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SUPPORT OF SMALL RESEARCH PROJECTS IN MATERIALS SCIENCES AT UNI--ETC(U)
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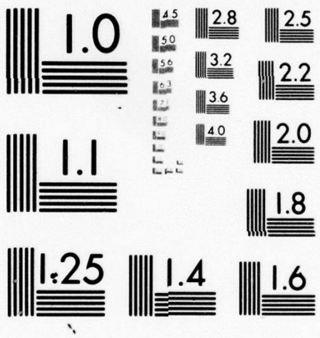

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SUPPORT OF SMALL RESEARCH PROJECTS IN MATERIALS SCIENCES AT UNIVERSITIES.

(10) B. N. Gregory

(11) 1979

(12) 57p.

Panel on Support of Small Research Projects
in Materials Sciences at Universities
Solid State Sciences Committee
Assembly of Mathematical and Physical Sciences
National Research Council

(15) F49620-77-C-0135

(16) 2306 (17) A1

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1979

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REPORT DOCUMENTATION PAGE

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BEFORE COMPLETING FORM

1. REPORT NUMBER
AFOSR-TR- 79-0838

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Support of Small Research Projects in Materials Sciences at Universities

5. TYPE OF REPORT & PERIOD COVERED
Final
1 Aug 1977 - 20 Jun 1979

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
B. N. Gregory

8. CONTRACT OR GRANT NUMBER(s)
F49620-77-C-0135

9. PERFORMING ORGANIZATION NAME AND ADDRESS
National Academy of Sciences
National Research Council
Assembly of Mathematical and Physical Sciences
2101 Constitution Ave Washington, DC 20418

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
61102F, 2306/A1

11. CONTROLLING OFFICE NAME AND ADDRESS
AFOSR/NE
Bolling AFB, DC 20332

12. REPORT DATE
1979

13. NUMBER OF PAGES
-56-

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A major question facing the nation's scienfitic community and makers of science policy is how to maintain the quality of our scientific programs in the face of shrinking resources, either from budgetary cuts or increasingly sophisticated and costly research needs.

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In pursuing this study, the Panel was asked to undertake the following general tasks:

(1) To assess the role of small research projects in relation to regional and national needs;

(2) To determine the factors affecting the production of high-quality research in small projects; and

(3) To recommend constructive modes of research organization and required support.

A

PANEL ON SUPPORT OF SMALL RESEARCH PROJECTS IN MATERIALS SCIENCES AT UNIVERSITIES

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PREFACE

BACKGROUND

A major question facing the nation's scientific community and makers of science policy is how to maintain the quality of our scientific programs in the face of shrinking resources, either from budgetary cuts or increasingly sophisticated and costly research needs.

To explore this situation the Solid State Sciences Committee of the National Research Council's Assembly of Mathematical and Physical Sciences initiated a series of meetings to inquire into the manner in which research is supported in the solid-state and materials sciences.

The first meeting occurred in July 1976, at the Argonne National Laboratory, where the need for large expensive research facilities for studying materials problems was discussed. It became clear at that time that the cost of constructing and operating large facilities has an impact on other programs. Therefore, a subsequent meeting was held at the National Academy of Sciences on December 16-17, 1976, to examine the changing research patterns in the science of materials at universities. From the discussion at this meeting, involving both practitioners and supporters of materials science, came a plan to study the factors that are necessary to establish guidelines for operating and supporting small research programs in the materials sciences at universities. The Department of Defense, in particular, through the Air Force Office of Scientific Research (AFOSR) and the Office of Naval Research (ONR), expressed its interest in the research generated by small research groups outside the major centers, and therefore its interest in understanding the special needs and circumstances of this community.

The AFOSR and ONR agreed to support an assessment of small research projects in solid-state and materials sciences at universities to be carried out by an *ad hoc* panel organized by the Solid State Sciences Committee as one element in the Committee's effort to develop a better overall understanding of the health and progress of the solid-state and materials-sciences research enterprise. The intent of the study was to evaluate scientific and technological opportunities, the patterns of support, and the factors that distinguish small research projects and affect their stability and viability.

OBJECTIVES

The general objectives of the study are to review and enlarge understanding of the role of small research projects in the U.S. solid-state sciences effort, to determine factors that lead to meaningful research projects, and to establish some guidelines to aid those who must make decisions concerning the allocation of resources. The intended audience includes both universities and funding agencies.

In pursuing this study, the Panel was asked to undertake the following general tasks:

1. To assess the role of small research projects in relation to regional and national needs;
2. To determine the factors affecting the production of high-quality research in small projects;
3. To recommend constructive modes of research organization and required support.

ORGANIZATION

The Panel was made up of individuals of diverse backgrounds in solid-state and materials sciences and included representation from both large and small universities and from industrial, nonprofit, and national laboratories, as well as a number of members with experience in the management of personnel and financial resources.

ASSUMPTIONS

In approaching their assigned task, the Panel members were in basic agreement on a number of points.

The Panel members agreed that in the localities and regions in which universities are situated, they have an important and complex role to play, involving education, cultural values, the availability of scholars and experts for consultation, and a host of other factors.

Next, the performance of high-quality research is a powerful force toward excellence in the science-based components of a university.

Further, the value of research has several dimensions. The most important aspects are the quality of the work and its cost effectiveness. In addition, the results of university research go beyond the scientific output to include such beneficial factors as the education of new generations of scientists.

Finally, the Panel perceives a national tendency to concentrate research on recognized problems, a tendency that naturally focuses on the relatively near future and that, carried too far, could be detrimental to the nation's long-range scientific and technological future. The advancement of science, as distinct from the creation of new scientific results in the service of technological development, is uneven. Certain fields move rapidly for a while and then slow down. This growth responds in part to forces from within the science, depending on what is ready to be done as well as on what needs to be done. Effectiveness in the pursuit of science requires that capable scientists have the opportunity to explore and pursue freely questions arising from this inner scientific logic. Too much emphasis on directed or group research, as compared with individual efforts, could restrict this exploration of scientifically significant problems and stunt future scientific and technical progress.

ACKNOWLEDGMENTS

The Panel would like to express its deep appreciation of those whose careful responses to its questionnaires (see Appendix A) have been so valuable. It also expresses thanks to William Sibley, Oklahoma State University, for his encouragement and guidance, and to Elias Burstein, University of Pennsylvania, Dean Eastman, IBM Corporation, and Robb M. Thomson, National Bureau of Standards. The Panel is grateful to the AFOSR and ONR for financial support (Contract No. F49620-77-C-0135), and to Larry Kravitz of AFOSR, in particular, for his interest and encouragement. The staff of the National Research Council, Charles K. Reed, Bruce N. Gregory, and Hope Bell, have been most helpful in the conduct of meetings and the preparation of this report.

CONTENTS

1

INTRODUCTION

The development of technology has paralleled man's ability to control and manipulate the materials he uses. In many fields, technology is limited by the inability to control the properties of these materials. Examples include efforts to increase the efficiency of fossil-fuel utilization through the increased heat-engine temperatures promised by advanced gas turbines and MHD generators or through electrochemical devices such as fuel cells and batteries. On the other hand, the fruits of recent work in preparing and controlling semiconducting properties on a microscale are seen in the proliferation of microprocessors and computing devices—a proliferation profoundly changing the course of our lives.

The range of materials and their properties utilized by modern technology is extremely broad and includes metals, inorganics, and organics; structures range from single crystals through polycrystals to glasses, and the combinations of these represented by polymers, by ceramics formed from partially crystallized glasses, and by composites.

Intrinsic properties of the bulk material are obviously important, but so are properties controlled by impurities and crystal defects, as well as properties of interfaces and surfaces. Temperatures of interest go from the lowest attainable to thousands of degrees Celsius. The materials are used for their optical, magnetic, and mechanical properties; their ability to permit or prevent the flow of electrons, atoms, and ions; their chemical durability in the presence of hostile environments; and their reactivity or ability to mediate chemical reactions.

The study of all these topics, and many more, we call materials science. Materials science is concerned with understanding in as basic physical and chemical terms as possible the properties and behavior of materials in all of their variety and manifestations, and with the specification of methods of preparation and fabrication to achieve desired combinations of properties. The study involves abstruse formulations of quantum mechanics, complex application of computer calculations, painstaking care in control over experimental conditions, and the highest attainable resolution in measurement and sensitivity in detection.

This catalog of the ramifications of materials science is only a small part of the actual picture, but it may show why over the years materials science in universities has been pursued in physics, chemistry, and electrical, mechanical, ceramic, metallurgical, chemical, and mining engineering departments, and why in recent years these have been joined by materials-science and materials-engineering departments. It is understandable, too, why no one department is able to encompass all the facets, and why those who work in materials science have been active in the development of interdisciplinary approaches to its problems. The divisions among disciplines and between science and engineering have become blurred as the complex nature of the subject has increasingly required contributions from many traditionally separate fields.

Along with this unfolding diversity has come an increasing sophistication and complexity in research tools and methods. The use of large machines, such as nuclear reactors and synchrotrons, and on a lesser scale high-voltage electron microscopes and molecular-beam epitaxial equipment, is becoming commonplace in some subfields of materials science. At the same time, in other such subfields important work continues to be done on simpler equipment. For instance, with some exceptions, significant diffusion and other transport measurements can still be carried out with the equipment of a decade or more ago, and as another instance, the miniaturization of computers has brought many complex theoretical problems within the range of relatively small, local equipment.

Materials science is therefore a highly diverse and interdisciplinary field characterized by a trend toward large facilities, although many significant materials research problems are appropriate for small research projects. The small research project, the effort of a single principal investigator and his students, or at most of no more than several such groups, is therefore still an important element in materials science. These small projects constitute at least half of the total materials-science effort at universities. They are the means for training graduate students in universities other than the few with major materials-research laboratories. They are also an important means by which independent researchers can develop their creativity and make the special contributions required by the diversity of the field, and they are even an important source of support for many who are also engaged at the same time in larger, more highly structured programs.

In this study we address some of the problems faced by small materials-science programs at universities and by the funding agencies that support them in maintaining research quality while coping with the interdisciplinary nature of the field and the growing trend toward use of expensive equipment. These considerations led us to examine various modes of research organization and support, as well as important factors influencing the effectiveness of small research projects. This report presents the Panel's findings and sets forth several recommendations that we hope can assist universities and funding agencies to better preserve and benefit from the values we find in small materials-science research projects.

2

CONCLUSIONS AND RECOMMENDATIONS

The major conclusions and recommendations of this report are based on the experience of the Panel members and supported by the results of surveys made in the course of this study. The surveys (discussed in detail in Appendixes B and C) involved only a limited sample, insufficient for detailed statistical analyses, and the response rates were low. Nonetheless, these surveys provided a number of important ideas and indications of the needs and problems of small materials research projects in universities. The conclusions and recommendations emphasize two major themes. One concerns the value of diversity in materials science, the importance of small research programs in maintaining that diversity, and the ways to support individual research grants on which small programs are necessarily based. The other theme is the shared responsibility, among universities, funding agencies, and investigators, for the health of small-project materials science. In the past there has been too much reliance on direct federal grants to support these research activities, and the role of the universities needs to be emphasized. At the same time, perhaps more local and regional support could be found, but we do not address this point specifically in these conclusions and recommendations. Although some of our recommendations may involve additional funds, our intention is to improve the efficiency of the work rather than to increase program size.

Individual grants provide support for able researchers at small institutions as well as for independent scientists at larger universities. The "small science" character of the materials sciences means that an imaginative individual can make important research contributions, thus the individual research grant is vital to continued progress in the materials sciences, and this mode of support should be continued.

By its nature materials science is complex, requiring efforts from a wide variety of disciplines in a variety of institutional arrangements. Diversity of approach is essential in the support of materials science. *The present diversity of research funding, with both individual and group (collaborative, hierarchical, and portfolio) modes of support, is highly desirable.*

There are also many advantages to team organization of research, especially the "alliance of equals" (a collaborative effort of individual principal investigators). This form of research is an intermediate mode between individual and group support. It is widely practiced and is generally viewed with favor by scientists and department heads (see Appendixes B and C). *Funding agencies should facilitate and be prepared to evaluate joint proposals from several principal investigators who request support for interdisciplinary research efforts.*

Individual research grants are subject to several burdens not shared with group-funded arrangements. They are more vulnerable to the lack of long-term stability. This is particularly true for postdoctoral contracts and even for support of graduate students, whose terms run typically from three to four years. Another unproductive burden is the frequency of proposal writing, which, while it can be shared in the group mode, falls entirely on the single principal investigator of an individual grant. To provide increased stability and to reduce the disproportionate administrative burdens of small research efforts, *we recommend that grant periods for small research projects be effective for at least three years.*

Regional and national research centers are becoming an important part of the materials-science scene and are viewed as valuable resources by both departmental heads and principal investigators (see Appendixes B and C). The use of specialized facilities, for example, x-ray sources, nuclear-magnetic-resonance spectrometers, and high-voltage electron microscopes, is often essential to progress in a particular research project. In the past these needs have been met, if at all, by informal collaboration between individual scientists needing such facilities and those having access to these tools. Recently, a number of regional centers have been established and structured to accommodate these needs. However, in many instances the regional center format may not be appropriate, research objectives being locally attainable in a fashion more compatible with university responsibilities. *Therefore, the impact of regional centers on small materials-science research projects should be carefully evaluated. Establishment of such centers should not preclude the provision for individual research projects, including necessary equipment.*

Insufficient provision has been made in the past for the maintenance of experimental equipment, as well as for the replacement of obsolete instruments. Both problems are especially severe for smaller research projects, because the costs represent a disproportionately large fraction of the entire grant. These problems can only become more serious as instrumentation becomes more sophisticated and expensive. *Support for the acquisition, updating, and maintenance of experimental equipment should be increased significantly. The universities, funding agencies, and investigators share responsibility for the maintenance of equipment, and explicit planning for the provision of such funds should be made at the time of acquisition.*

A first-class research effort in the materials sciences, in common with other disciplines, requires that the university provide an environment conducive to excellent work. Important elements include supporting services and facilities and ready access to scientific communication. Our survey indicates that many facilities and services provided by the universities, including libraries, computers, laboratory space, and machine and glass-blowing shops are adequate but that electronics shops are not. *Electronics shops, capable of design and construction of instruments, as well as of their maintenance and repair, are important to research productivity and should be improved.*

Scientific communication at the local level appears to be adequate, but travel to national and international meetings depends heavily on grant funds and often requires presentation of papers or participation in committee work or meeting organization. These provisions discriminate against the younger faculty members who are still establishing their research programs and reputations, yet who need the intellectual stimulation and contacts provided by such meetings as much as or more than do older members. *Travel to scientific meetings should be viewed as an essential part of the research process and sufficient funds made available, through university sources as well as grants, to allow all active research faculty to participate.*

3

NATURE OF THE UNIVERSITY MATERIALS-SCIENCE COMMUNITY AND ITS RESEARCH SUPPORT

DESCRIPTION

University research in materials science in the United States is traditionally conducted in physics, metallurgy, ceramics, and chemistry departments. It has long been an important component in the first three and is becoming so in chemistry. To these have been added strong Materials Research Laboratories (MRL's) in more than a dozen universities in the last two decades. The MRL's were developed initially with Advanced Research Projects Agency (ARPA) or Atomic Energy Commission (AEC) support and are now funded by the National Science Foundation (NSF) and the Department of Energy (DOE). The MRL's vary greatly in size and complexity but in all cases represent concentrated efforts with common purposes and commonly funded support facilities.

The university-based small research projects in materials science, which are the subject of this report, represent the national effort in materials science in universities other than those having agency-funded MRL's. This research takes place in universities of various sizes and reputations. Projects usually involve an individual scientist working only with his students or a few scientists loosely and temporarily grouped for mutual strength. In many cases, an individual is not likely to have colleagues in the same field at his university. These projects are not usually served by facilities supported by an institutional grant, although there are a few important exceptions to this pattern. Materials research is characterized by a wide variation in the way it is organized and funded.

One of the strengths of materials research on university campuses has been the diversity of funding modes and the multiplicity of funding sources. This diversity and attendant flexibility are important because of the multidisciplinary character of the field.

Over the past few years, materials research at universities has been mainly supported by the Department of Defense (20%), Energy Research and Development Administration (20%), NSF (57%), and National Aeronautics and Space Administration (3%). Figure 3.1 illustrates the pattern of funding by the NSF Division of Materials Research (DMR). Data for mean grant sizes for individual grants for fiscal years 1974 through 1979 are shown for that Divisions's programs. Also shown are the total dollars of support represented by those grants and by grants to "larger enterprises" (MRL's, the National Magnet Laboratory, synchrotron radiation facilities, and the Small-Angle Neutron Scattering Facility). The overall trend for individual grants amounts to an annual increase of about 10 percent per year, somewhat less in recent years than the aggregate for "large enterprises."

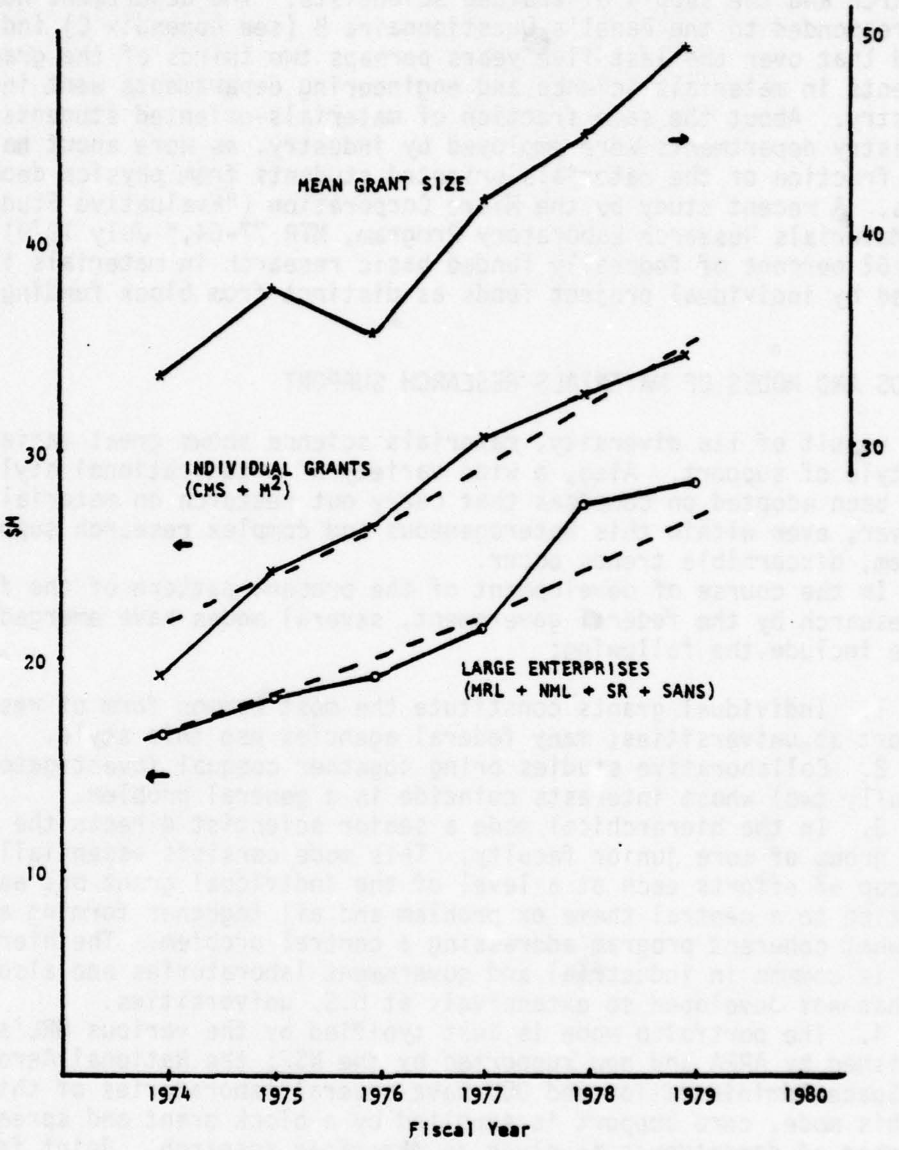

Figure 3.1 Mean grant size and total funding for individual project awards in the NSF Division of Materials Research (DMR), defined as the Condensed Matter Sciences (CMS) and Metallurgy and Materials (M^2) Programs. Total funding for "Large Enterprises" in DMR is defined as the Materials Research Laboratory (MRL), National Magnet Laboratory (NML), Synchrotron Radiation Facilities (SR), and Small-Angle Neutron Scattering (SANS) Programs. Dashed lines indicate 10 percent inflation. Mean grant size is defined as total project funding divided by number of awards times average duration per grant.

Small research projects make a significant contribution to both research and the supply of trained scientists. The department heads who responded to the Panel's Questionnaire B (see Appendix C) indicated that over the last five years perhaps two thirds of the graduate students in materials science and engineering departments went into industry. About the same fraction of materials-oriented students from chemistry departments were employed by industry, as were about half that fraction of the materials-oriented students from physics departments. A recent study by the Mitre Corporation ("Evaluative Study of the Materials Research Laboratory Program, MTR 77-64," July 1979) found that 62 percent of federally funded basic research in materials is supported by individual project funds as distinct from block funding.

TRENDS AND MODES OF MATERIALS RESEARCH SUPPORT

As a result of its diversity, materials science shows great variability in style of support. Also, a wide variety of organizational styles have been adopted on campuses that carry out research on materials. However, even within this heterogeneous and complex research support system, discernible trends occur.

In the course of development of the present pattern of the funding of research by the federal government, several modes have emerged. These include the following:

1. Individual grants constitute the most common form of research support at universities; many federal agencies use this style.
2. Collaborative studies bring together coequal investigators (usually two) whose interests coincide in a general problem.
3. In the hierarchical mode a senior scientist directs the work of a group of more junior faculty. This mode consists essentially of a group of efforts each at a level of the individual grant but each relating to a central theme or problem and all together forming a somewhat coherent program addressing a central problem. The hierarchical mode is common in industrial and government laboratories and also abroad but has not developed so extensively at U.S. universities.
4. The portfolio mode is best typified by the various MRL's established by ARPA and now supported by the NSF; the National Aeronautics and Space Administration and DOE have several laboratories of this type. In this mode, core support is supplied by a block grant and spread over a number of departments involved in materials research. Joint facilities are usually maintained. "Thrusts," or fields of specialization, now are identified for the large groups, but the overall program at each university is generally not so coordinated as in hierarchical modes. Similar arrangements also occur in the Department of Defense (DOD) Joint Services Electronics Program.

We discuss these various modes in greater detail in the sections that follow.

INDIVIDUAL GRANTS

The individual grant has been the backbone of research support in the United States. It allows a funding agency to consider a highly qualified researcher as a resource and to provide funds to support this researcher's work. Many scientists prefer to operate under an individual grant, although, when another type of grant is necessary to obtain or use some equipment or facility essential for the work, they usually will accept the alternative mode. It is of great importance to a scientist, particularly below the professorial level, to have a personal grant when matters of salary, retention, or promotion are under discussion. The separate recognition inherent in an individual grant can be important when cooperative research is undertaken, for each researcher is then contributing as an equal.

The individual grant allows a researcher freedom of choice in proposing research problems and flexibility in altering the direction of the research during the course of the work. These features enhance the opportunity for maximum creativity and maximum contribution to the advancement of science.

Individual grants also have some disadvantages. More time is expended in proposing, reviewing, processing, managing, and reporting individual grants than is the case with larger, coordinated programs. It is difficult to fund large equipment under an individual grant. The stability of shared facilities supported only by individual grants is poor because the failure of any one contributor to obtain continuing funding threatens the viability of the facilities. The scope of the research undertaken in this mode is obviously limited, although use of individual grants need not discourage cooperation among researchers unless there are administrative impediments.

COOPERATIVE RESEARCH

Cooperative research involves merging either or both the project direction and the equipment common to the several investigators' objectives. The responses by department chairmen to the Panel's Questionnaire B indicated that most departments (15 of 21) have projects with some form of team organization. For the most part these are organized around a joint interest rather than a shared facility. Most of the team efforts described by the chairmen consisted essentially of a loose association, or alliance, of coequals on a voluntary basis. Of the team efforts reported, funding was about equally divided between separate grants and a single grant for the team. The universally expressed opinion, of those reporting use of the team approach, was that it increased productivity because of the increase in expertise and breadth of personnel and facilities; however, some problems were also noted. A few of these centered on difficulty in apportioning credit when consideration is being given to promotion, tenure, or salary increases; other difficulties were related to interdepartmental problems. In the case of hierarchical organization, the loss of the leader can impede research progress.

Collaborative Mode

Collaborative research can entail the sharing of research direction of a project among individuals on the same campus (intramural) or on different campuses (intermural) or individual interactions with government laboratories or other research centers. The advantages of such interactions can include improved quality of research, effective communication, growth potential for junior investigators, and enhanced cost effectiveness. The impediments to such collaboration can involve the personalities of the investigators, real or imagined institutional constraints, and the spatial separation of the investigators. The motivation for collaboration centers on either the availability of special equipment and materials or a shared interest in a topic.

The availability of specialized equipment used on a time-sharing basis by several investigators enhances the probability of cooperative research. This is especially so for intramural research. Sharing of program direction is not required in this case, and the institution profits by reduced purchase and maintenance costs. Also, it is possible for investigators in different fields to interact, and transfer of technological information can flourish.

It is easier to extend cooperation based on the availability of equipment to intermural interactions than it is to share research direction. However, problems connected with teaching commitments, travel costs, and general inconvenience to student and professor alike apply severe restraints. Individual scientists have considerable flexibility in research direction in this mode. Discontinuance of an association can be easy and amiable when interests separate and easily renewed when they reconverge. The scientific interplay can be valuable. Even in the most tenuous arrangements some degree of contact is automatically built into this mode, and beneficial interactions usually occur. The principal investigators who responded to the questionnaire, admittedly mostly well-established researchers, were enthusiastic about team efforts. In cases where the participants are of comparable stature and make equivalent contributions, there is little difficulty with apportionment of credit; in those cases where either age or stature is significantly different care must be exercised by the university to ensure that credit is properly distributed. This is especially important for untenured faculty.

There are also advantages and disadvantages in terms of management. The administrative effort by the granting agency can be reduced considerably. Little if any additional bureaucracy is added at the university. Flexibility with respect to junior personnel and technical help is increased. On the other hand, in the Panel's experience, the current peer review scheme of evaluation of proposals discriminates against this mode because reviewers often dislike some part of the collaborative proposal or believe that the total cost is excessive.

Hierarchical Mode

The hierarchical mode of research has a pyramidal structure, with a single leader who exercises both intellectual and fiscal control. Several junior faculty may be members of the team, together with a number of postdoctoral fellows and graduate students. The style is much like an individual grant, except that the research productivity of the leading individual can be multiplied many times over. This mode of operation can be highly effective in developing a field of research. It is common in U.S. government laboratories and in industry and is a usual feature of European universities and research institutes in materials science. It is less used in universities in the United States, although examples can be found or have existed. Frequently, the leader has been a faculty member who developed a group within a department or a college. In other instances, the leader had or achieved increased power by becoming a department head. The responses to the questionnaires from departmental chairmen confirmed that this mode is not commonly used.

There are definite advantages to this scheme. The scale of the problems that can be attempted is much larger than for most other types of support. Cooperative activity of the group is maintained through fiscal control as well as intellectual leadership. The style may involve either strict or loose control, but a major focused effort can be attempted. The budget, which can range upward from $250,000 a year, is sufficiently large that major support facilities can be secured and maintained. In some instances total support can come from a single source, but the size of the budget often requires that the program be supported by a merging of grants.

This mode of operation can achieve spectacular success if the intellectual leadership and administrative skills of the leader are exceptional. To permit that success, long-range support is required, perhaps ten years or more. Several factors may limit the viability of the group, among them (a) the administrative and fiscal responsibilities of the leader may become so severe that the inellectual leadership falters, and (b) the field may pass the leader by, so that the effort becomes obsolete. When such a group ceases to function for whatever reason, it is important that the junior members have access to individual grant support so that they may quickly acquire momentum on their own.

Hierarchical grants have an obvious advantage to a successful leader, providing high visibility and power, both locally and nationally. This mode also can have advantages for new faculty members, who quickly become part of an ongoing program and thus avoid the hiatus of research productivity that often occurs as an unattached faculty member builds an individual program; however, junior faculty members can be enmeshed in a system in which individual characteristics are suppressed or unrecognized, and advancement at the institution can be difficult. This latter feature often accompanies the pyramidal research structures commonly found in European universities. Not only is advancement difficult, but the professional welfare of the junior member may be tied to the success or failure of the leader. When senior members leave for any reason, universities must understand the need for junior members to move out on their own. Perhaps for some of these reasons, the majority of researchers responding to the questionnaire did not favor this mode.

Portfolio Mode

The portfolio mode, in which a large block grant made to a single university funds a diverse group of researchers working in a number of somewhat related problem areas, is exemplified by the NSF MRL Program and the DOD Joint Services Electronics Program. Somewhat similar programs also are or have been funded by DOE and the National Aeronautics and Space Administration. In these portfolio programs, it is usual for several researchers, most often from different disciplines, to work on a problem, the scope or subject matter of which would make it difficult to fund under an individual grant. Either the problem is so broad that a large and diverse effort is required, or its subject matter is such as to fall outside the usual areas of interest of the largely discipline- or mission-oriented funding agencies. In NSF parlance, these broad problems are called "thrust" areas.

Portfolio grants, since they are large and cover diverse scientific interests, allow the procurement and maintenance of large equipment and central facilities. Such shared facilities can be an important stimulus to cooperative research, especially when they are housed in a building that provides space for different types of materials researchers. Synergistic effects often result from this type of operation, which suggest new approaches leading to scientific progress. Cooperative efforts of this kind have a positive impact on the training, experience, and outlook of graduate students. Their backgrounds can be greatly broadened as they pursue thesis research in this kind of atmosphere.

The control exercised by local management in directing these block-funded portfolio programs can be a significant factor in bringing different researchers together. In many cases, the initial impetus for the cooperative venture—money—is quickly replaced by the realization of the advantages to be accrued from the "thrust"-research mode of working. The potential for local management to respond quickly to significant opportunities is perhaps unexcelled. Likewise, the local initiative and flexibility allow the provision of enough support to new faculty to allow them to concentrate on a good scientific start and to turn to grant seeking only after they have established their own scientific programs.

The Mitre Report ("Evaluative Study of the Materials Research Laboratory Program, MTR 77-64," July 1979) found that the administrative costs of comparable-size research efforts were lower for NSF grants using this mode than those for individual NSF grants. However, this cost difference lies mostly in the fact that individual grants require detailed and complex research proposals, whereas for the portfolio mode, project selection is delegated to local university managers, who work with much simpler proposals.

The portfolio approach is not without problems, however, particularly on campuses where block-funded programs have been under way for a long time. Faculty working on individual programs do not welcome being told that they will have to change some (or all) of their procedures. Few portfolio programs are big enough to provide all the research support necessary for an able and productive researcher. On balance, however, the portfolio mode is an important source of cooperative research.

4

FACTORS INFLUENCING RESEARCH EFFECTIVENESS

GENERAL

The complexity of materials research means that special consideration must be given to its organization. Equipment, supporting services, communication, and the policy of the university in regard to teaching load and other responsibilities are important factors in the efficient production of knowledge. In this section we discuss some of the factors that influence progress in materials science.

Because money is limited, it is necessary to organize research in such a way that cost effectiveness is optimized. Input costs include those for salaries, services, communications, materials, and equipment. Some of the primary outputs are published research results such as data, theoretical concepts and techniques, and instruments and materials or the recipes for them. There are also, however, significant outputs in the form of student training and the development of young scientists. The national need to train students is obvious. There is also a need to ensure, in the course of research, that junior faculty have adequate opportunity to develop their talents, for the future availability of research results will depend on them.

If one considers only the cost effectiveness of the execution of materials research and emphasizes the primary research outputs, group efforts have some definite advantages over individual efforts. Facilities can be shared, and, by avoiding duplication of small facilities, more sophisticated equipment can be made available. Specimens with their analyses can be shared. A common and local base in concepts and theoretical tools means that interactions among the investigators can be more helpful and supportive. Progress made in one field can provide answers and tools in another, and communications within the group can be relatively easy. From the standpoint of the funding agency, a group effort can provide fewer contact points and simpler management. A majority of the responses to the Panel's questionnaires, from both principal investigators and departmental chairmen, favored such group efforts, principally in the form of voluntary alliances of approximately coequal individuals.

In addition to "alliances of equals" involving collaborations of individual investigators, the Panel believes that regional centers should be examined, since they could ameliorate the problem of providing access to specialized facilities and equipment for the small research project. The Panel and a majority of those responding to the questionnaires indicated the potential usefulness of such regional centers.

EQUIPMENT

Materials research requires the use of multiple tools to examine the properties of condensed matter. Thus it is often necessary to control external conditions of temperature, pressure, and chemical activity while measurements are being made and to study simultaneously several aspects (e.g., electrical, magnetic, and optical measurements often occur together) of material properties to arrive at a thorough understanding of the behavior. Therefore, a wide variety of specialized items of equipment is often required, in addition to general support equipment such as electron microscopes, x-ray spectrometers, and specimen-preparation equipment. The pace of equipment development, particularly in electronics, results in constantly increasing sophistication and rapid obsolescence of much specialized equipment. This was indicated strongly by the Panel's questionnaires in that 50 percent of the individual researchers reported that their dedicated equipment was obsolete, and only 25 percent described this equipment as state of the art. Also, about 80 percent indicated a lack of funds for maintenance and replacement of obsolete equipment.

In many instances, the cost of essential equipment makes it impossible for the small group or department to secure such for its own use, and this results in shared usage. Thus 91 percent (35) indicated that they had access to general-purpose equipment in other departments or industrial or government laboratories. Other equipment such as that to provide synchrotron radiation and extremely high magnetic fields and neutron sources is so complex and expensive that it can only be maintained at regional or national facilities. Also, the more sophisticated versions of nuclear-magnetic-resonance spectrometers and scanning electron microscopes might be expected to reside primarily in regional facility centers. There do not seem to be institutional barriers to the use of such outside facilities, although concern was indicated about teaching arrangements, the inconvenience and expense of travel, and the loss of control over equipment and programs.

On the other hand, the successful establishment of specialized research facilities operating on a user basis involves certain conditions. A long-range commitment to maintenance and upgrading must be made by the host organization. In order that the facility might be kept up to the state-of-the-art level, the host organization should be one in which a first-class research capability exists in the fields of use or operation of the equipment. For the center to fulfill its function of allowing less-well-endowed universities access to state-of-the-art facilities, travel funds for users should be included in the budgets of the regional centers. The NSF in fiscal year 1978 launched a program for the establishment of regional facilities of this kind, the Regional Instrumentation Facilities Program, by funding six facilities. In fiscal year 1979, another group will be funded. The Panel believes that there are strong needs in materials science for facilities of this kind but that the impact and usefulness of the initial program should be carefully evaluated.

UNIVERSITY RESEARCH ENVIRONMENT (SUPPORTING SERVICES, TEACHING LOADS, AND STUDENTS)

The types of supporting services generally expected from the universities include library, computer facilities, and various shops (machine, glass, electronic). The amount of supporting services is strongly correlated with the mode of funding. Portfolio grants or block funding generally contain funds not only for purchase of equipment and facilities but also for the support of technicians, and for maintenance of the eouipment. Individual grants seldom contain such funds. Large equipment items must be obtained by special-equipment grants, often with matching funds by the university, whereas technicians and maintenance services are expected to be supplied by the universit. The response to the questionnaires showed that libraries and computer facilities are adequately supplied by the university. Thirteen percent of the computer facilities were funded entirely by the university, 67 percent jointly by the university and outside grants, and 20 percent from outside grants. However, other services such as machine shop and especially electronics facilities are less well provided; about 75 percent of the researchers reported adequate machine shops, but only 55 percent had adequate electronics facilities.

The teaching environment and loads were considered good by 93 percent of the respondents. However, there appeared to be a slight discrepancy in the way administrators and individuals counted their teaching loads. The individuals claimed that they had smaller loads than the administrators estimated. In general, it was believed that a teaching-research ratio of about 50-50 was optimal. About 25 percent mentioned that increased credit for research is desirable.

The number of graduate students per faculty member has been declining in recent years. A number of questionnaire respondents considered this number to be less than optimum from the standpoint of effective research effort. However, the market conditions may not warrant that optimum number and should be seriously considered before implementing any policy to increase the number of graduate students.

The number of postdoctoral fellows appears to have undergone a drastic reduction in the last few years, with 19 of 25 of the individual researchers reporting that the supply of suitably trained people is smaller than they would like. This probably reflects a number of changes—both positive and negative—such as better acceptance of industry and government laboratories as desirable employers, decreased probability of obtaining a tenured faculty position, and increasing discrepancy between academic and industrial salaries. Thus it appears that market forces are changing the postdoctoral supply in a manner that reflects the changing attitudes of the new PhD's.

INDIVIDUAL GROWTH AND DEVELOPMENT

Research activities must be carried on in such a way as to ensure the capability to provide future research results, while supporting present research. The adequate development of junior faculty is an important part of this responsibility. Scientific and technological progress is made by individuals and not by institutions or organizations; the latter can only provide, at best, the proper environment.

The usefulness of the provision, by university departments, of seed money to start young faculty members in research is well recognized, as evidenced by the responses to the Panel's questionnaires. The mode of government funding of research can also influence the start-up and subsequent careers of young university scientists as discussed in Chapter 3. Writing proposals and setting up laboratories are difficult and time-consuming activities that can make heavy demands on beginning faculty members. Slippage of a year or two in producing research results can be very damaging to the tenure aspirations of the junior members of faculties.

Communication is one of the major stimulants to research. Even telephone communications can be the occasion for a significant change in research direction or the recognition of the proper interpretation of a puzzling result. Because of its interdisciplinary nature, extensive communication is especially valuable in materials science. Therefore, the need for opportunities for interaction with peers is acute.

The various means of communication and of keeping informed of current developments include intradepartmental and interdepartmental interactions, seminars, outside colloquium speakers, publications, outside meetings, travel, and telephone conversations. The questionnaires showed that most researchers responding believed that they had access to a sufficient number of colloquia and seminars. For about one half of the respondents, research grants and contracts provided the sole support for travel to meetings. Those researchers with support could attend a reasonable number of national meetings (the average for all respondents was between two and three a year) and had some access to international meetings (somewhat less than one per year on the average). In most of the remaining cases, university funds were available for only one trip per year to a professional society meeting for the purpose of presenting a paper or chairing a session. The system clearly discriminates against the young faculty member on his own, before his attempts to obtain grant support have borne fruit, and the researcher in the smaller department, in which obtaining grants is difficult, yet these are the people perhaps in greatest need of the stimulation and contact provided by major meetings. University policy in this regard would be worth reviewing.

APPENDIX A
COVERING LETTER, PREAMBLE TO QUESTIONNAIRES, AND QUESTIONNAIRES A AND B

Covering Letter

Dear Questionnaire Recipient:

Another questionnaire from Washington must be as welcome as a cold snap during an oil shortage! Yet perhaps you can see that it is a necessary and bearable burden. In the Preamble to the enclosed questionnaire we have tried to explain exactly what we, my fellow members of the Panel on the Support of Small Research Projects in Materials Sciences at Universities and myself, are trying to do.

This is a period when research costs are rising rapidly and when there is increasing pressure to concentrate on short-term goals. Funding sources must be concerned with obtaining maximum research productivity in the work they support. The question as to what are the most effective modes of organization possible for university efforts in materials sciences is a very real and urgent one. On the one hand, agglomeration of individual efforts into some sort of team approach can carry with it economies and advantages resulting from sharing of materials and facilities, and the synergistic effect of people working on related problems. On the other hand, there are important values in the independence and freedom of action of the individual researcher, having to do with such things as diversity of approach, educational needs down into the undergraduate levels, local and regional needs, and university advancement policies should not be lost.

This present Panel was established to spend some time looking into this situation, with the aim of arriving at recommendations to both the universities and the funding agencies for ways to preserve these values while meeting the needs of the funding agencies for furthering their missions in the most effective way. To do this, we need your help, and this questionnaire is our request for it. Please give it your earnest attention. It would be most helpful if it could be returned within two weeks to

Bruce N. Gregory
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, D.C. 20418

Additional comments would be most welcome.

Sincerely,

Alan D. Franklin, Chairman
Panel on Support of Small Research
Projects in Materials Sciences
at Universities
National Research Council

Preamble

This questionnaire is sent to you by a group of your colleagues, listed below, who are serving as a Panel on Support of Small Research Projects in Materials Sciences* at Universities, under the auspices of the National Research Council, and with support from the Air Force Office of Scientific Research and the Office of Naval Research. The Panel was instigated and organized by the Solid State Sciences Committee of the NRC.

The objectives for the study, set forth in the proposal accepted by AFOSR and ONR, state:

"The general objective of the study panel will be to review and enlarge on our understanding of the role of small research projects in the nation's solid state sciences effort, to determine factors that lead to meaningful projects, and to establish some relatively specific guidelines to aid those who must make decisions concerning the allocation of resources."

This statement defines a two-part audience for the study. One part consists of the universities themselves, to whom the study should convey an increased appreciation of the modes of organization and the circumstances that are most apt to allow moderate-sized materials research efforts at universities to be not only scientifically successful but also competitive in the bid for support. The other major part of the audience is comprised of those in the funding agencies and elsewhere, who control resources and make decisions about their allocation. It is hoped to convey to them ideas concerning modes of organization which might not only maximize research productivity but also be most appropriate and acceptable to the universities

This questionnaire is being sent to a number of active research investigators in the fields of the materials sciences covering a rather wide spectrum of institutional size and magnitude of materials research activity. With it, we hope to create a picture of what the successful research environment is, what the constraints and limitations are, and what the thoughts of successful research investigators and department heads are on modes of operation most suitable to viable, competitive research activity.

The reports of the Panel will not deal with individual responses but will contain only information obtained by summing over groups of institutions. However, it was felt advisable not to make the responses anonymous in order that

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* Materials Science here is taken to include at least elements of:

Solid State Physics	Ceramics and Ceramic Engineering
Solid State Chemistry	Polymer Science (but not monomer chemistry and polymerization)
Metallurgy and Metallurgical Engineering	Materials Science and Engineering

The typical setting for this study is taken to be a university materials research activity comprising 2—6 faculty members, although information on larger and smaller groups is needed for comparison.

information already available in the files of the NSF and elsewhere might be made use of, thus making this questionnaire, already too burdensome, as simple as possible. Needless to say, responding to this questionnaire is entirely voluntary as is identifying yourself and your institution. Your careful attention will be very helpful.

Carl Bleil, General Motors
Praveen Chaudhari, IBM
James H. Crawford, Jr., U. North Carolina
LeRoy Eyring, Arizona State U.
Douglas Finnimore, Iowa State U.
Alan D. Franklin, NBS (Chairman)
Paul Gilles, U. Kansas
Arthur Heuer, Case Western Reserve U.
Alan Portis, U. California at Berkeley
Mary B. Stearns, Ford
Stanford Sternstein, Rensselaer Polytechnic Institute
Charles Wert, U. Illinois, Urbana

Questionnaire A, sent to Principal Investigators

I. University:
Department:
Responder:

II. Research Personnel

A. Graduate Students:

1) How many graduate students do you now have working in your laboratory? ________
2) Is this number greater or smaller than three years ago? ____
3) Do you anticipate an increase or a decrease in graduate student availability in the next three year period? ________
4) Are you satisfied with the quality of your research students? ____

B. Post Doctoral Associates:

1) How many post-doctoral research associates are employed in your research program? ________
2) Has this number increased or decreased over the past three years? ________
3) Is the supply of suitably trained post-doctoral candidates in your field of interest
   a) adequate? ___
   b) inadequate? ___
   c) satisfactory? ___

III. Research Environment

A. General

1) Do you find the environment generated by your administration conducive to research? teaching? How could it be improved?

B. Teaching Loads

1) Do you consider your present teaching load and other departmental duties represent a proper balance between teaching and research? If not, how should it change?

2) What is your average teaching load?

C. Contact with colleagues:

1) Does your department provide regularly for outside seminar and colloquium speakers? How often in your field?

2) Does your department or institution adequately provide for travel to general and topical conferences? How often do you attend seminars or conferences on the 1) local, 2) national, and 3) international level?

3) Do your have adequate interaction with your scientific peers in general? If not, what are the major constraining influences?

IV. Research Facilities

A. Library:

1) Are adequate facilities available either at your institution or some convenient, nearby location?

B. Shops:

1) Are shop (machine, glass, electronics, analytical, etc.) facilities and staffing levels adequate to meet the needs of your research?

2) Identify any deficiencies of the above?

3) Are these facilities accessible and/or affordable?

C. Computers:

1) What types of computer services are available to you (on or off campus)?

2) Are they adequate for your research?

3) Is payment for computer service from grant funds required or does your institution bear the cost?

D. Space:

1) Is there adequate laboratory space for your research?

E. Equipment:

1) Is special equipment dedicated more or less completely to your research needed in your program? If so, is enough available and is it adequate? Is it state-or-the-art, acceptable, or obsolete?

2) Do you need general purpose equipment such as spectroscopes, electron microscopes, etc.? If so, are they available locally? Are they maintained and staffed adequately, and of adequate sophistication?

3) Please give an order-of-magnitude figure for the amount of money spent at your institution for equipment in each of the past two categories above over the past 5 years, broken by source (federal grant, state or local grant, industry, institution, etc.). What should each set of figures have been?

4) What is your department's policy on equipment maintenance? Are enough funds available, and what is their source?

5) Are there funds earmarked for the replacement of obsolete equipment? What is their source?

6) If general purpose equipment is not available to you locally, do you have access to it outside your department?

   Where (another department or university, at a government or industrial laboratory, or at a shared facility or regional center)?

   What sort of arrangements (rent, fees, etc.) are required and how was the agreement realized (through a university, funding agency, personal contact, etc.)?

   What are your major problems in using this sort of arrangement?

7) Do you, or could you, make use of specialized regional centers, such as for materials preparation and (structural and compositional analysis) or an NMR or accelerator facility?

   Are there institutional constraints impeding this?

   What are the major problems you see?

V. Regional Research Centers

A. Regional and Industrial Research Interests:

1) Are you engaged in any materials research problems or projects which are peculiar to your region or locality?

Can you identify any that might draw local support? Please list them.

2) Have you established research linkages with industry (local or national)?

B. Regional Research Centers

1) If a regional center offering cooperative research opportunities and/or facilities in your field of interest were located nearby would you be interested in using it?

What facilities would you want?

2) Do you think regional research centers could:
   a) provide more stability for you than at present for research funding?____________
   b) make better facilities present than you now have access to? ________
   c) better serve the interests of local small industry than the present arrangements?_________
   d) provide more opportunities than are now available for you to interact with your scientific peers?________

3) Would you use its facilities all year or summer only? ___________

4) What distance of travel would inhibit your use? ___________

5) Would there be serious institutional constraints on your using it? _________
What are they?

VI. Funding

A. Please list, in order of magnitude figures and broken down by source (federal, state, or local government grant; industry; institution; other) the research funds available for your program over the past 5 years.

VII. Research Organization

A. Do you work now as a member of a research "team" (formal or informal)?

By team is meant 3—4 faculty members pursuing related facets of a common research theme, sharing materials, facilities, concepts, etc. If so, could you briefly describe:

1. Is the team a voluntary association of equals, or is it grouped around a senior faculty member?
2. Is there a single research grant, or does each member have his own grants, with himself as principal investigator?
3. Is the team more productive than the separate individuals would be each going his own way? If so, why?

4. What problems has this mode created for you? Are there hindrances created by university needs and policies?

B. If you do not work as a member of such a team, what pros and cons do you see for yourself in such a mode of organization?

Questionnaire B, sent to Department Chairmen

I. University:
Department:
Responder and Title:
% of Departmental Research classified as materials research:

II. **Graduate student data**

A. Enrollments:

1) What is the present graduate student population of your department? ______
2) How many of these are now engaged in materials or solid state research? ______
3) What was your graduate student enrollment three years ago? ______
4) What level of enrollment do you anticipate for three years hence? ______

B. Sources of Graduate students:

List approximately the number of students presently enrolled who received their BS degrees:

1) at colleges or universities with no substantial graduate program in the sciences ______
2) at colleges or universities with substantial graduate programs in the sciences ______
3) from your immediate locality including your own institution ______
4) from foreign (not English) universities ______

C. Degrees granted and their destination:

1) How many Ph.D. degrees did your department grant in each of the past five years?

2) How many M.S. or M.A. degrees did your department grant in each of the past five years?

3) Estimate how your Ph.D. recipients of the past five years are distributed over the following categories of employment:
Academic: ______
Industrial Research/Development: ______
Federal Research/Development: ______
Other: ______

4) Estimate how your Master's degree recipients of the past five years are distributed over the following categories of employment:
Academic: ____
Industrial Research/Development: ____
Federal Research/Development: ____
Other: ____

III. Faculty

A. Statistical:

1) What is the total number of your faculty? ____
2) How are these distributed over professional ranks including instructors (lecturers)?

3) What percentage of your faculty is tenured? ____

B. Faculty Duties:

1) What is the standard (average) faculty teaching load in semester hours or the equivalent? ____
2) Is this load adjusted in any way for those members with active research programs? ____
3) Does graduate student supervision count toward total reaching load? If so, how?

4) How does your department encourage research involvement of your faculty members?

5) What fraction of your faculty is fruitfully engaged in research (whether or not they are supported by a grant or contract)?

6) What do you consider to be an optimum division of effort between teaching and research among your faculty (cf. question 5)?

IV. Research Environment

A. Off-Campus Research and Regional and/or National Centers:

1) Is release time granted faculty members who wish to conduct research off-campus? ____
2) Does shifting research emphasis to research centers (regional research centers or National Laboratories) work a hardship on your faculty members? ____
Upon you? ____
3) Do you find the concept of regional research centers attractive from the standpoint of stability of research support?

4) Would your department participate in shared facilities or a regional center?

B. Outside contracts:

1) Are regular seminars and colloquia supported by your department? __________ How frequently? __________
2) Is faculty travel to scientific conferences (general or topical) supported by your department or institution? __________
3) What is the mode of support of faculty travel? __________

4) What are the criteria for institutional or departmental support of faculty travel?

V. Research Support (Federal)

A. Statistical: (For each of the past five years, if possible and where appropriate)

1) Give the total amount of Federal support of research in materials science in your department:

2) List the number of Federal contracts and grants and their average duration.

3) What do you consider the minimum size of a viable research grant in materials science (a) experimental, (b) theoretical?

4) What is the average fraction of faculty salary supported on each research grant?

VI. Research Support (Internal, regional, etc.)

A. Statistical: (For each of the past five years, if possible and where appropriate)

1) How much materials related research in your department is directly supported by your institution? (Please give the aggregate total)

2) Of the above, what is the fraction for operating costs of equipment, including maintenance?

3) Is there any return of overhead funds to your department for maintenance or direct support of research?

4) What is the aggregate amount of materials science research support from regional, local, or industrial sources? Is this generalized support or for specific projects?

B. Research Initiation:

1) Does your department (institution) provide seed money or start-up funds for new faculty members? ______________________
2) How long can a new member count on such support before obtaining a grant? ______________________
3) Is there any follow-on support for terminated contracts or grants to insure the completion of students' degree requirements? _____ ______________________
4) Do limitations here limit the nature of the studies that can be undertaken? ______________________
What changes in support patterns that might help can you suggest?

C. Regional Research Activities:

1) Has your department identified any materials research problems or projects which are peculiar to your region or locality?

Would these draw local support?
Is your department engaged in working on any of these?

2) Please describe whatever research linkages your department has established with industry.

3) Would participation in a regional research center addressing such interests be of value to your department? _______ Why?

What would be the advantages and disadvantages for the university or department in such an arrangement?

D. Equipment:

1) For each of the past five years, please estimate the amount of money spent by the department for materials-related research equipment, broken down by source (Federal, state, or local grants; industry; institution; private; etc.).

2) What should these figures have been for the department to have maintained maximum effectiveness?

3) Would participation in regional shared facilities be a viable mode of operation for your department?
What are the advantages and disadvantages?

VII. Research Organization

A. Do research teams (formal or informal) exist in your department? By "team" is meant 3-4 faculty members pursuing related facets of a common research theme, sharing materials, facilities, concepts, etc.

If so, could you briefly describe:

1) Are they voluntary associations of equals, or the result of dominant individual faculty members with junior faculty people in support?

2) Do they work on a single, or a few, grants, or each on his own research grant?

3) Have they led to increase in research productivity?
How?

4) What problems do they provide the Administration, the department head, the faculty member involved?

5) Does their existence help or hinder the career advancement of the faculty members involved?

B. If such teams do not exist, what are the pros and cons of such a mode of organization in your department?

APPENDIX B
ANALYSIS OF RESPONSES TO QUESTIONNAIRE A, SENT TO INDIVIDUAL PRINCIPAL INVESTIGATORS

Nature of the Sample

Table 1 presents the distribution of the sample by department and the number of responses received to Questionnaire A.

Table 1 Distribution of Sample and Response Rate

Academic Department	Questionnaires Sent	Responses Received
Ceramics	6	2
Chemistry	17	8
Geology	1	0
Materials science and engineering*	23	13
Mechanical engineering	2	1
Metallurgical engineering	7	2
Physics and astronomy	29	14
Science and mathematics	1	1
Total	86	41 (48%)

*All departments with materials, materials science, or materials engineering in their titles, regardless of what other subjects are also included.

Because of the low response rate, the findings of the survey can only suggest possible trends that would be worthy of attention and further exploration. They are, however, quite useful in providing clues to needs and problems of small materials science research projects in universities.

For information on the respondents' institutions, the Panel used figures made available by the National Science Foundation's Division of Materials Research (NSF-DMR) for FY 1975 and FY 1976 on the number of grants awarded, total grant money, and success rate of proposals for each institution as a whole. These data offer a special view of an institution's place in the overall materials science research picture and can be useful.

Figure 1, which shows the distribution of respondents according to the NSF-DMR support received by their institutions, averaged over 1975 and 1976, indicates the magnitude of the materials science effort. The sample for this study has an equivalent representation of schools with programs from small to moderately large.

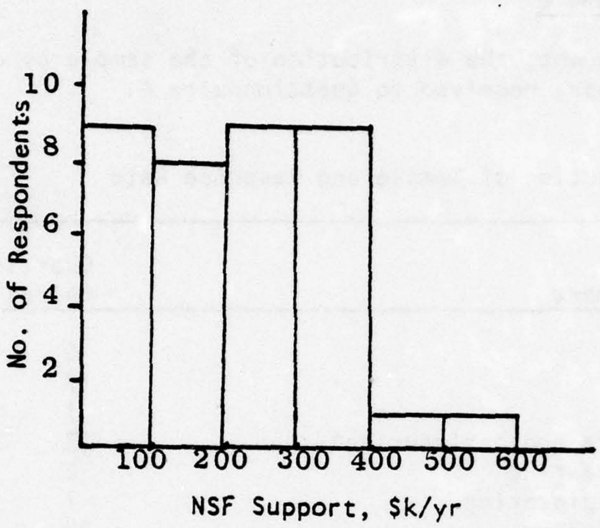

Figure 1. Distribution of respondents according to support provided institution by the NSF Division of Materials Research, averaged over FY 1975 and FY 1976.

Figure 2 shows the distribution of respondents according to the success rate of their institutions in terms of proposals funded by NSF-DMR, averaged over FY 1975 and FY 1976. The respondents are located in institutions that appear reasonably successful in obtaining grants from NSF-DMR. The median lies near 60 percent, so that a researcher at a median institution gets about two grants for each three proposals submitted. This finding perhaps accounts for there being only one respondent who specifically mentioned (for Question III A.1) that proposal writing was a problem.

There is a weak correlation apparent in these NSF figures for the schools in the sample between institutional program size and success rate; Figure 3, in which these two quantities are plotted against one another, illustrates this. The correlation coefficient (Pearson's r) is 0.3. A researcher at a school in this sample with a small program apparently has to work somewhat harder to obtain a grant than does his colleague at a school with a large program, but the difference is not overwhelming. In general, the respondents represent research groups from institutions in which successful research in materials science is done.

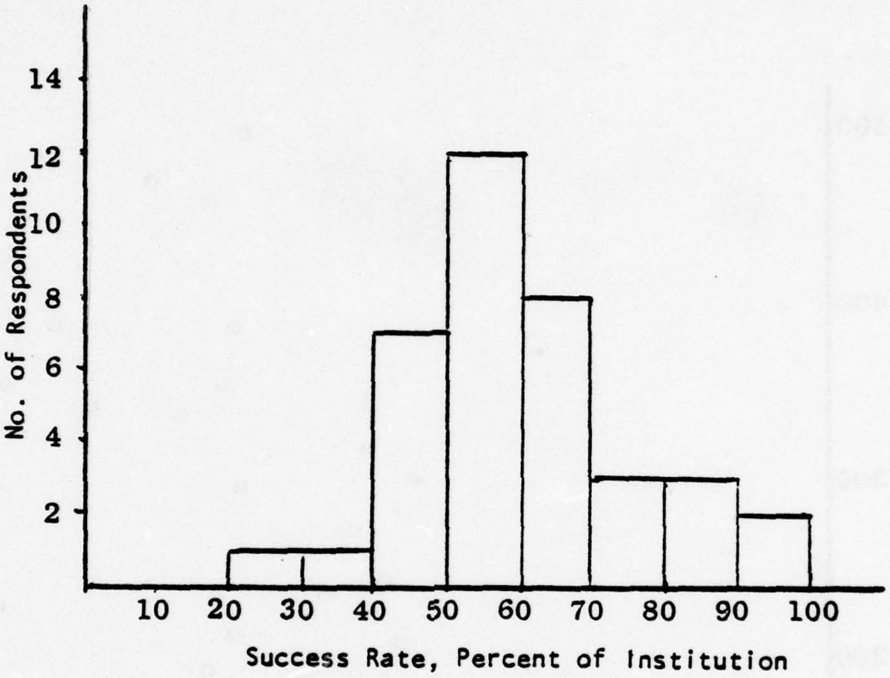

Figure 2. Distribution of respondents according to success rate of institution's proposals to the NSF Division of Materials Research, averaged over FY 1975 and FY 1976.

The data also suggest that the projects tend to be somewhat smaller at schools with smaller overall programs. A plot of the mean support per project against total NSF support from DMR appears in Figure 4. The relationships depicted in Figures 3 and 4, although not specifically treated in the questionnaire survey, suggest additional characteristics of the sample for this study.

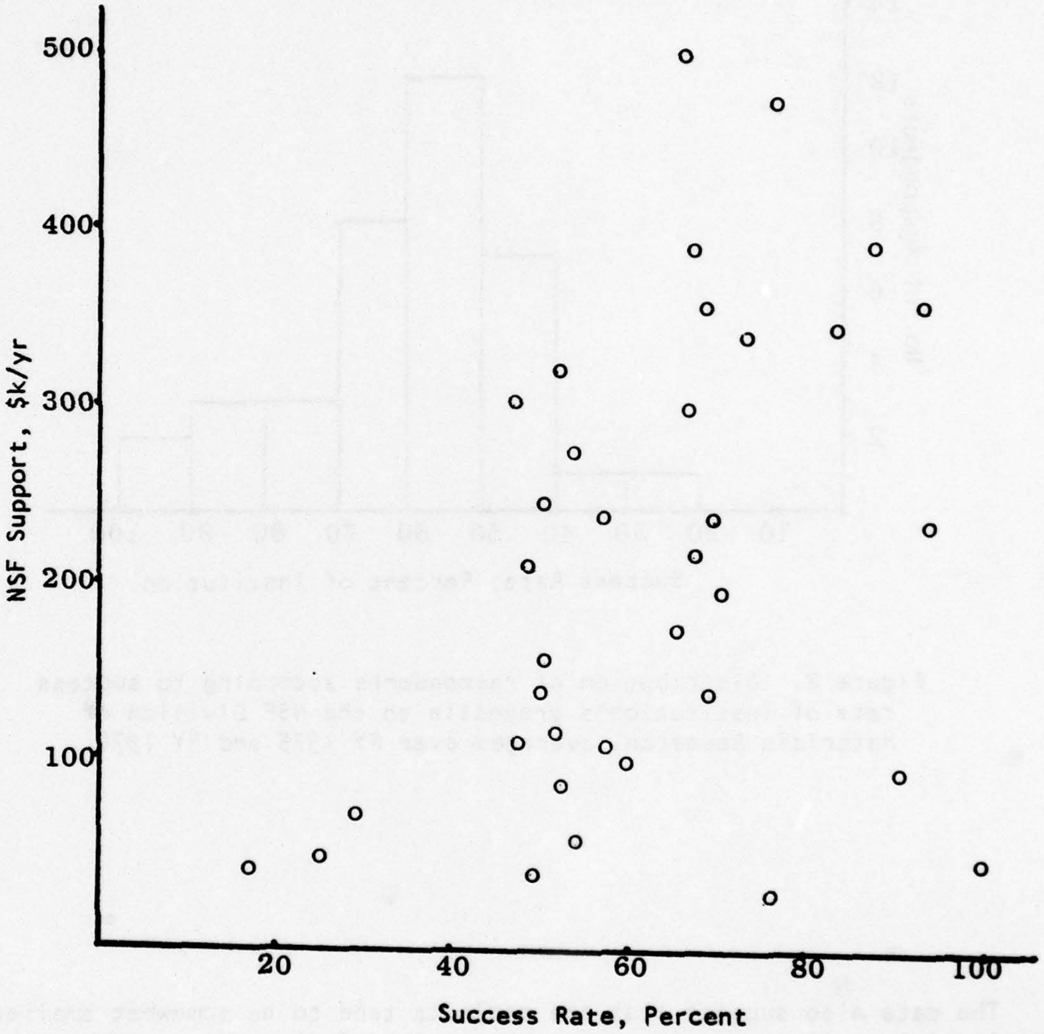

Figure 3. Correlation between program size and success rate.

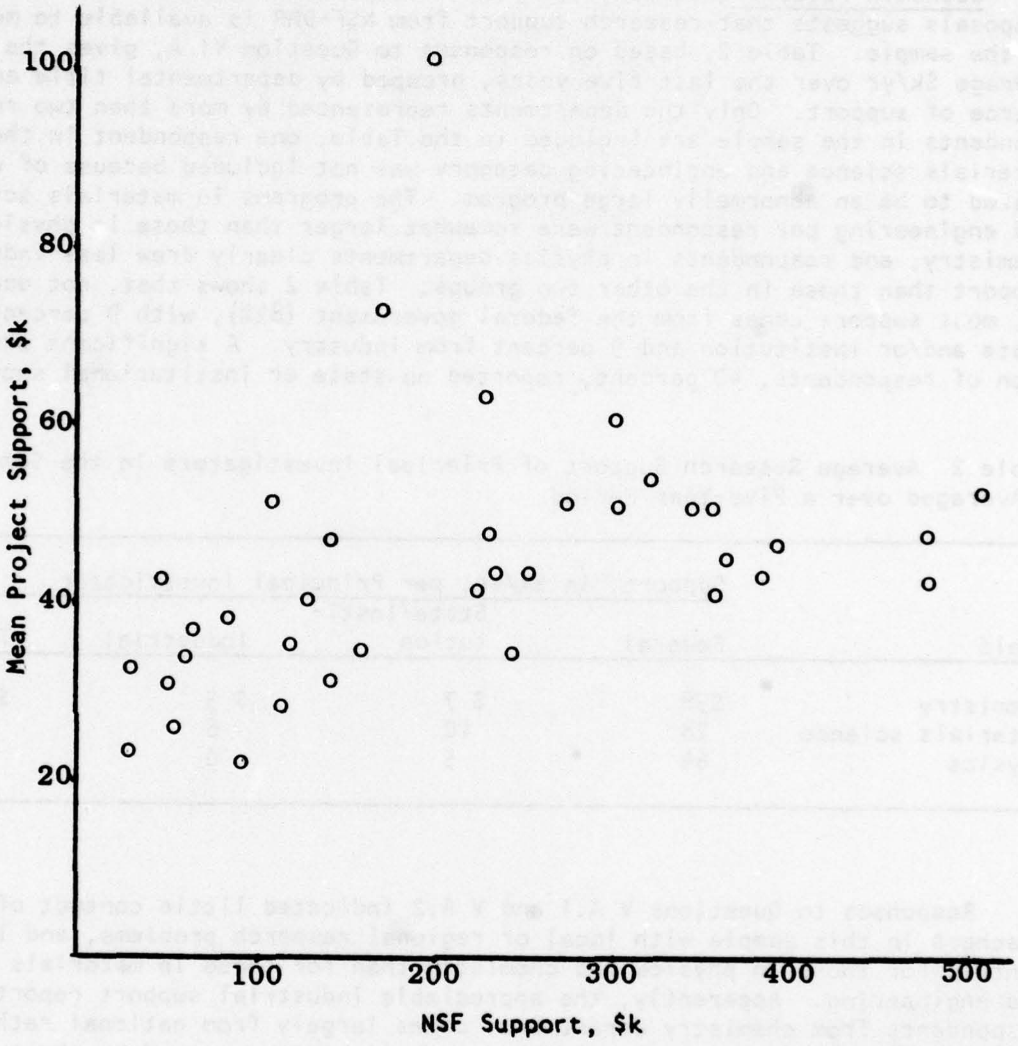

Figure 4. Correlation between mean NSF Division of Materials Research support per project and total NSF Division of Materials Research support for each institution.

Factors Affecting Research Productivity

Economic Factors (Section VI): The discussion of success rate for proposals suggests that research support from NSF-DMR is available to most of the sample. Table 2, based on responses to Question VI A, gives the average $k/yr over the last five years, grouped by departmental title and source of support. Only the departments represented by more than two respondents in the sample are included in the Table; one respondent in the materials science and engineering category was not included because of what appeared to be an abnormally large program. The programs in materials science and engineering per respondent were somewhat larger than those in physics and chemistry, and respondents in physics departments clearly drew less industrial support than those in the other two groups. Table 2 shows that, not unexpectedly, most support comes from the federal government (82%), with 9 percent from state and/or institution and 9 percent from industry. A significant proportion of respondents, 40 percent, reported no state or institutional support.

Table 2 Average Research Support of Principal Investigators in the Sample Averaged over a Five-Year Period

	Support, in $k/yr, per Principal Investigator			
Field	Federal	State/Institution	Industrial	Total
Chemistry	$58	$ 7	$ 5	$70
Materials science	78	10	6	95
Physics	64	5	0	70

Responses to Questions V A.1 and V A.2 indicated little contact of reseachers in this sample with local or regional research problems, and less contact for those in physics and chemistry than for those in materials science and engineering. Apparently, the appreciable industrial support reported by respondents from chemistry departments comes largely from national rather than local industry, and the industrial research linkages reported by those in physics departments (in response to V A.2) imply consultation and collaboration on research problems of scientific interest rather than on problems that industry is interested in supporting or willing to support.

Research Environment (Section III): Many respondents complained of too much paperwork, administrative details, red tape, and federal regulations. As noted earlier (page B.2), and somewhat unexpectedly, excessive proposal writing was not much complained of, perhaps because the sample was selected from successful researchers.

Teaching loads were not viewed as excessive by most respondents, although about 25 percent mentioned increased credit for research as desirable.

Scientific communication was a sufficiently important problem to elicit comments. Some 25 percent expressed concern, in one way or another, with isolation from peers. In most cases, institutional support for outside speakers brought into a group seemed adequate. Travel to scientific meetings, however, did not appear to be well supported; respondents reported that university support for such travel was, on the average, about $200 per year per faculty member, with most respondents relying of grant funds for their attendance of, on the average (mean), slightly more than two national and slightly more than one international meeting per year. These figures were relatively independent of field. Often university support for meeting attendance was tied to presentation of a paper or serving as a session chairman.

Facilities (Section IV): In regard to support services, library and computer services were uniformly reported as the least adequate, but there were few complaints about space. Some respondents reported problems with shops; although 75 percent reported adequate machine shops, only 55 percent approved of their electronics shops.

Not surprisingly, respondents reported equipment problems. Although some of those answering the various parts of question IV E (33-36) reported enough (63%) and adequate (71%) dedicated equipment, as many as 50 percent reported their equipment obsolete or, at best, acceptable-to-obsolete. Only 25 percent were willing to say that their dedicated equipment was at the state-of-the-art level. There was some correlation (shown in Figure 5) between the size of a respondent's program and his view of the adequacy of his dedicated equipment. Of those answering, 87 percent reported that the general-purpose equipment they needed was available locally; however, only 68 percent (of 34 respondents) reported that it was of adequate sophistication. Equivalent numbers of respondents reported a lack of university policy for equipment maintenance (20) and the existence of such a policy (19) in their institutions. Three fourths (78%) of 36 respondents reported that funds for equipment maintenance were not adequate. Seventy-eight percent also reported no funds earmarked for the replacement of obsolete equipment.

Of 35 respondents, 91 percent indicated that they had access outside their departments to the general-purpose equipment they needed and could not get locally. However, only 40 percent (of 40) reported the use of specialized regional facilities. Most of those going outside their departments for needed equipment found it in another department or university or in industrial or government laboratories. Few reported any concern about institutional barriers to the use of such outside facilities; the problems reported pertained to travel time, clumsiness of long-distance arrangements, the difficulty of working away from home base, the scheduling and adjusting of teaching commitments, and the loss of control over equipment, program, and techniques.

Supply of Students and Postdoctoral Fellows (Section II): Table 3 displays the mean number of graduate students and postdoctorals per respondent, subdivided into the departmental fields for which there were more than two respondents. Respondents in departments of chemistry and physics reported fewer

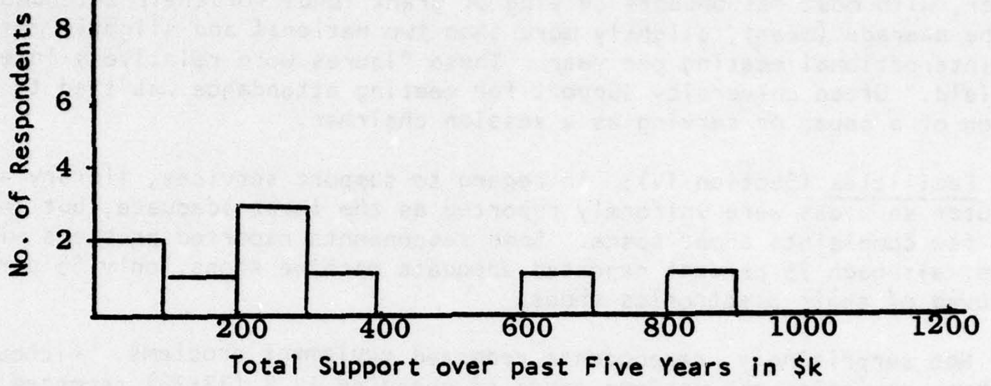

Figure 5a. Distribution of respondents who reported their dedicated equipment <u>inadequate</u>, according to the total funds available for their programs.

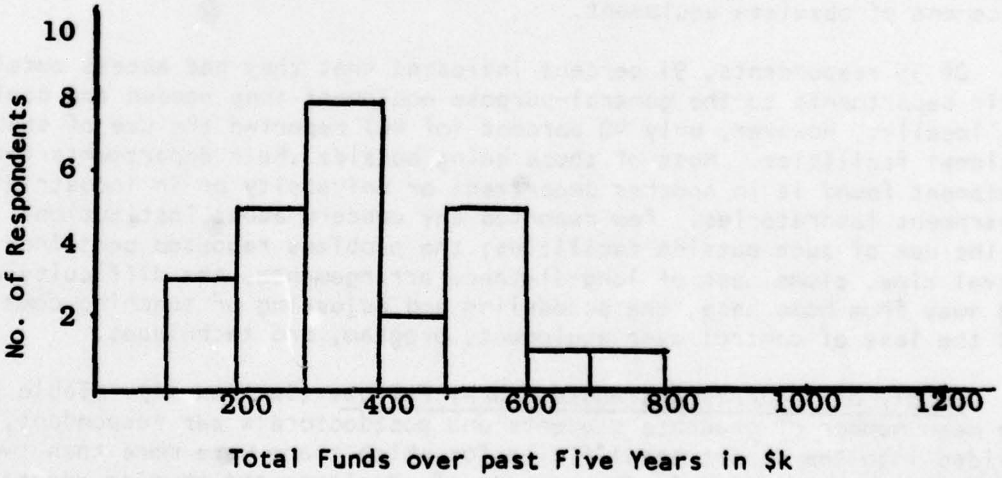

Figure 5b. Distribution of respondents who reported their dedicated equipment <u>adequate</u>, according to the total funds available for their programs.

graduate students than did those in materials science. More respondents in both these fields also reported decreases in the number of students over the past five years than reported increases, whereas the majority of respondents in materials science and engineering who indicated a change in the number of students reported an increase. In spite of recent decreases in graduate students, physicists expected an increase over the next five years; the expectations of chemists and materials scientists and engineers were for a steady state.

With respect to postdoctoral fellows, physicists and materials scientists reported a trend toward what they viewed as an inadequate supply; chemists anticipated no change in what they generally viewed as an adequate supply. Indeed, as Table 3 shows, for chemistry the ratio of postdoctorals to graduate students was somewhat more favorable than for the other two fields.

Table 3 Mean Number of Graduate Students and Postdoctorals per Principal Investigator by Department

Department	No. of Respondents	Mean No. Graduate Students	Mean No. Postdoctorals
Chemistry	8	2.9	1.8
Materials science	13	6.0	1.6
Physics	14	3.9	1.1

Use of Regional Research Centers (Section V)

Because of varied interpretations of what was meant by "Regional Research Centers," the questionnaire produced some variations in the responses. The definition used in the questionnaire was "offering cooperative research opportunities and/or facilities in your field of interest." Interpretations ranged from a competing or complementary laboratory, offering joint appointments, to service facilities performing, for example, analyses on order. Most respondents apparently interpreted the term as meaning a centralized special facility to be visited and used on a short-term basis more as a source of equipment and services than as a locus of joint research.

Table 4 presents the findings on the types of equipment and service needs most often reported by the respondents.

Of 37 respondents, 86 percent regarded the regional research center as a potential source of better facilities; 67 percent, as a source of better service to local industry; and 65 percent, as a source of better interaction with peers. Forty-four percent did <u>not</u> see the regional research center as a possible source of more stable funding.

Table 4 Types of Facilities Needs Most Frequently Reported

Needs		Number Reporting
Analytical services and facilities		14
Surface analysis (e.g., Auger, SIMS, ESCA)	(10)	
General chemical characterization	(4)	
Electron microscopy in various forms (STEM, high resolution, high voltage, etc.)		9
Materials preparation and processing		7
Synchrotron source		4
Spectroscopic (NMR, far infrared, time resolved, low temperature, etc.)		4

Provided that travel time was short enough, such facilities could be used all year, subject to scheduling of teaching duties and arranging for release time. No other institutional barriers were anticipated by the respondents.

Research Organization (Section VII)

There was little opposition expressed to the use of a team approach in research; of 30 unambiguous responses, only four could be interpreted as opposed.

Of 40 respondents, 18 indicated that they were currently involved in a research team consisting of more than one faculty member. However, only two of these teams appeared to be hierarchical, that is, under a senior member of the faculty; the rest were more a voluntary association of equals. Yet, nearly half of those indicating that they were members of a team worked under a single grant covering all members of the team. Only two respondents suggested administrative constraints, which involved adjustment of teaching loads and the need for independent visibility in achieving tenure.

Several respondents commented that team efforts could not be legislated but had to be entered into freely by interested people. Efficiency, division of labor, stability, and the need for multidisciplinary cooperation on materials were most often mentioned as reasons for a positive view of the team approach. Stimulation was another desirable feature. Negative responses suggested that originality and high-risk experiments are difficult with teams. Several also mentioned the problems of loss of autonomy and delays in the conduct of research.

APPENDIX C
ANALYSIS OF RESPONSES TO QUESTIONNAIRE B, SENT TO DEPARTMENT HEADS

Nature of the Sample (Sections I and II)

Table 5 shows the distribution of the sample among academic departments, the number of questionnaires sent, and the number of responses.

Table 5 Distribution of Sample and Response Rate

Academic Department	Questionnaires Sent	Responses Received
Biomedical engineering	1	0
Ceramic engineering	2	1
Chemical engineering	4	0
Chemistry	17	3
Engineering and applied science	1	0
Geological sciences	1	0
Materials science and engineering*	13	4
Mechanical engineering	2	1
Metallurgical engineering	2	2
Mining, etc., engineering	2	1
Physics (and astronomy)	29	12
Total	74	24 (32%)

*All departments with materials, materials science, or materials engineering in their titles, regardless of what other subjects are also included.

Because of the quite low response rate to this part of the survey, the results must be viewed with caution; however, they can suggest characteristics and problems of small research efforts in materials science for further investigation.

Figure 6 shows the distribution of departments of the respondents in terms of senior faculty, defined as full and associate professors. The median is just over 15 in a range of from 4 to 37. The sample contains a few sizeable departments but is composed mainly of medium- to small-sized ones.

Figure 7 shows the distribution of responding departments in terms of all graduate students (including part-time and Master's degree candidates, as well as PhD's) and also those engaged in materials research. Not only are most departments in the small-to-medium range overall (for example, with less than 100 students), but the materials research group is typically quite small. Only 4 of 21 departments had more than 25 materials science students, and only 8 departments had more than 15.

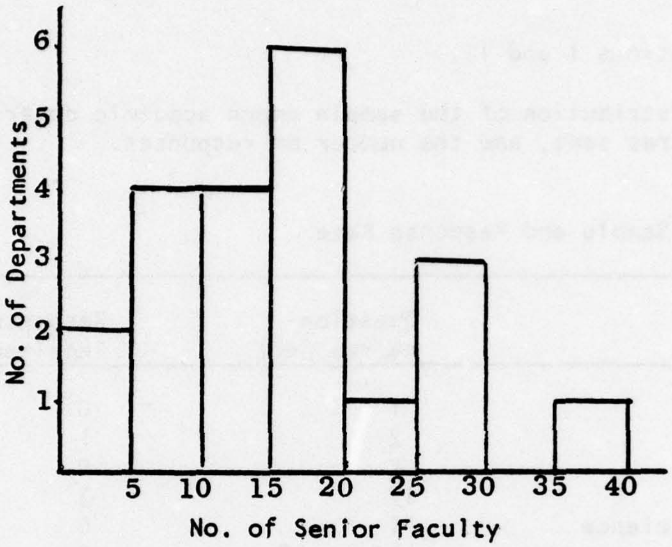

Figure 6. Distribution of departments in terms of size (number of senior faculty, i.e., professors plus associate professors).

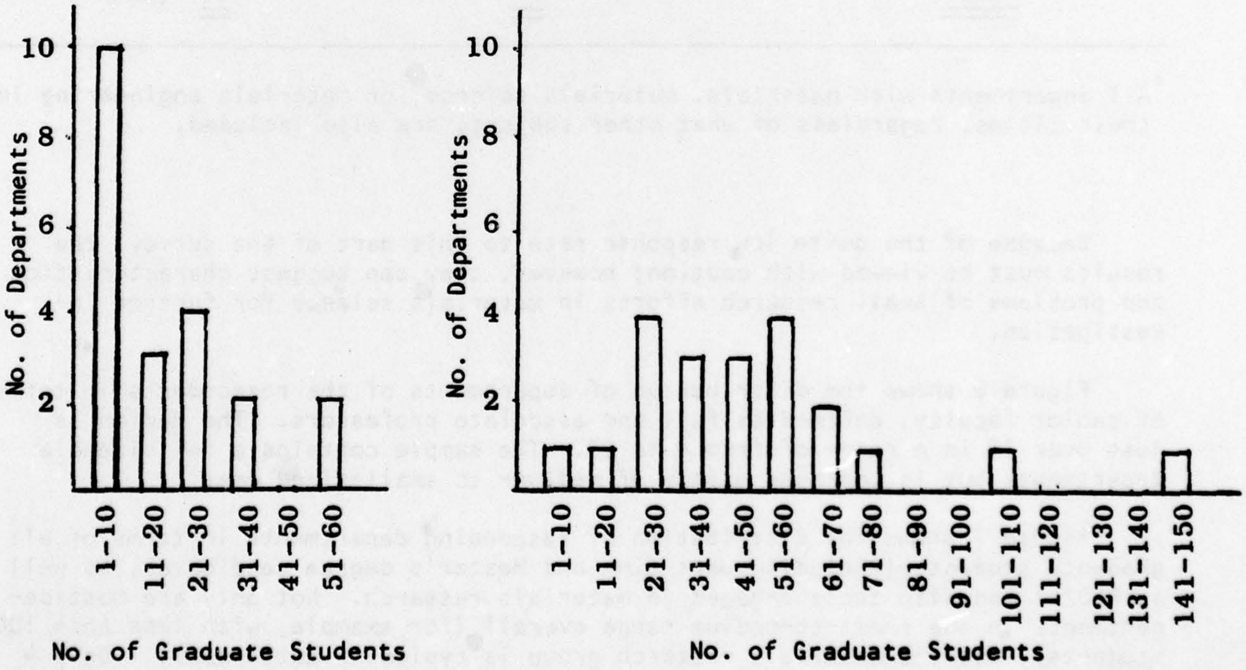

Figure 7. Distribution of departments according to number of materials sciences graduate students and total number of graduate students.

In terms of federal support for their materials research, the distribution of departments responding is shown in Figure 8. They are roughly uniformly distributed around a median of between $150k/yr and $200k/yr.

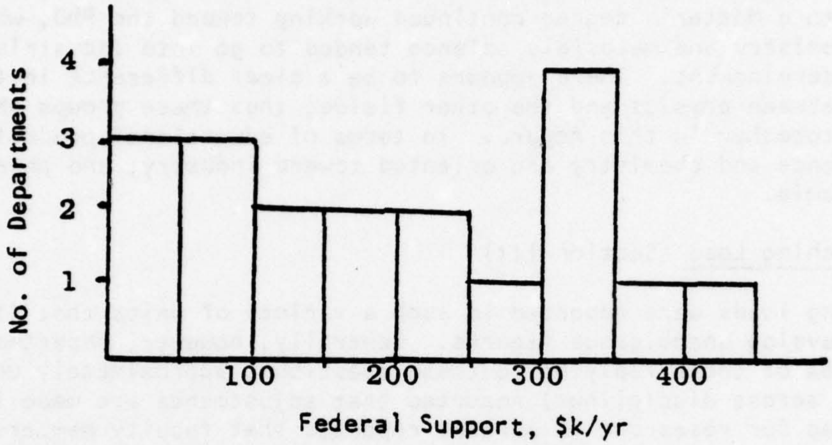

Figure 8. Distribution of federal support for materials research by number of departments.

Although the number of responses is too small for a significant analysis by field, it is useful to look at the data on graduate students grouped by the three largest fields in the sample: chemistry, materials science, and physics. Table 6 presents these data.

Table 6 Total Graduate Students and Graduate Students in Materials Science in Three Departments

	All Graduate Students		Materials Science Graduate Students	
Department	Mean	Range	Mean	Range
Chemistry	50	29-60	10	1-26
Materials science	56	17-150	26	10-30
Physics*	43	7-73	11	3-30

*Most physics departments were in the medium grouping (31-100) defined by Madey and Schoepfle, <u>Americal Journal of Physics</u> 43 (7), 637 (1975); the rest (3) were in the small category.

A majority of the PhD graduates from the materials science departments that responded to the survey appear to go into industry, as do almost half of those from the chemistry departments that responded, although more of the chemistry PhD's go into academic or postdoctoral positions than do materials sciences PhD's. Physics departments that responded indicated that nearly half of their PhD's went into academic positions. Most physics graduate students with a Master's degree continued working toward the PhD, whereas those in chemistry and materials science tended to go into industrial research and development. There appears to be a clear difference in this distribution between physics and the other fields, thus these groups should not be treated together in this regard. In terms of educational product, materials science and chemistry are oriented toward industry, and physics toward academia.

Faculty Teaching Load (Section III)

Teaching loads were reported in such a variety of units that it was difficult to develop unambiguous figures. Generally, however, departmental chairmen (76% of those replying to these questions, approximately uniformly distributed across disciplines) reported that adjustments are made in the teaching load for research; 62 percent reported that faculty members get some credit for graduate student supervision, again independently of field. The fraction of faculty engaged in research was uniformly high, with a mean across all schools reporting of about 81 percent and a range of from 33 to 100 percent. The appropriate balance between research and teaching was reported as about 50/50, with some time for other university duties. In smaller departments, a lower proportion of the faculty were apt to engage in research (see Figure 9).

Research Environment (Section IV)

Department chairmen generally gave a favorable response to questions concerning participation in off-campus centers. Nineteen departments responded to the question "Would your department participate in shared facilities or a regional center?", 12 saying "yes" and 4 some form of "probably." Sixteen responded to a similar question, "Would participation in a regional research center addressing such interests be of value to your department?", with "such interests" defined as "materials research problems or projects which are peculiar to your region or locality." Of the 16, 10 said "yes", and 5 replied with some form of "possibly."

There were advantages and disadvantages seen by the departmental chairmen in the use of off-campus facilities. The advantages cited included: (a) access to facilities and equipment not otherwise available; (b) the chance to broaden the base of expertise and to form a critical nucleus arising from the collaboration afforded by such centers; and (c) the generally improved communication with peers and the broadening of graduate student experience that participation in the activities at a center would allow.

On the other hand, 80 percent of the department chairmen responding saw hardship for their faculty members in the use of off-campus centers, and 65 percent saw hardship for themselves. The disadvantages included difficulties

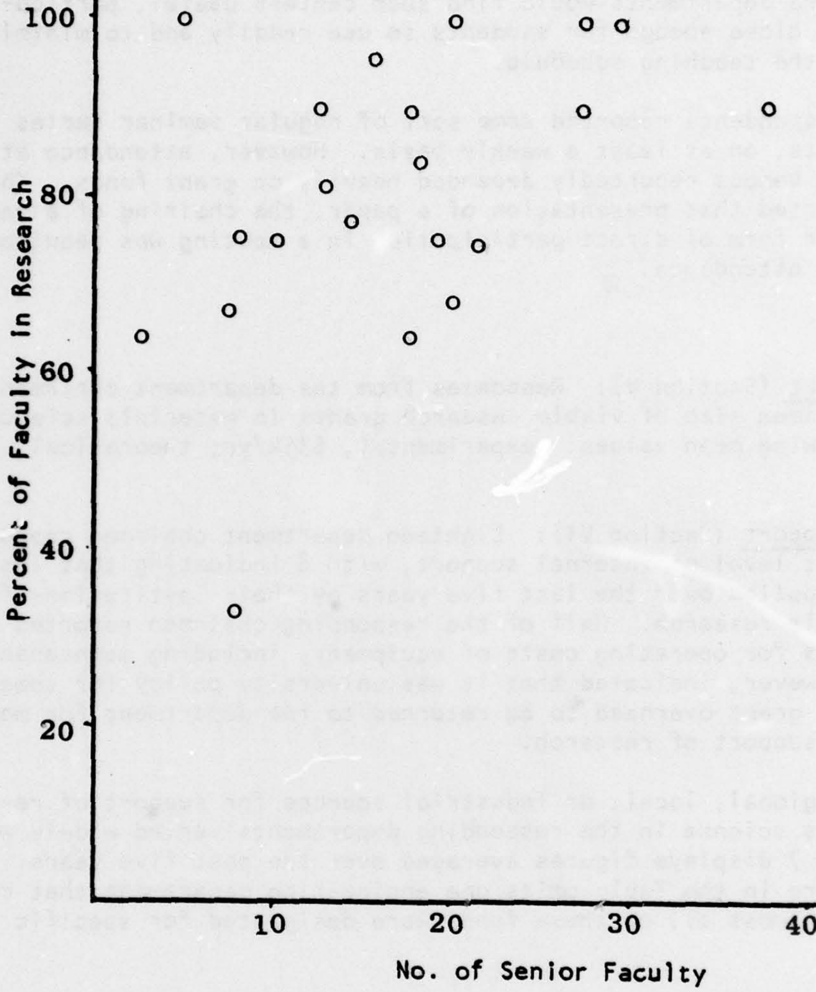

Figure 9. Relationship between department size (number of senior faculty and research activity (percent of faculty in research).

Overall, the responses seemed to suggest that although there were problems in an expanded use of regional centers or shared facilities, these were soluble and the departments would find such centers useful, particularly if they were close enough for students to use readily and to minimize interference with the teaching schedule.

Almost all respondents reported some sort of regular seminar series in their departments, on at least a weekly basis. However, attendance at meetings away from campus reportedly depended heavily on grant funds. Thirty-eight percent reported that presentation of a paper, the chairing of a session, or some other form of direct participation in a meeting was required to obtain support for attendance.

Research Support

Federal Support (Section V): Responses from the department chairmen concerning the minimum size of viable research grants in materials science produced the following mean values: experimental, $35k/yr; theoretical, $23k/yr.

Nonfederal Support (Section VI): Eighteen department chairmen responded to a question about level of internal support, with 8 indicating that less than $5k/yr was supplied over the last five years by their institutions for support of materials research. Half of the responding chairmen reported no institutional funds for operating costs of equipment, including maintenance. Nine out of 21, however, indicated that it was university policy for some funds derived from grant overhead to be returned to the department for maintenance or direct support of research.

Funds from regional, local, or industrial sources for support of research in materials science in the responding departments varied widely with discipline. Table 7 displays figures averaged over the past five years. The "Overall" figure in the Table omits one engineering department that reported $500k/yr. Almost all of these funds were designated for specific projects.

Table 7 External Nonfederal Support for Materials Science Research

Department	$k/yr
Chemistry	7
Materials science	37
Physics	7
Overall	13

In regard to research initiation and termination, almost all universities provided some seed money, available for one or two years, to get a new faculty member started in research. Some support usually was also available (in 80% of the responding departments) on termination of a grant to keep the graduate students going, if only in the form of teaching assistantships. A number of chairmen mentioned specifically the need for longer support periods, better matched to the duration of the normal graduate student research program.

Figure 10 shows the distribution of departments according to their annual expenditures for materials-related research equipment, averaged over the past five years. The median is about $50k-$60k/yr. These figures might be compared to modern equipment costs, such as $100k-$500k for electron microscopes, or about $400k for an ion microprobe.

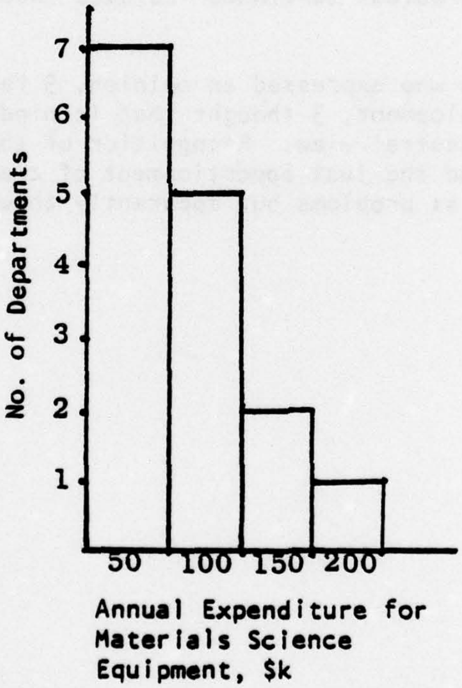

Figure 10. Distribution of departments by annual expenditure for materials research related equipment for department.

Research Organization (Section VII)

The use of some form of team organization of research was reported by 15 of the 21 department chairmen responding. These teams were organized more around common research topics than around shared facilities. Most were loose associations, or alliances, of equals on a voluntary basis, with the use of separate grants for each investigator about as prevalent as the use of a single grant for the team. Heirarchical organizational arrangements were seldom reported in this sample.

With one exception, the chairmen of departments using a team approach reported that in their opinion this type of organization increased productivity. The major reasons given for favoring the team approach were (a) an increase in the expertise available, in the breadth of approach to a problem, and in the facilities available and (b) a better chance of obtaining support. Some respondents expressed the view that, for a small department, concentration in a few fields allowed these to be investigated intensively. It was also pointed out that this concentration had a negative effect in that it limited faculty members in choice of research topic and students in choice of learning area. Collaboration between universities was suggested as a way to minimize this negative effect. Other problems mentioned included interpersonal and interdepartmental friction.

Of 14 department chairmen who expressed an opinion, 9 felt that team research helped in career development, 3 thought that it hindered career development, and 2 expressed a neutral view. Recognition of the contributions of junior members of a team and the just apportionment of credit for research accomplishment were perceived as problems but apparently thought to be soluble.