much from the answers, but it is interesting to note that photography is the most popular one. Close behind came golf, gardening, music, fishing, home workshops, woodworking, skiing, and then a miscellaneous variety. Only three people mentioned any interest in stamp collecting.

The young technical man is also frequently advised to enter technical societies and become an active participant in their activities. There was only one man who did not belong to at least one technical society. I do not know just what is the matter with him. A sizable percentage belong to as many as six or eight technical societies. On the the other hand, it is interesting to note that twenty-two of these men are not active participants in the technical organizations. Only a few are actually active in more than one or two.

About 40 per cent of the technical men belong to no civic or welfare organizations of any kind. Apparently far too few of them have much interest in the well-being of their neighbors. Something like 50 per cent of them belong to one or two organizations. About the same percentages are shown for membership in social clubs. I should like to make the point again that industrial leaders have only recently come to realize their responsibilities in connection with civic and welfare organizations. If a similar survey is taken a few years from now, I feel sure it will disclose a very different picture.

We hear a great deal of talk about how much hard work is required for success. We tried to find out just how hard these men work at company business outside of office hours. We gave them four possible answers: (1) habitually, (2) fairly often, (3) seldom, and (4) never. The most popular answer was "habitually" with "fairly often" close behind it. We apparently are justified in assuming that they put in a great deal of hard work. A couple of fellows admit that they do no outside work, but the majority do. The figures suggest why some of the men at the top of the heap get pretty impatient with the young technical men who come to work at 8:00 o'clock and quit at 4:30 and wonder every Christmas time why they didn't get a raise. It has been my own experience that the further men are up the line the harder they work. It is important to emphasize to the young technical man that he will probably not be able to do a good job if he works only eight hours a day.

We attempted to discover some of the generally valuable qualities for a young technical man to have. We did not indicate particular qualities, but asked the respondents to write in their own answers. One respondent said that the ability to "marry the boss's daughter" would be helpful and another declared that it was important to "select the proper parents." We had to do a bit of combining of approximately similar answers. The most usual reply was that the ability to get along with other people is essential. Not far behind was the willingness to work hard and the ability to express one's self. Personality might be combined with the ability to get along with others, but it was mentioned specifically by about 18 per cent. Good thinking and planning ability was mentioned by only 17 per cent, although certainly all would have agreed that this factor is important. There are other factors which probably most of the men simply took for granted but that only a few mentioned, such as fundamental honesty and a good technical background. The group seemed to feel strongly, however, that the ability to get along with other people is important.

In summarizing the conclusions to be drawn from the survey, I wish to emphasize one last time that the size of the sample was small and that any statistical comparison to large groups would be unfortunate. The fact that the people surveyed are leaders in the field of industrial research, however, does give the survey a certain significance. We drew the following general conclusions from the answers to our questions:

1. Hard work, including substantial amounts of time spent outside regularly scheduled hours, is characteristic of those who have succeeded in industrial research.

2. Moving around from one company to another has not appeared to be necessary to achieve success.

3. The present leaders of industrial research moved ahead fairly rapidly both in the achievement of supervisory responsibility and in the increase of their salaries; but on an average, it has taken the man to whom this survey was addressed about twenty-five years to reach his present position.

4. Most leaders of industrial research feel that the proper use of English, both written and oral, is extremely important for achieving success.

5. Development of personality and the ability to get along with others is an item of substantial importance in any successful technical man's career.

Training of Research Personnel in the Universities

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The part which has been assigned me in this Symposium on Cooperative Engineering Research is the "Training of Research Personnel in the Universities." In a way, I am somewhat miscast in the role of spokesman for the universities; although the subject of training research personnel is one with which I am vitally concerned, my experience has come from working in an industry-centered, cooperative educational venture. I suspect, however, that the objectives of a university research training program and the objectives of an educational program of the Institute of Paper Chemistry are much the same and, if this is the case, we share many problems.

What is this job that the universities are expected to do? It might seem rather simple—just to train sufficient men to meet the peak requirements and possessing at least the minimum specifications of industry—men who should speak and write the English language clearly and with understanding, men who are able to read a foreign language when necessity arises, men who are broad in their general training yet experts in their specialization, critical of their own work and the work of others, humble yet confident, possessing originality, enthusiasm, and energy, full of imagination and initiative, daring in concept yet sufficiently cautious in operation, with a working understanding of cost accounting, labor and management relations, psychology, statistics, engineering, and so forth. They should be acquainted with conventional laboratory techniques and aware of new ones, be at home sufficiently in the library to find their way through the literature of yesterday and today. They must be personable, show leadership ability, like to work with other people yet able to work alone, and most important of all—they should realize that formal academic training is only the beginning of their education; they must expect to continue their education for the rest of their working days. This is quite an order, and there are those who question the real significance of some of the specifications set up.

This breakdown of the research men industry would like to get from the universities should serve to show that the universities have a real job to do in training large numbers of men to fit industrial needs. It would not be quite so bad if all the men and women who were making themselves available for the training could demonstrate by some appropriate series of tests that they either had or could develop these desirable characteristics. Unfortunately, this is not always possible. Many of the universities where the largest numbers of men are trained for industrial research are public institutions and some of these find it difficult to deny admittance to applicants from their own states able to supply the appropriate diplomas and transcripts even though they lack the other qualifications. The private institutions might be expected to exercise somewhat more selection in the make-up of their student bodies, but effective mechanisms for sizing up the over-all qualifications of the applicants for their graduate schools are not yet fully developed. In addition, during recent years, many graduate schools have been forced to admit students of mediocre to average ability to serve as teaching assistants in the elementary courses of their under-graduate programs. The various methods of selection leave much to be desired.

In the eyes of industry just how well are we training our technical men for careers in research? A partial answer to this question may be found in the answers to a recent questionnaire which was sent to many technical leaders of the chemical industry by the Committee on Professional Training of the American Chemical Society. The report was published just two years ago. These leaders were asked to list both the weak and the strong points in the training. Although there was considerable variation in the answers depending on the experiences of the critics, certain points were frequently stressed in report after report. I shall try to classify them in order of their frequency or seeming importance.

The most common criticism was directed toward the ability of the technical men to master the English language. They seemed to be unable to express themselves briefly, clearly, grammatically, and to the point, and both written and oral reports were equally bad.

The second point frequently made was that the technical man was narrow in his scientific interests. If he was an organic chemist, he was just an organic chemist and unable to adjust himself to the problems that overflowed into adjoining disciplines. What is even worse, he might look upon himself as a carbohydrate chemist (or just a cellulose chemist). It has been said of him that he started to specialize too early and continued his specialization too long.

The third criticism was almost as common. The technical man was said to be lacking in his ability to think creatively. He seemed to do well what he was told to do but found it hard to go beyond that point. This criticism was expressed in a number of ways but it always boiled down to the above.

These criticisms in a way are criticisms of his technical know-how.

There were criticisms also of his attitudes. He was often accused of lacking humility, of expecting that industry owed him a living even before he started working, of distrusting the motives and ethics of industry. Some said he was a poor housekeeper in his laboratory and careless of his own safety and the safety of those working near him; others that he was unable to get along with labor or with management.

On the other side of the picture, the men who answered the questionnaire were frank to admit that the facts which the student had learned in school were well learned and the laboratory techniques taught were used capably and effectively.

All of us who have worked with young technical men can identify specific criticisms with specific co-workers, but it is the rare man who fits them generally. Such a man would not be long employed. These criticisms are valuable to all those who are concerned with the training program. They serve to establish, in a way, the general use requirement of the educational product. It is important that we be aware of the more important areas of failure and to do something to strengthen them or else develop new production flowsheets capable of yielding a better product than industry has specified.

Since many men and women engaged in industrial research, particularly the junior members of the group, generally ended their formal education with a B.S. or an M.S., it should be realized that the organized training program for this group was carried on in a college or in the undergraduate program of a university or technical school; their further education should be one of the opportunities and responsibilities of industry. These same schools serve in an even more important capacity, for they participate actively in the training of the doctors by laying the groundwork on which the graduate school builds.

I cannot forego this opportunity of paying homage to the many small colleges which have provided the primary stimuli responsible for starting so many research men on their careers in science. The Steelman Report memorialized a few of these schools; the more recent National Research Council report provided some basic figures. This report served to emphasize again the fact that good undergraduate preparation does not of necessity require four years spent in marble halls with starred men in the *American Men of Science*. Even the latest in scientific equipment and the most complete libraries are not essential for the production of leaders in science. The fact that the student has all these advantages in turn does not disqualify him for success. If we assume, just in order to argue better, that the winning of a Ph.D. is a measure of the preparation for research and attempt to determine from the figures in the N.R.C. report which schools sent the highest percentage of their arts and science graduates on to achieve the Ph.D., we find some surprising results. For lack of time, I have had to assume that the total number of such graduates between 1932-41 is represented with some accuracy by ten times the number graduating in 1938—any flaws in the assumption may change the order but not the general classification. Using the figures for the number of Ph.D's listed in the report and the number of B.S.'s and B.A.'s graduating, I estimated the percentage of those graduating who go on for Ph.D degrees. The schools ranking at the top, on this basis, were the California Institute of Technology, Reed, Kalamazoo, Nebraska Wesleyan, Antioch, Iowa Wesleyan, Oberlin, Hiram, Wabash, Monmouth, DePauw, Haverford, and Manchester. If we limit ourselves to chemistry, there are four schools in the top group—Monmouth, Hiram, Antioch, and Wabash—and right behind are Iowa Wesleyan, California Institute of Technology, Manchester, Central of Missouri, Kalamazoo, Emory, Mississippi, Hope, Reed, Oberlin, DePauw, Juniata, Carleton, Haverford, Beloit, etc. This list is not complete and only generally accurate, but it is given to illustrate the importance of the colleges (and of many small name ones) in our science training program. I should like to emphasize what a wonderful thing it would be if industry recognized teaching merit as well as research merit in awarding its financial grants. It is too bad some of the men and schools which have been responsible for the positions of our industrial science today cannot receive their rewards on earth. We have medals for everything but this.

What is the secret behind the achievements of some of these schools? It is not necessarily buildings, equipment, and endowment. One school which I have listed quite high confesses to having an endowment of $638,642, a budget of $450,000, and a library in all fields of 32,600 volumes. The total value of buildings, grounds, and equipment comes to $645,000 and it has two men teaching chemistry and one physics. Another coeducational school—this one with an endowment of $900,000 and buildings, grounds, and equipment valued at $632,000–sent 5.1 of every hundred graduates on to the Ph.D. in science. Why?

It is certainly not the research activity of the faculty; I doubt whether a research paper has come from either school in all the years. It is not erudition nor an unusual knowledge of chemistry.

I have visited many of these schools and generally there was a *faculty man* who seemed to have certain qualities. He was genuinely interested in the students, had a sense of humor and not too great regard for his own importance, insistent on his students making the most of their opportunities, and appreciating the qualities of both the straight A's and straight C's. Many of these men received their own training back in the days when the university graduate schools were relatively small and from men of similar broad interests. It should be viewed with regret, with some concern, that the circle has been rapidly cut into by death or retirement. It will be interesting to see whether the young research-conscious instructors who replace them will be able to do as well. At least they will be faced with a real challenge. It seems too bad that these real teachers will not have more of a chance to pass on to the new recruits and to some of the least inspiring teachers in our graduate schools the virtues they have distilled during their fruitful days—at least to give them some advice. Too many of our young Ph.D's start in their teaching with neither training nor experience and the faults they develop in those early years are compounded to the point where it would take an earthquake to shake them out of their patterns. The faults that industry finds in its research men can be matched in the field of education. And it is especially true that there are so many exceptions that they prove the rule.

In the competition for high-grade technical men between the university and industry, how can we retain as teachers those men of personality, understanding, warmth, intellectual genius who are leaving our universities for industrial work? Their departure cuts deeply at the roots which nourish the plant. Or if they stay in teaching, how can we insure that they will not be so heavily loaded by consulting appointments, government contracts, industrial projects, and the like that their days of creative educational leadership are not cut into or taken away completely? This is one of the real problems of today. The process of survival of the fittest works to the advantage of industry and the disadvantage of education.

Assuming that something can be done about the teachers, how can we raise the mean level of the graduate students? One way would be to eliminate the unfit. That would help by making higher standards possible (and this is important), but it would not increase the numbers of the fit. Another way to eliminate the unfit would be to persuade some of the able seniors going into industry to continue with graduate work. This would require financial help in many cases or a process of persuasion by the graduate schools that four years in industry is *not* the equivalent of four years in graduate school, and then make it stick by improving the four years in school. This is quite an undertaking, as we know only too well. In some schools a vital interest in the future of the student is lacking and the only one with a positive program to suggest to the student is the industrial representative and he (as a group) becomes the elder brother, father confessor, and general adviser of the student, taking the function which should be operated by the faculty or administration of the school. What can be done to meet the justifiable criticisms (and these are justifiable) of the graduates of our colleges and universities?

The first criticism had to do with the inability of the research man to speak clearly or write well. This is one of the hardest to handle, for the responsibility for the situation can be assessed against all the earlier training of the student and any changing of this process will be time-consuming. There are some things we can do, however. The communication habits of our young people are only in part the fruits of their earlier courses in language. What would happen if all the instructors the culprit had as an undergraduate and as a graduate were to refuse to pass him on any work of inferior quality with regard to form as well as to content? This is done by some instructors in engineering, and it often seems that the work of these engineers surpasses the work of many of the liberal arts chemists in the field of self-expression. We have on the staff of the Institute of Paper Chemistry one man who is an expert in the field of corrective and correct speech and another man who is one of the outstanding authorities in the country as a technical editor. The services of both men are called upon constantly in our work with our students, and we think it has paid real dividends. This may be difficult to achieve in larger graduate schools.

The second criticism related to the narrowness of training. This can be corrected, if it is important, by changing the curriculum and degree requirements. For us it is important, and our graduates receive instruction in the fields of physics and biology in addition to chemistry; the integration of the work is achieved by handling many of our more advanced courses as seminars with intergroup direction. The extent to which this is desirable would appear to be governed by the situation. Care must be taken not to spread too thinly.

The criticism with reference to the lack of better creative thinking deals with a point we have been studying for some time. Two years ago we changed our curriculum so that time was provided for a program best described as "preparation for research." A series of problems are assigned one at a time to the individual students, each one representing some actual question within our industry. The student is expected to study the background and outline an approach which could reasonably be accomplished within the limits of time or other conditions imposed. He writes up the program as a formal report, presents this to a faculty committee, and defends his proposal orally before the committee. Seminars are held during the early part of the period on the tools for research—patents, statistics, instrumentation, etc.–and on the attitudes of the research man in the fields of ethics, personnel, labor and management, etc.

Criticisms with reference to attitudes are more difficult to deal with directly. Here an honest, frank, and effective counseling service can be of some assistance. In our case, the office handling the testing program handles the counseling program and, wherever possible, we attempt to point out to the students at the beginning of their course the indications of the testing program with reference to their personality needs.

There are many other points that might be raised in connection with the subject. For example, the research attitude can be developed early in the undergraduate course by utilizing the laboratory courses for the purpose. Instead of a detailed outline of a laboratory preparation in organic chemistry, the student might be one of a research group (the class or section) to study the variables in an organic reaction and their influence on the main reaction and on side reactions. But time does not permit more than this very sketchy study of an extremely important question.

I should like to point out in closing that there are only a limited number of top-level people available each year for graduate work in science and for positions in industry; during the past decade the demand has greatly exceeded the supply. It seems necessary if we are to meet the needs that such people as are available be used to the best advantage.

In the first place, we should make sure, as far as possible, that young people of high scientific aptitude be trained for science. Possibly we should start looking for them during their high school years. Several programs are functioning in this direction—the Westinghouse Science Talent Search, the Junior Academies of Science, etc. Superior students needing financial help for college or graduate training should have the opportunity to work for this support.

The superior student does not always make the best research worker. Conversely much good research is accomplished by students of lesser ability, measured by psychological tests or by grades. Possibly we should pay more attention to the training of these B and C students than we do.

Many of the best men in the industrial research laboratories would be better men if they could learn to share their work with subordinates. As an illustration, I know a number of fine research men who spend quantities of time doing a routine job of glass blowing where the work could more profitably be assigned to a professional glass blower. Others do routine laboratory manipulations which might be handled just as well by laboratory assistants. Possibly in our educational program there might be a place for consideration of such items as program planning, time assignment, and the like.

Finally, it sometimes seems as though industry holds the management qualities of an individual in higher esteem than his research qualities. At least, the ultimate in financial recognition is generally assigned to management positions, and fine research men are transferred from the field of scientific activity to management in order to justify the necessary financial reward. It would seem as though the scientist should be paid for his scientific achievements and be left where he can be productive in the field for which he was trained.

I should like to close on the note that our colleges and universities have done a magnificent job of training research men for industry. The predominant position of the American chemical industry bears testimony to this. We can do a still better job, and the remarks in this paper are directed toward that end.

The Engineering Experiment Station of the University of Minnesota was established by an act of the Board of Regents on December 13, 1921.

The purpose of the Station is to advance research and graduate study in the Institute of Technology, to conduct scientific and industrial investigations, and to cooperate with governmental bodies, technical societies, associations, industries, or public utilities in the solution of technical problems. The results of scientific investigations will be published in the form of bulletins and technical papers. Information which is of general interest and yet not the result of original research may be distributed in the form of circulars.

For copies of publications or other information concerning the work of the Station address the Director of the Engineering Experiment Station.

Bulletins

*1. The Use of Marl in Road Construction, by Charles H. Dow. viii + 67 pages, 10 plates, 61 illustrations. 1923.

*2. The Manufacture of Portland Cement from Marl, by Raymond E. Kirk. viii + 52 pages, 1 plate, 9 illustrations. 1923.

*3. Transmission of Heat through Building Materials, by Frank B. Rowley. viii + 74 pages, 46 illustrations. 1923. (See Bulletin No. 12.)

*4. The Manufacture of Portland Cement from Marl, by Raymond E. Kirk. Revised edition. x + 98 pages, 3 plates, 24 illustrations. 1926.

*5. Turns and Phases in Squirrel Cage Windings, by George F. Corcoran and Henry R. Reed. iv + 45 pages, 15 illustrations, 9 oscillograms. 1927.

*6. Integral Waterproofing Compounds for Concrete, by M. B. Lagaard. vi + 25 pages, 12 illustrations. 1927.

*7. Manifold Phenomena in Internal Combustion Engines, by Kalman J. DeJuhasz. vi + 35 pages, 15 plates, 10 illustrations. 1931.

*8. Heat Transmission through Building Materials, by Frank B. Rowley and Axel B. Algren. viii + 106 pages, 63 illustrations. 1932. (See Bulletin No. 12.)

*9. Influence Lines for Arches, with Tables, by Walter J. Grabner and Joseph A. Wise. iv + 30 pages, 5 plates, 12 diagrams. 1933.

*10. An Investigation of Motor Oils, by Burton J. Robertson. vi + 47 pages, 4 illustrations. 1935.

*11. Motor Oils for Winter Use, by Burton J. Robertson. vi + 29 pages, 1 chart. 1936.

12. Thermal Conductivity of Building Materials, by Frank B. Rowley and Axel B. Algren. x + 134 pages, 109 illustrations. 1937. $1.50. (Purchased through University Press.)

*13. An Investigation of Motor Gasolines, by Burton J. Robertson. vi + 45 pages, 5 plates, 5 illustrations. 1939.

*14. Square Sections of Reinforced Concrete under Thrust and Nonsymmetrical Bending, by Paul Andersen. vi + 42 pages, 8 figures, 23 diagrams. 1939.

*15. Laboratory Studies of Asphalt Cements, by Fred C. Lang and T. W. Thomas. x + 96 pages, 43 illustrations. 1939.

16. Factors Affecting the Performance and Rating of Air Filters, by Frank B. Rowley and Richard C. Jordan. viii + 54 pages, 21 illustrations. 1939.

*17. Methods of Moisture Control and Their Application to Building Construction, by Frank B. Rowley, Axel B. Algren, and Clarence E. Lund. iv + 57 pages, 26 illustrations. 1940.

*18. Condensation of Moisture and Its Relation to Building Construction and Operation, by Frank B. Rowley, Axel B. Algren, and Clarence E. Lund. vi + 69 pages, 28 illustrations. 1941.

19. Pulp, Paper, and Insulation Mill Waste Analysis, by Frank B. Rowley, Richard C. Jordan, Reuben M. Olson, and Richard F. Huettl. vi + 55 pages, 34 illustrations. 1942.

20. Conservation of Fuel, by Frank B. Rowley, Richard C. Jordan, and Clarence E. Lund. vi + 61 pages, 22 illustrations, 17 tables. 1943.

21. Aids to Technical Writing, by R. C. Jordan and M. J. Edwards. viii + 112 pages, 60 illustrations, 13 tables. May, 1944.

*22. Vapor Transmission Analysis of Structural Insulating Board, by F. B. Rowley and C. E. Lund. vi + 71 pages, 24 illustrations, 16 tables. October, 1944.

23. Economics of Insulation, by F. B. Rowley and R. C. Jordan. v + 69 pages, 17 illustrations, 7 tables. May, 1945.

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24. Factors Affecting Heat Transmission through Insulated Walls, by F. B. Rowley and C. E. Lund. iv + 25 pages, 8 illustrations, 8 tables. April, 1946.
25. Vapor Resistant Coatings for Structural Insulating Board, by F. B. Rowley, M. H. LaJoy, and E. T. Erickson. vi + 31 pages, 9 illustrations, 10 tables. September, 1946.
26. Moisture and Temperature Control in Buildings Utilizing Structural Insulating Board, by Frank B. Rowley, Millard H. LaJoy, and Einar T. Erickson. vi + 38 pages, 16 illustrations, 8 tables. July, 1947.
27. Water Permeability of Structural Clay Tile Facing Walls, by J. A. Wise. iv + 32 pages, 26 illustrations, 4 tables. August, 1948.
28. Thermal Properties of Soils, by Miles S. Kersten. xiv + 227 pages, 138 figures, 15 tables, 5 plates. June, 1949.

Technical Papers

*1. Condensation within Walls, by F. B. Rowley, A. B. Algren, and C. E. Lund. 12 pages. January, 1938.
*2. The Variation in the High-Frequency Resistance and Permeability of Ferromagnetic Materials Due to a Superimposed Magnetic Field, by James S. Webb. 9 pages. April, 1938.
*3. Air Filter Performance as Affected by Kind of Dust, Rate of Dust Feed, and Air Velocity through Filter, by F. B. Rowley and R. C. Jordan. 10 pages. June, 1938.
*4. "Transverse" Acoustic Waves in Rigid Tubes, by Henry E. Hartig and Carl E. Swanson. 9 pages. October, 1938.
*5. Condensation of Moisture and Its Relation to Building Construction and Operation, by F. B. Rowley, A. B. Algren, and C. E. Lund. 9 pages. January, 1939.
*6. Air Filter Performance as Affected by Low Rate of Dust Feed, Various Types of Carbon, and Dust Particle Size and Density, by Frank B. Rowley and Richard C. Jordan. 11 pages. March, 1939.
*7. Rapid Temperature Measurements of Cast Iron with an Immersion Thermocouple, by Fulton Holtby. 19 pages. May, 1939.
*8. The Determination of the Currie Point Temperature by the High Frequency Resistance Method, with J. M. Bryant and J. S. Webb. 2 pages. February, 1939.
*9. A Theory Covering the Transfer of Vapor through Materials, by Frank B. Rowley. 5 pages. June, 1939.
10. Effect of Weight of Tampers and Number of Tamps on the Flexural Strength of Concrete Silo Staves, by C. A. Hughes, Dalton G. Miller, and Philip W. Manson. 11 pages. September, 1939.
*11. Measurement of Very Short Time Lags, by J. M. Bryant and M. Newman. 10 pages. September, 1939.
12. Electronic Measurements of Surge-Crest Voltages, by J. M. Bryant and M. Newman. 11 pages. September, 1939.
*13. Standard Air Filter Test Dust, by F. B. Rowley and R. C. Jordan. 6 pages. October, 1939.
14. Improvement in Radio Sounding Balloons; a Short Cycle Radiosonde, by J. Piccard and H. Larsen. 4 pages. November, 1939.
*15. A Graphical Method of Analyzing Eccentrically Loaded Concrete Sections, by Paul Andersen. 3 pages. January, 1940.
*16. The Effect of Lint on Air Filter Performance, by F. B. Rowley and R. C. Jordan. 7 pages. January, 1940.
17. Air Density Tables, by C. T. Boehnlein. 107 mimeographed pages. April, 1940.
18. Power and Velocity Developed in Manual Work, by C. A. Koepke and L. S. Whitson. 7 pages. May, 1940.
*19. Permeability, Acid, and Absorption Tests of Mortars Used in Dry Tamped Silo Staves, by C. A. Hughes. 26 pages. June, 1940.
20. Supercharging a Stock Engine, by B. J. Robertson. 2 pages. March, 1940.
*21. A Comparison of the Weight, Particle Count, and Discoloration Methods of Testing Air Filters, by F. B. Rowley and R. C. Jordan. 10 pages. January, 1941.
22. Simplifying Hypodermic Injections, by Thelma Dodds, Lucile Petry, and C. A. Koepke. 10 pages. December, 1940.
23. The Effects of Insulation, Weather Stripping, and Fan Operation on Air Filtration, by F. B. Rowley and R. C. Jordan. 5 pages. January, 1941.

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24. The "Plug" Method for Obtaining the Compressive Elastic Properties of Thin-Walled Sections, by Howard W. Barlow, Henry S. Stillwell, and Ho-Shen Lu. 6 pages. January, 1941.
*25. Not Published.
26. Predicting Dust Concentrations, by Frank B. Rowley and Richard C. Jordan. (Four Parts.) 14 pages. January, 1942.
*27. Developments in High-Speed Cathode Ray Oscillography, by J. M. Bryant and M. Newman. 8 pages. March, 1942.
28. Fuse Failures on Rural Lines Due to Lightning, by J. M. Bryant, L. C. Caverley, M. Newman, and J. H. Wilcox. 16 pages. April, 1941.
29. The Resistance to Combined Flexure and Compression of Square Concrete Sections, by Paul Andersen. 27 pages. July, 1941.
*30. Economical Air Velocities for Mechanical Air Filtration, by Frank B. Rowley and Richard C. Jordan. 6 pages. July, 1941.
31. Control Point Computed for Cracking Furnace, by R. E. Summers. 2 pages. July, 1941.
32. Construction and Operaton of a 15-Inch Cupola, by Fulton Holtby. 4 pages. August, 1941.
33. What CO_2 Is Best?, by R. E. Summers. 4 pages. August, 1941.
34. Rapid Temperature Measurements of Molten Iron and Steel with an Immersion Thermocouple, by Fulton Holtby. 13 pages. November, 1941.
35. Comparative Performance of Four Different Types of Dust Counters, by F. B. Rowley and R. C. Jordan. 26 pages. November, 1941.
36. Design Diagrams for Square Concrete Columns Eccentrically Loaded in Two Directions, by Paul Andersen. 13 pages. December, 1941.
37. On Propeller-Tip Interference Due to the Proximity of a Fuselage, by A. Gail and Ho-Shen Lu. 6 pages. December, 1941.
38. Lightning Discharge Investigation—I, by J. M. Bryant and M. Newman. 10 pages. April, 1942.
39. The Effect of Fine Aggregate on the Durability of Mortars, by C. A. Hughes and K. Anderson. 16 pages. March, 1942.
40. Effect of Surface Resistance on Thermal Conductivity by the Hot Plate Method, by Robert Lander. 13 pages. May, 1942.
41. Overloading of Viscous Air Filters During Accelerated Test, by Frank B. Rowley and R. C. Jordan. 10 pages. June, 1942.
*42. Abnormal Currents in Distribution Transformers Due to Lightning, by J. M. Bryant and M. Newman. 5 pages. September, 1942.
43. Repeated Load Test in Highway Subgrade Soils and Bases, by Miles Kersten. 20 pages. July, 1943.
44. Heat Transmission through Insulation as Affected by Orientation of Wall, by Frank B. Rowley and C. E. Lund. 4 pages. July, 1943.
45. Design and Performance Characteristics of a New Type Adhesive Impingement Dust Counter, by Frank B. Rowley and R. C. Jordan. September, 1943.
46. Discoloration Method of Rating Air Filter, by F. B. Rowley and R. C. Jordan. 10 pages. September, 1943.
47. A New Type Adhesive Impingement Dust Counter, by Frank B. Rowley and R. C. Jordan. 10 pages. April, 1944.
48. Valve Guide Leakage in an Automotive Engine, by Myrl A. Lindeman and B. J. Robertson. 22 pages. May, 1944.
49. Factors Affecting Thermal Conductivity, by Robert Lander. 34 pages. July, 1944.
50. Automotive Engine Performance and Various Compression Ratios and Fuels, by Myrl Lindeman and Thomas Murphy. 29 pages. August, 1944.
51. Water Vapor Transfer from a Gas-Fired Furnace Installation, by C. E. Lund and M. H. LaJoy. 19 pages. December, 1944.
52. Carbon Dioxide Variation in a Vented Stack, by Millard H. LaJoy. 27 pages. May, 1945.
53. Thermal Conductivity of Insulating Material at Low Mean Temperatures, by F. B. Rowley, R. C. Jordan, and R. M. Lander. 6 pages. December, 1945.
54. Thermal Short Circuits in a Metal Wall, by R. M. Olson. 21 pages. May, 1946.
55. A Method for Measuring Tool Tip Temperatures, by B. A. Crowder. 18 pages. June, 1946.

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56. Calculation of Bearing Capacities of Footings by Circular Arcs, by Paul Andersen. 3 pages. June, 1946.
*57. Progress Report of Subcommittee on Methods of Measuring Strength of Subgrade Soil. Review of Methods of Design of Flexible Pavements, by Miles S. Kersten. 12 pages. April, 1947.
58. Subgrade Moisture Conditions beneath Airport Pavements, by Miles S. Kersten. 15 pages. April, 1947.
*59. Low Mean Temperature Thermal Conductivity Studies, by Frank B. Rowley, Richard C. Jordan, and Robert M. Lander. 6 pages. January, 1947.
60. Comfort Reactions of 275 Workmen during Occupancy of Air-Conditioned Offices, by F. B. Rowley, R. C. Jordan, and W. E. Snyder. 4 pages. June, 1947.
*61. Ground Temperature Distribution with a Floor Panel Heating System, by A. B. Algren. 9 pages. May, 1948.
62. A Statistical Analysis of Water Works Data for 1945, by G. J. Schroepfer, A. S. Johnson, H. F. Seidel, and M. B. Al-Hakim. 32 pages. October, 1948.
63. Theory and Use of Capillary Tube Expansion Device, by M. M. Bolstad and R. C. Jordan. 6 pages. December, 1948.
64. Heating Panel Time Response Study, by A. B. Algren and Ben Ciscel. 4 pages. March, 1949.
65. Impact Strength Testing Machine, by F. B. Rowley and M. H. LaJoy. 16 pages. June, 1949.
66. Ground Temperatures as Affected by Weather Conditions, by A. B. Algren. 6 pages. June, 1949.
67. Theory and Use of the Capillary Tube Expansion Device. Part II, Nonadiabetic Flow, by M. M. Bolstad and R. C. Jordan. 7 pages. June, 1949.
68. Thermal Conductivity of Soils, by M. S. Kersten. July, 1949.
69. Specific Heat Tests on Soils, by M. S. Kersten. 5 pages. May, 1949.

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*1. List of Publications for Vocational Guidance in Engineering, Architecture, and Chemistry, by Alexander S. Levens. 8 pages. 1932.
2. Wartime Refrigeration Training at the University of Minnesota, by R. C. Jordan and C. E. Lund. 3 pages. September, 1944.
3. Five-Year Mechanical Engineering Curriculum, by R. C. Jordan. 5 pages. January, 1947.

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