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A STUDY OF THE IMPACT OF THE CERAMIC MATERIALS RESEARCH PROGRAM AT THE UNIVERSITY OF WASHINGTON

GRANT NUMBER NGL 48-002-004

by

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University of Washington

Seattle, Washington

November 15, 1969

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A STUDY OF THE IMPACT OF THE CERAMIC MATERIALS RESEARCH PROGRAM AT THE UNIVERSITY OF WASHINGTON

PART I

INTRODUCTION

This is the final report to the National Aeronautics and Space Administration of research conducted during the period from June 15, 1968 through September 15, 1969 with supplemental funds to Grant Number NGL 48-002-004. The research team for this project was:

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The Ceramic Materials Research Program is an interdisciplinary program at the University of Washington funded by Grant Number NGL 48-002-004 from the National Aeronautics and Space Administration. Established in June 1963 by the initial award of grant funds, the program has completed its sixth year of operation. The initial basic goals of establishing an interdisciplinary research program in ceramic materials were the training of additional

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*Currently Assistant Professor of Management, College of Business Administration, Drake University.

engineers and scientists and the advancement of fundamental research in ceramics. An additional purpose was the development, at the recipient institution, of an enduring capability for research upon the nature and properties of ceramic materials.

Technical evaluation of the research effect of this interdisciplinary program has been made periodically. Each Fall, Mr. James J. Gangler, NASA technical monitor for the program has discussed the research with the faculty supervisors and each Spring a committee consisting of NASA and/or NASA contractor-personnel has reviewed the overall program. In addition, status reports which briefly describe recent progress and future plans are submitted semiannually. The results of these visitations and reports have been generally favorable, relative both to research accomplishments and to the interdisciplinary efforts of the participants.

On June 15, 1968 this project to evaluate the impact of the Ceramic Materials Research Program was initiated. Although there had been substantial technical evaluation of the program, there had been no detailed evaluation of its organization and administration or its effect on the educational and research efforts of the University of Washington. The objective of this study was to determine the impact of the Ceramic Materials Research Program upon the University of Washington. The study investigated the impact at three levels: (1) the Ceramic Engineering Division, (2) the College of Engineering, and (3) the University.

During the first phase of the study we identified the administrative, organizational, and structural relationships of the CMRP from the beginning of the program in 1963 through March 1969. We investigated the changes in the program and the factors causing those changes. Various measures of the level of program activity--such as number of graduate students, number of seminars, and extent of faculty involvement--were utilized. This historical perspective of the CMRP provided the foundation for the interview-questionnaire phase of the study.

The second phase of the study involved a social-psychological analysis of the attitudes, opinions, and reactions of the various participants in the CMRP. Initially, we used questionnaires in order to obtain information from graduate students and faculty participants in the program. This was followed by personal interviews with all faculty participants and with the administrative staff in order to investigate, in more detail, questions arising from the written responses. This allowed us to develop broader and deeper insights into the program. We have also interviewed a number of people within the NASA organization to obtain general information concerning NASA-sponsored University programs.

The final stage of the study was the interpretation and evaluation of data. We developed conclusions concerning the impact of the CMRP with special emphasis on the organization and administration of the CMRP, the interface between this program and NASA, and an evaluation of the progress toward meeting program objectives.

The results of this investigation were presented in:

> John W. Stockman, An Appraisal of the Impact of an Interdisciplinary Research Program: The Ceramic Materials Research Program at the University of Washington, Doctoral Dissertation, University of Washington, Seattle, Washington, 1969.

This document has been made available in its original form to various interested parties at NASA and the University of Washington.

In this final report to NASA on the research project it did not seem appropriate to include all of the information contained in the dissertation. In order to reduce redundancy, we will provide a review of the findings and then move to further analysis and interpretation. In this section we will not be bound by the more formal research design of the dissertation. In addition, we will present a number of tentative conclusions based upon our informal observations. Members of the research team had discussions with professors and students directly engaged in the Ceramic Materials Research Program, University administrators, members of industry, and NASA officials which provided relevant information and insights. Thus, a number of "informed impressions" were developed which cannot be presented under a strict research design. The research team has continually discussed these impressions and concluded that it will be useful to present our interpretations. It is anticipated that Part III of this report, Analysis and Interpretation of Research Findings, will serve as a basis for further program review and perhaps future research efforts.

The plan of presentation of this report is as follows:

Part I Introduction

Part II An Overview of the Findings of the Research Study

Part III Analysis and Interpretation of Research Findings

PART II

AN OVERVIEW OF THE FINDINGS OF THE RESEARCH STUDY

Since the end of World War II there has been a significant increase in federal government sponsorship of research programs at universities. At the macro level, there is general recognition that these programs have contributed significantly to the development of undergraduate and graduate programs in the various academic fields and to the creation of new knowledge. There have been many studies which have looked at the technical outputs from these programs. However, there is limited information concerning the impact of specific research programs upon the structure, processes, and goals of a university. This study was designed to investigate in detail the impact of a specific federally sponsored program--the Ceramic Materials Research Program at the University of Washington, funded by a grant from the National Aeronautics and Space Administration. It provides information on the nature of the program and on the contributions which it has made toward meeting the university's and the sponsoring agency's objectives. It also sheds new light upon the administrative and organizational approaches necessary for successful objective accomplishment.

This part of the report will be presented in four sections:

(1) NASA-University Relationships

(2) The Ceramic Materials Research Program

(3) Research Design and Method of Study

(4) Research Findings

NASA-University Relationships

The relationships between NASA and universities is part of the overall consideration of the impact of federally sponsored programs upon our society. There has been a growing importance in the interface and relationships between the federal government and institutions of higher learning.

> The condition of mutual dependence between the federal government and institutions of higher learning and research is one of the most profound and significant developments of our time. It is abundantly clear that the fate of this nation is now inextricably interwoven with the vigor and vitality of these institutions. In turn, the fate of these institutions is dependent upon the wisdom and enlightenment with which federal funds are made available in support of their activities. It is imperative, therefore, that the conditions governing this mutual interdependence be subject to continuing appraisal and that the policy underlying administration of federal programs in support of research assures that this relationship will continue to be mutually beneficial.[1]

One of the major problems growing out of this growing interdependence is that of measurement of accomplishments of the various programs. Before considering the impact of one such program, the Ceramic Materials Research Program, it is desirable to look at a number of broader issues, such as the objectives and programs of NASA, the overall relationship of federal programs to institutions of higher education, and the problems associated with the measurement of the impact of federal programs. This preliminary investigation sets forth the environmental framework for the more detailed investigation of the Ceramic Materials Research Program.

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[1] Federal Support of Basic Research in Institutions of Higher Learning, Committee on Science and Public Policy, National Academy of Sciences - National Research Council, Washington, D.C., U.S. Government Printing Office, 1964.

NASA's Objectives and Programs

The unexpected prestige and success enjoyed by the Soviet Union as a result of the launching of Sputnik I in 1957 was undoubtedly one of the major forces which led to the establishment of the National Aeronautics and Space Administration (NASA). For the first time, intensive consideration of the nation's role in the exploration and utilization of space was formally undertaken. Subsequently, recommendations evolved for the creation of a civilian space agency to direct a dynamic program of space exploration. The National Aeronautics and Space Act of 1958 formally established NASA.

Perhaps the most important goal guiding NASA is that activities are to be directed toward the peaceful utilization of space. It is clear that Congress did not intend for NASA to engage in the development or implementation of military systems in space.

Explicit objectives delineated in the Space Act of 1958 were that the space activities of the United States should contribute substantially to:

> (1) The expansion of human knowledge of phenomena in the atmosphere and space;
> (2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles;
> (3) The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space;
> (4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;
> (5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;
> (6) The making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities,

> of information as to discoveries which have value or significance to that agency;
> (7) Cooperation by the United States with other nations and groups of nations in work done pursuant to this act and in the peaceful applications of the results thereof; and
> (8) The most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment.[2]

In early 1961 the national space program was changed dramatically with the announcement of the objective of a manned moon landing and return by 1970, the Apollo Program.

A NASA organization structure, adapted to meeting the requirements of rapidly changing technology and many diverse programs has evolved. There are four major program areas--manned space flight, space science and applications, tracking and data acquisition, and advanced research and technology. These program areas are supported by a complex of functional activities reporting to the Office of the Administrator and by a number of field installations. The four program offices serve as the focal point within the NASA organization for integrative management on a program basis.

Many of the research and development activities conducted in conjunction with the national space program are performed in organizations other than NASA. Although overall control and direction is vested in NASA, much of the actual work is performed in the laboratories and/or plants of these outside establishments.

A recent article pointed out that NASA attempts to create "centers of excellence" in American industry and institutions of learning through its

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[2] U.S. Statutes at Large, Vol. LXVII, p. 427.

funding. Approximately 93 cents of every $1 appropriated for NASA ultimately benefits over 200 colleges and universities and some 20,000 prime and sub-contractors.[3] Thus, by contracting out much of its work, NASA not only succeeds in achieving the primary goals of the space program, but it also fulfills a secondary goal of proliferating the overall scientific knowledge of the nation.

There are approximately 200 universities currently receiving support from NASA in the form of grants or contracts. About 1750 grants or contracts are presently being funded for approximately $95 million.[4] Specific programs involving universities, such as the Sustaining University Program, have been substantially reduced. The SUP has been reduced from 150 to 60 participating universities, and funding has been cut from $46 million to $10 million within the past few years.[5] The effects of such cutbacks are far-reaching.

NASA's university programs are a part of the many federally sponsored programs in institutions of higher education. There are a number of broad issues related to these programs.

Federal Programs and Institutions of Higher Learning

Beginning with the tremendous technological and scientific explosion of the 1950's, federal programs have increasingly supported institutions of higher

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[3] John Mecklin, "Jim Webb's Earthy Management of Space," *Fortune*, August, 1967, p. 85.

[4] U.S., Congress, House, Committee on Appropriations, *National Aeronautics and Space Administration Appropriations for 1969*, Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, 90th Cong., 2nd Sess., 1968, 1294.

[5] *Ibid.*, 1295.

learning as a means of ensuring continued progress in this so-called "age of innovation." Support is provided to help explore the ramifications of scientific progress and to discover what alternatives exist in the utilization of the newly acquired knowledge. Never before has the responsibility of government vis-a-vis the support of education been more apparent than it is today.

It is also becoming apparent that for many institutions, the relationship is becoming one of growing dependence, to the extent that a great many institutions and programs of study would cease to exist if federal funds were withdrawn. It is difficult to assess the full impact of federal programs upon higher education, but it is clear that the effect has been great. Indiscriminate or random cutbacks in federal support would seriously jeopardize our educational system.

The major impact of federal support has come at the graduate level, in the sciences, and at large, prestigious public and private institutions. The current trend in governmental cutbacks will seriously impair or possibly eliminate many graduate research programs. Cutbacks primarily affect research activities in the short-run, but the ultimate long-run effect is undoubtedly a weakening of educational opportunities for many individuals. The future of not only university research activities, but also graduate education is inextricably dependent upon continued federal support. There is a need to carefully assess past and current performance of university programs supported by federal funds to determine the full extent of the ramifications. To indiscriminately eliminate support without careful assessment may yield consequences which can never be corrected. However, there are many very difficult problems associated with measuring the impact of federal programs.

Measuring the Impact of Federal Programs

The multitude of major federal programs such as those concerned with poverty, space, defense, social welfare, transportation, and urbanization necessitate the outlay of huge sums of money in order to achieve their goals, stated or implied. Future planning and policy making depends a great deal upon whether or not these programs are adjudged as successfully accomplishing the goals set for them. The problems of measuring the benefits to society are exceedingly complex.

The space program, with its stated primary goals of space exploration and utilization, undoubtedly has many second-order consequences. The new technological discoveries it has spawned affect not only the quantity and quality of material existence, but also the direction of educational programs, as well as social goals and values.

Underlying the preceding discussion is the notion that to be successful, federal programs should be organized and administered to reflect a responsiveness to environmental changes. In order to reflect an awareness of and reaction to the changes which take place, an organization framework built upon a cybernetic information feedback system should be achieved.

On strictly a theoretical basis, accurate measurement and automatic feedback can be built into any organization model. In reality, however, neither really exists in a form which ensures prompt and appropriate responses to changes in the environment. In fact, feedback often is so slow that much effort and many dollars are wasted on programs which may be obsolete in terms of current needs. At this point in time, we do not possess the tools to accurately measure the results of federal programs. However, several approaches have been utilized in recent years to assist governmental policy makers in making decisions which affect the entire nation.

We have developed an elaborate system of national economic accounting which is useful in establishing national goals and programs. One of the most important measurements of our progress is growth in GNP. The reliance upon statistical and economic measures to assess the state of the nation can be observed in the manner in which we report much of our governmental information. Budget messages, employment data, economic indicators, the President's Economic Report, and even the State of the Union Address by the President, all depend heavily upon economic statistics of one sort or another.

This reliance upon economic factors fails to measure many of the social impacts of various government programs or services. Without an accurate reflection of both the economic and social impact of such programs, government policy is at best incomplete and at worst inappropriate and misleading. The feedback of both economic and social impacts is necessary if sound budgetary decisions leading to astute national policy are to be made.

The recently developed planning-programming-budgeting system now being utilized by many federal departments is a further attempt to develop more effective means for establishment of national policy and for program planning and evaluation. In introducing this system to many new areas of national government, President Johnson pointed out that it would enable government policymakers to:

1. Identify our national goals with precision and on a continuing basis.
2. Choose among those goals the ones that are most urgent.
3. Search for alternative means of reaching those goals most effectively at the least cost.
4. Inform ourselves not merely on next year's cost, but on the second, and third, and subsequent years' cost of our programs.

5. Measure the performance of our programs to ensure a dollar's worth of service for each dollar spent.[6]

At first glance, the PPBS system appears to be the answer to the measurement problem identified earlier. It attempts to clarify objectives; introduces cost-effectiveness analysis and program competition; and relates this information to national goals. Upon closer analysis, however, one becomes wary of the semantics involved; much of the terminology is ambiguous and little is defined operationally. For instance, who determines the national goals which the multitude of programs are designed to achieve? What techniques are available, other than the traditional economic measures, to improve the measurement of performance and to assess the benefits resulting from such programs? And, finally, how is the comparison of national goals vis-a-vis program output to be made?

If an information feedback system is to be truly beneficial, it must make use of social measures as well as the traditional economic approaches. Recently, many writers are advocating a system of national social accounting. They recommended that we turn our attention toward the development of social indicators which will provide us with measurements of social as well as economic progress.

The area of social accounting is so new that few, if any, operational models exist to guide one in exploring the social ramifications of a given program. Much of the initial work in this area emerged as an attempt to assess the impact of the space program. Although the advances are minimal,

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[6] U.S., Congress, Senate, Subcommittee on National Security and International Operations of the Committee on Government Operations, Planning-Programming-Budgeting, 90th Cong., 1st Sess., 1967, p. 1.

it appears that current efforts will have a significant impact upon future thinking. Development of a system of national social accounting would provide much new information necessary for national policy formulation as well as program planning and evaluation.[7]

In the appraisal of the national impact of many governmental programs we are hampered by the lack of explicit social indicators. If we were dealing with a purely economic problem, we would have a vast array of economic statistics which could provide adequate means of measurement. However, in evaluating such a complex social issue as the impact of NASA's programs upon our society we must rely upon relatively incomplete and inferential data. Therefore, more meaningful information might be gained by looking intensively at a specific NASA-University program.

The Ceramic Materials Research Program

This report is concerned with a specific NASA sponsored university research program--the Ceramic Materials Research Program at the University of Washington.

The Ceramic Materials Research Program was established at the University of Washington on June 1, 1963, under the National Aeronautics and Space Administration Grant Number NGL 48-002-004. The stated objectives of the program are: (1) the education and training of Ph.D. students in ceramic engineering and associated disciplines; (2) the development of interests of

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[7]The most comprehensive works to date dealing with the general topic of national social accounting are Raymond A. Bauer (ed.), Social Indicators (Cambridge: The MIT Press, 1966), and Bertram M. Gross, The State of the Nation: Social Systems Accounting (London: Social Science Paperbacks, 1966).

colleagues in other disciplines within the university to do research on ceramic materials; (3) the accomplishment of fundamental research upon the nature and properties of ceramic materials; and (4) the development of an enduring research capability at the University of Washington. Subsequently, a fifth objective was interjected into the program, namely, to develop communications between the university personnel and those interested in ceramic materials research at NASA research centers, other federal agencies, ceramic and aerospace industries, and other institutions of higher learning.[8]

In order to accomplish these stated purposes, the research funds have been used to make financial support available to graduate students and to members of the faculty for research on ceramic materials. In addition, funds are available to purchase capital equipment necessary for the implementation of such research.

The interdisciplinary framework of the CMRP is perhaps its most important facet. Weekly seminars by participating or visiting faculty members and discussion groups within research areas are conducted to enhance the interaction of the participants. During the academic year 1968-69, the grant supported a total of 25 research projects supervised by 22 faculty members from 8 academic disciplines. Student participation at the present time includes 5 M.S. and 20 Ph.D. students in 8 academic disciplines.

Research Design and Method of Study

The major function of an exploratory study is to gain additional knowledge about a phenomenon in order to provide new insights into its occurrence

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[8]Denver Research Institute, Proceeding of the University of Denver Colloquium on the Effects of a National Space Program on Universities (Denver, April 4-5, 1968), pp. 147-148.

and consequence. When existing knowledge is minimal, the research design must be flexible enough to capture as many divergent aspects surrounding the phenomenon as possible. In light of the limited number of previous studies and the comparatively small amount of data available concerning the impact of university programs supported by NASA, it became obvious that an experimental design, purporting to test explicit hypotheses was premature. Recognizing the limitations, an exploratory--rather than an experimental--design was chosen.

A researcher can adopt any of several approaches to data collection congruent with the exploratory framework.[9] This study employed a tripartite approach to data collection consisting of: (1) an examination of existing records available on the CMRP; (2) semi-structured questionnaires; and (3) personal interviews. This multiple approach provides a basis for both a quantitative and qualitative appraisal of the impact of the CMRP.

Examination of existing records provided an indication of the more obvious material benefits that have ensued as a result of the CMRP. Specific factors reported are the organizational structure, administrative framework, and research activities of the CMRP. Utilizing the semi-annual program reviews submitted to NASA since the beginning of the CMRP, the overall growth and development of the program was investigated.

Many of the benefits accruing from the CMRP were easily discernible. Information concerning equipment acquisition, student matriculation, faculty involvement, and departmental representation was obtained by consulting historical records. These data were concrete, factual materials not requiring

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[9] Claire Selltiz, et al., Research Methods in Social Relations (New York: Holt, Rinehart and Winston, 1959), p. 52.

subjective interpretation by the researcher. However, they do not represent the full impact of the program.

In order to more thoroughly investigate the personal and organization impacts of the CMRP, participants were asked to complete a questionnaire dealing with various aspects of the program. Faculty and administrative personnel were interviewed to obtain a wider range of responses to more value-laden questions. This study assumed that the attitudes and opinions of individuals intimately involved in the CMRP are as important in evaluating the impact as are the more obvious material benefits.

Research Findings

Within the College of Engineering, concentration upon the many engineering aspects of materials is pursued in the Department of Mining, Metallurgical, and Ceramic Engineering (see Figure 1). The Division of Ceramic Engineering was established as an academic discipline in 1919 at the University of Washington. It received support through the College of Mines until 1947 and subsequently through the College of Engineering. A major teaching and research laboratory facility was constructed as a result of a $500,000 State Legislature appropriation in 1961. An additional allocation of $197,000 was awarded for the acquisition of instruments and other capital equipment in 1963.

Program Areas

The initial research proposal submitted to NASA, dated March 14, 1963, outlined various research projects which represented the spontaneous interest of faculty members who desired to participate in the CMRP. For the most part,

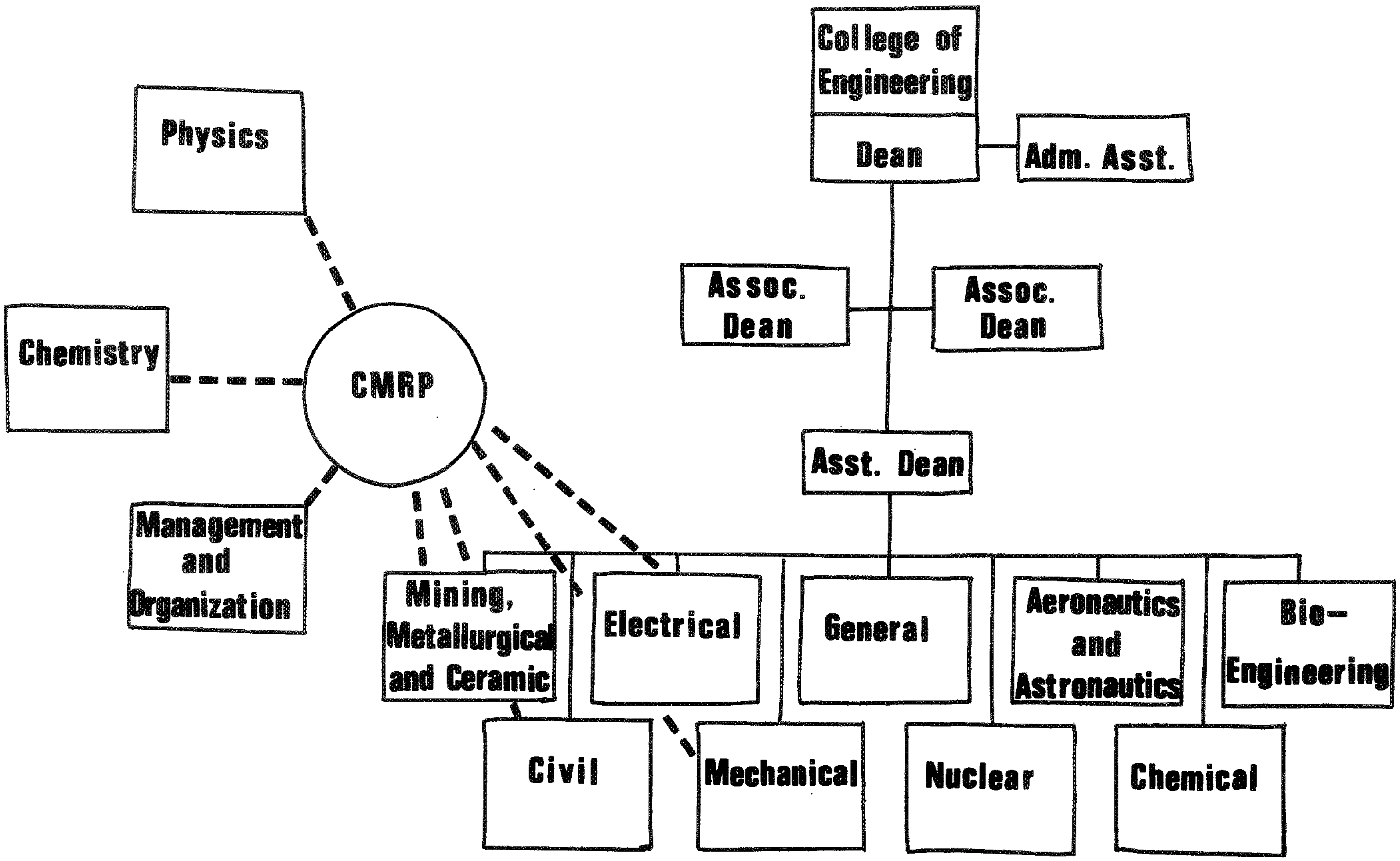

Figure 1

ORGANIZATION STRUCTURE OF THE COLLEGE OF ENGINEERING AND THE CMRP AT THE UNIVERSITY OF WASHINGTON these projects were small, independent endeavors that were undertaken to expedite the initial progress of the CMRP. Areas included environmental effects on ceramic materials, development of new ceramic materials, processing techniques, structural design investigations, and the gathering of fundamental data at high to very high temperatures.

It was soon recognized that if the CMRP was to become a viable research program, coordination and integration of research activities was necessary. In a supplementary proposal on May 13, 1963, the scope of the overall research effort and the intended meaning of ceramic research was delineated. A general criterion for considering an acceptable project was that the studied materials or phenomena be of ceramic interest or that they represent model studies clearly related to ceramic materials and space orientation. Hereafter, the overall research direction of the CMRP was to be organized along lines of interest relating ceramic materials to energy effects. The major energy forms under which research would be related were: (1) chemical; (2) electrical; (3) thermal; (4) mechanical; and (5) radiation--other than thermal.

Second-year research endeavors continued to follow the energy form categorization. Rather than continue to support a number of small projects, it was decided to focus attention and support on a few select areas in order to achieve national visibility. Accordingly, the development of areas of proficiency in the mechanical and chemical areas was initiated. The priority assigned to these areas was exemplified by rather heavy funding and reflected the feeling that through the development of well-conceived research areas, faculty members from many departments within the University could effectively be drawn into the overall program.

Third-year research continued the development of areas of proficiency in the chemical and mechanical areas. Major emphasis within the chemical study areas concerned research on the zirconium-oxygen-carbon system. Selection of the Zr-O-C system as the subject for the general study of the effects of the chemical environment upon ceramic materials was proposed to allow greater interdisciplinary coordination and integration of research activities. Also during the third year, the original research areas were modified slightly into new categories, namely: (1) chemical; (2) surface phenomena; (3) solid state ceramics; (4) processing; and (5) radiation.

During the fourth year, consolidation of the radiation and solid state ceramics areas took place to further identify closely related areas of research. Thus, the broad research areas were reduced to four namely: (1) chemical (Zr-O-C); (2) solid state; (3) surface phenomena; and (4) processing. Any future research suitable for support, yet not fitting into any of the prescribed categories, would be included as "miscellaneous."

A significant reorientation in research areas took place during the fifth year. Because of the prior success of working on a common system in the chemical areas (Zr-O-C), a similar approach to the entire program was adopted. The change also reflected an attempt, by stressing a unique research approach, to avoid concentration in the solid-state area which other schools were focusing upon. Subsequent research was directed toward obtaining additional scientific and engineering knowledge about refractory ceramic structural materials. This change was prompted, in part, by future requirements for hypersonic and re-entry vehicles to be developed utilizing materials that exhibit thermal and structural integrity. This broad problem area includes studies in the chemical, mechanical, solid-state, and processing areas. To account for possible overlap, and to assist in a further refinement of the research program, the surface phenomena area was consolidated into one of the other areas, and a new area--atomic and molecular--was established to encompass solid-state and radiation activities. Following this restructuring, four broad research areas evolved: (1) mechanical; (2) processing; (3) chemical; and (4) atomic and molecular.

Nearing the end of its sixth year, the CMRP is continuing to conduct research in the areas established during the fifth year. No significant changes in research scope or direction have occurred during the interim period.

This brief historical account shows the flexibility and responsiveness of research activities in the CMRP. Considerable change has taken place since the first year, and in every instance it occurred primarily to improve the overall program. Initially, research activities were somewhat unstructured and unrelated, but over time, they evolved into a structured and coordinated categorical framework. Responding to both internal and external requirements, the CMRP has evolved into what would appear to be a viable research program.

Administrative Structure

The proposal for the Ceramic Materials Research Program submitted to NASA in March 1963 did not set forth a plan of organization and administration. NASA requests that the University develop a more specific plan of organization and administration, to be submitted as a supplement to the original proposal. It was necessary for the University of Washington to establish new organizational arrangements for this program. This supplement, after substantial internal discussion and adjustments, was submitted to NASA in May, 1963, and served as the "first approximation" for the administrative structure.

The development of a viable organization did not occur immediately. There were a number of administrative difficulties which were not resolved until the second year of the program. There was a learning-adapting process to find satisfactory administrative and organizational arrangements. The lack of a clear-cut and fully-agreed-upon administrative structure during the early phases of the CMRP can be attributed to a number of factors. First, the program was initiated with very short lead time and it was necessary to develop new administrative policies and procedures after the grant was received. There was a concurrency approach in which the necessary organization evolved while the program was underway. Second, this type program was new to the University of Washington. It did not have established organizational structures and administrative procedures which could be readily applied. The receipt of such a large grant was not a routine event for the University. It was exceptional and required many new organizational and administrative adjustments. The various participants in the program, faculty and administrators, had to work out new relationships and roles for the program. Third, this was a very large grant for a relatively small division of the University. The Ceramic Engineering Division had four faculty members and no administrative structure. The primary authority was at higher administrative levels in the School of Mineral Engineering (presently the Department of Mining, Metallurgical and Ceramic Engineering) and the College of Engineering. Fourth, the sponsoring organization, NASA, was faced with some uncertainties. Although it had a background of experiences in other materials research programs at Rice University and Rensselaer

Polytechnique Institute, each of these programs had somewhat different objectives and administrative arrangements from the CMRP.

Thus, there were substantial uncertainties concerning the appropriate organizational arrangements for CMRP during the first years. The program underwent a shake-down process during which satisfactory administrative arrangements were developed. Some of the more specific administrative and organizational issues facing the program during its initial stage were:

1. The nature of the program and its objectives. Although the program was for interdisciplinary research concerning the nature and properties of ceramic materials, there was still latitude for various interpretations. There were differing views concerning what was appropriate research within the grant. The major question centered around the degree of the relationship of the research activities to ceramic materials. Should the program have a very strong ceramic materials orientation with the other disciplines supporting this endeavor or should the relationship of specific projects to ceramic materials be relatively loose? In the initial proposal there were a number of relatively independent research projects. However, during the early phases of CMRP it moved to a more specific program area orientation. Thus, a strong orientation toward research and academic training in ceramic materials developed.

2. The degree of autonomy for the program. Rather critical issues arose during the first year concerning the degree of autonomy for CMRP. Many specific issues developed concerning the relationship

between the Principal Investigator (and the Ceramic Materials Research Committee) and the Administrative Board which represented various administrative levels in the University. There was also uncertainty and differing viewpoints on the relationship of the CMRP to the existing departmental and college administrative structures. There appeared to be reluctance on the part of various University administrators to transfer substantial autonomy to the Principal Investigator and the Ceramic Materials Research Committee for the administration of the program. Numerous meetings were held between University, college, and departmental administrators, faculty participants, and NASA officials concerning the administrative set-up for the program. For example, in some documents it was specified that the Principal Investigator had technical direction of the program but the administrative direction was the responsibility of the Administrative Board. However, it was very difficult to differentiate between technical direction and administrative direction. It was evident that the NASA technical monitor for the program hoped for substantial authority and responsibility in the hands of the Principal Investigator as it would be less desirable for him to deal with the Administrative Board and/or specific research supervisors on detailed issues. He desired to have an integrated program with major interface with the Principal Investigator who could speak with authority for the entire CMRP.

Thus, during the first years, numerous conflicts arose concerning the authority of the Principal Investigator and the Ceramic Materials Research Committee in such areas as the assignment of faculty personnel, the allocation of funds for student fellowships, the use of travel funds, and the purchase of major items of equipment. The development of an effective budgetary process was particularly difficult. During the initial years, a separate research budget was maintained within the individual research supervisor's department. This led to numerous budgetary centers and a lack of coordination and control over the budgetary process. In the 1967-68 academic year these budgetary functions were transferred to the program office under the direction of the Principal Investigator.

From review of the documents and interviews with various participants who were involved in the program at that time, it is our impression that there slowly evolved an administrative structure which provided more autonomy for the Principal Investigator and the Ceramic Materials Research Committee with the Administrative Board serving as a broad policy making and review board. As the University gained experience during the first years, many of these administrative and organizational questions were resolved.

After completion of the first year of the program, the original Principal Investigator resigned from the University faculty. The second, and current, Principal Investigator assumed coordination of the program at that time. During the next year, the Administrative Board, particularly the chairman, increased the authority and autonomy of the Principal Investigator. He was given substantially greater program autonomy and took a stronger role in both technical and administrative matters.

3. Developing an integrated interdisciplinary program. There were a number of problems during the early years related to the development of an integrated interdisciplinary effort. These were resolved by recognizing the responsibility of the Principal Investigator and the Ceramic Materials Research Committee to coordinate the program on an interdisciplinary basis. If the major authority over the program had remained (or been exercised) by the various deans, departmental chairmen, and University administrators, it is likely that the efforts would have been dissipated into unrelated and uncoordinated research projects and academic programs. In order to have an integrated program which would meet the specific objectives set forth for CMRP, it was necessary to develop an administrative structure approximating that of a program management set-up in government or industry. In effect, after a period of conflict and adjustment, the Principal Investigator became the program manager.

One major issue related to the interdisciplinary nature of the CMRP concerned the proper location of the principal administrative responsibility within the University. The program was initially established under the administrative supervision of the Graduate School. There was a recent review of the overall administrative structure with other offices considered for possible supervision. Since the College of Engineering is the home of the principal academic discipline and the majority of the participating faculty, location in this college was an obvious possible choice. The

Office of the Vice President for Research was also considered because of the substantial research involvement by a number of university departments in CMRP and the primary responsibility of this office for administering research programs. However, one of the prime objectives of the program is the training of graduate students. Also CMRP has a broad interdisciplinary focus involving several colleges. Therefore, it seemed appropriate that the administrative supervision remain within the Graduate School.

It should again be emphasized that the current administrative structure did not arise spontaneously but developed through a learning-adapting process. It is impossible to document all of the differing viewpoints and conflict resolutions that have occurred since the beginning of the program. However, we should recognize that many adaptations have occurred and will continue. We can now turn to a description of the current administrative structure of the program.

Current Administrative Structure

The responsibility for coordination and direction of the CMRP rests with two administratively autonomous groups, the Ceramic Materials Research Committee and the Ceramic Materials Administrative Board. The specific functions of these groups relate to different aspects of the program. The CMR Committee is responsible for the coordination and integration of research and training activities in the program; the Administrative Board, representing all administrative levels of the University, is responsible for the final ratification of research and budget recommendations proposed by the CMR Committee.

Organizationally, the most important position in the CMRP is that of the Principal Investigator. The individual fulfilling this role is a member of the Administrative Board and also serves as chairman of the CMR Committee. The Principal Investigator's primary duties include:

(1) Maintaining proper orientation of research with respect to the original and supplemental proposals and the grant instrument.
(2) Maintaining laison with the Materials Research Branch, the Office of Advanced Research and Technology, NASA.
(3) Maintaining laison with NASA Flight Centers, contractors, and other research centers to discuss their problems and observe procedures and methodology of research. This would be done through visits, attendance at meetings and seminars, and by correspondence.
(4) Scheduling seminars and/or colloquia for verbal progress reports of projects and arrange for appropriate speakers from off-campus.
(5) Periodic discussions of projects with the individual project supervisors and assist supervisors and other interested faculty personnel in keeping current with the state of the art in ceramic materials research.
(6) Preparation of semi-annual progress reports assuring that all aspects of research are covered, especially those which are NASA oriented.
(7) Preparation of proposals necessary to keep the program continuing.
(8) Coordination of the use of common equipment.
(9) Preparation of agenda for meetings of the CMR Committee and circulation of appropriate information to committee members prior to each meeting.
(10) Supervision of support personnel relative to their normal activities. The secretary assigned to the program would handle the following:
    (a) Preparation of purchase requisitions and handling of paper work following receipt of items purchased.
    (b) Preparation of service record changes on personnel assigned to the project and disbursement of pay checks from the program office.
    (c) Maintaining current budget status reports.
    (d) Making travel arrangements and handling paper for reimbursement.

(e) Handling correspondence necessary for the program, typing reports and maintaining program files.[10]

As chairman of the CMR Committee, the Principal Investigator supervises the activities of an interdisciplinary committee appointed by the Dean of the Graduate School and consisting of representatives of each of the major research areas. CMR Committee membership is assumed on a rotating basis, with staggered three-year appointments to ensure continuity. The primary function of this group is to evaluate research proposals submitted by interested faculty and to recommend which projects should subsequently be supported with grant funds. Functions of the CMR Committee are to:

(1) Provide sound research direction.
(2) Provide a reasonable level of information circulation throughout the University faculty by means of its research area group activities.
(3) Provide an opportunity for participation by all interested members of the faculty while recognizing the interest of primary supporting areas.
(4) Safeguard the interests of NASA and the University of Washington.

Meetings of the CMR Committee are held two to four times a year to assess the current axtivities of the CMRP and to provide direction for future endeavors.

One of the major responsibilities of the research area representative is to organize informal meetings with faculty members from various disciplines who are interested in conducting research in that area. As chairman of the group, the area representative is responsible for discussing space-related research involving ceramics relevant to the area of concern, and also for rendering advice vis-a-vis current research endeavors. This informal research

[10]Outlined in the Minutes of Meeting of the Ceramic Materials Research Committee on September 18, 1963, pp. 1-2.

area discussion group meets two to four times a year and in no way constitutes a formal, policy-making body. As stated earlier, the position of chairman of the research area group is filled on a rotating, three-year basis. Participation in these discussion groups is purely voluntary and it is possible for an individual faculty member to be involved in two or more of these groups, depending upon his interests.

The major policy-making body of the CMRP is the Administrative Board representing all administrative levels of the University of Washington. Membership is appointed by the Dean of the Graduate School and includes a representative of the Graduate School as ex officio chairman. The remaining positions are filled by the Associate Dean for Research of the College of Engineering, the Chairman of the Department of Mining, Metallurgical, and Ceramic Engineering, and the Principal Investigator. The primary function of this body is to evaluate recommendations received from the CMR Committee concerning research proposals and requisitions for equipment. The decision to support specific projects and to allocate funds for equipment lies solely with this body. For the most part, the Administrative Board is the representative of the University Administration and, as such, is responsible for the overall supervision of activities in the CMRP, including appointment notifications of faculty and student participants, budget ratification and allocation, and determination of the overall direction and progress of the program.

From an organizational standpoint, the structure of the CMRP is efficient. It effectively utilizes overlapping group memberships to link the program together. Likert has introduced the concept of the "linking pin" as a means of identifying influential positions within organizations.[11] Based upon the notion that upward influence and feedback are necessary ingredients in any hierarchical organization, certain positions perform the function of linking the various levels of the organization together. In this linking position, an individual acts as a member in one group and leader in another. By exerting upward and downward influence, he fulfills a vital linking function for the entire organization.

It may be noted that the CMRP is characterized by several distinct, but overlapping groups. The Principal Investigator serves as the link between the Administrative Board and the CMR Committee. As a member of the Board he attempts to exert upward influence. He also fulfills a leadership role as the Chairman of the CMR Committee, and in this position exerts downward influence. Functionally, the Principal Investigator serves as a link for communication and feedback information from one group to the other.

In a similar manner, the representatives of the research areas serve as a link between the CMR Committee and the informal discussion groups. As members of the former group they exert downward influence, and in the latter role, upward influence. From a functional standpoint, formal communication channels are available, both upward and downward, from the informal area discussion groups to the Administrative Board. The important linking roles are assumed by the Principal Investigator and the research area representatives. The overlapping group structure of the CMRP and the important linking positions are depicted in Figure 2.

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[11] Rensis Likert, New Patterns of Management (New York: McGraw-Hill Book Company, Inc., 1961), pp. 113-115.

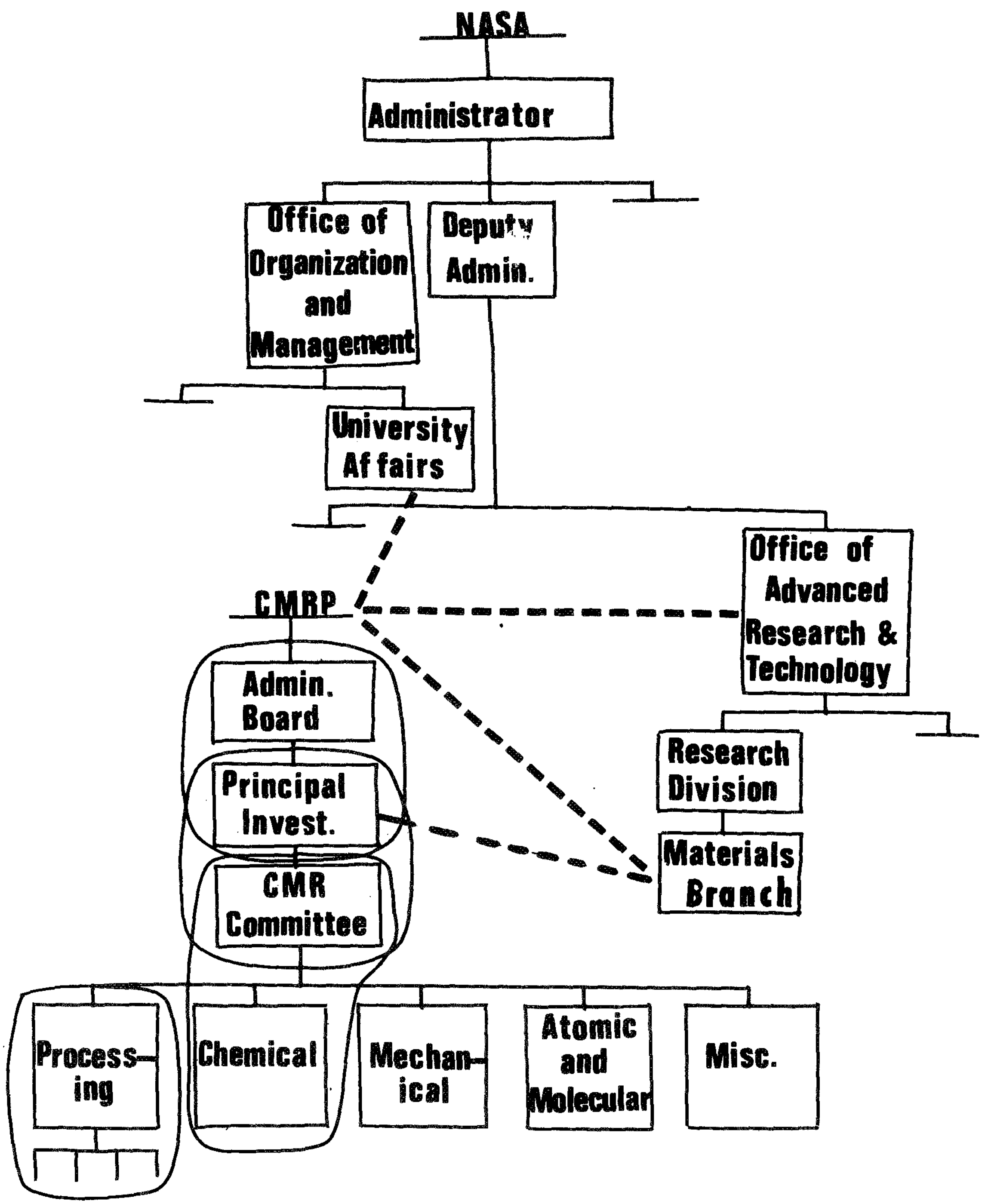

Figure 2

ORGANIZATION CHART OF THE CMRP SHOWING OVERLAPPING GROUPS AND LINKING POSITIONS

Funding of CMRP

All requests for funding submitted to NASA from any university are initially sent to the Office of University Affairs. After identification and sorting procedures, the proposals are forwarded to and evaluated by the designated program office from which funding is sought. If the proposal successfully receives a recommendation for support from the program office, funds from that source are returned to the Office of University Affairs for distribution to the University. The CMRP submits all proposals to the Office of University Affairs and receives funds through the Office of Advanced Research and Technology (OART). Semi-annual status report statements indicating the progress and activities of the CMRP are subsequently returned to OART through the Office of University Affairs for program appraisal and evaluation.

The CMRP submits a yearly proposal showing the general research plan for the coming year and the budget that is necessary to provide equipment and to support faculty, student, technical, and secretarial activities. On approval of OART, a grant document for funds is forwarded from the Office of University Affairs to the University of Washington. Allocation to specific projects is completed in accordance with the recommendations of the CMR Committee and subject to the approval of the Administrative Board.

The CMRP received an initial grant of $400,000 for the period 1963 to 1966. Subsequent supplemental grants were received in the amount of $500,000 for the period from 1965 to 1968; $300,000 for the period extending 1966 to 1969; $300,000 for the period 1967 to 1970; $300,000 for the period from 1968 to 1971; and $266,300 for the period 1969 to 1962. The allocation of these funds according to specific proposals is shown in Figure 3.

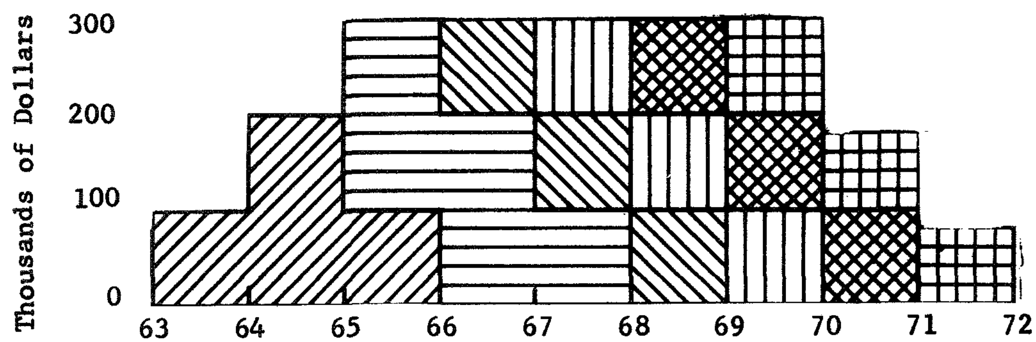

Figure 3

ALLOCATION OF FISCAL YEAR FUNDS ACCORDING TO PROPOSAL ACTIVITY

Since its establishment in 1963, the CMRP has received approximately $1.8 million in support. In 1968, the University of Washington received $51,546,075 in federal research support. Of this total, less than 1 per cent, or $420,080 was from NASA. The CMRP was funded at $300,000 and represented approximately two-thirds of the total NASA support.

NASA support of research at the University has declined over the past few years. NASA support amounted to $895,000 in 1965; $560,000 in 1966; $658,202 in 1967; and, as mentioned above, $420,080 in 1968. The CMRP has been funded at a consistent level of $300,000 in each of these years.

The College of Engineering received approximately $2.4 million in 1968 of which $300,000 or approximately 10 per cent was represented by the CMRP. Within the Mining, Metallurgical, and Ceramic Engineering Department, the CMRP represents approximately two-thirds of a total sum of $450,000 received in research support. For a relatively small Division, Ceramic Engineering receives a substantial amount of research support from the federal government. Indeed, funds from other sources are almost negligible, thus making the CMRP the principal source of support for Ceramic Engineering research.

Graduate Education

The CMRP exists not only to further the education and training of graduate students in Ceramic Engineering, but also to benefit graduate students in associated disciplines. The major impact, however, is no doubt upon students in Ceramic Engineering. Relative variations in the graduate enrollment of the Ceramic Engineering Division are shown in Figure 4.

The number of Ph.D. students has steadily increased since the CMRP was established, and the estimated enrollment for the coming academic year maintains

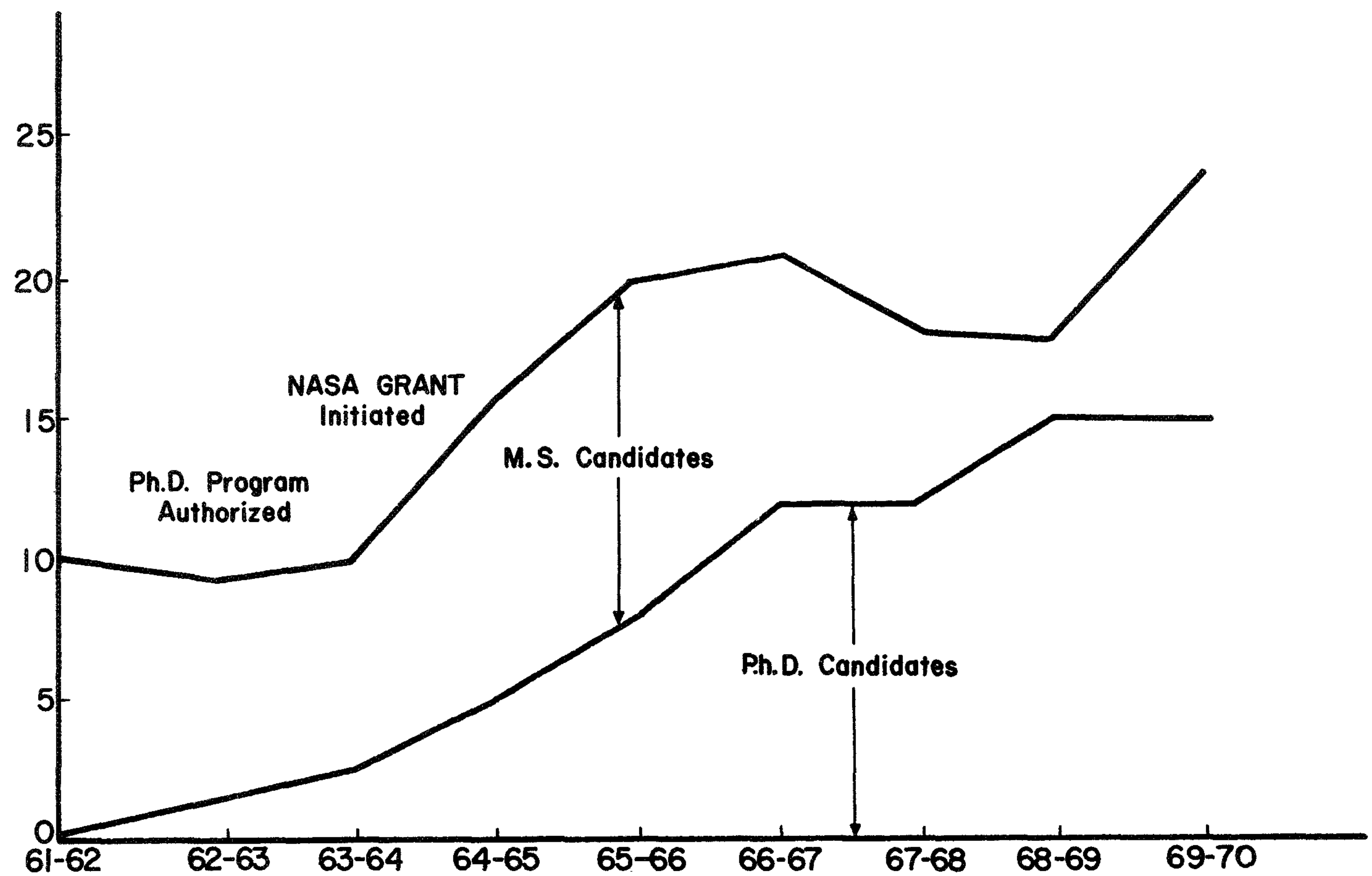

FIGURE 4

EFFECT OF NASA GRANT NGL 48-002-004 UPON GRADUATE ENROLLMENT IN CERAMIC ENGINEERING, UNIVERSITY OF WASHINGTON this trend. The sharp reduction in Master's students in 1967 and 1968 was, according to divisional records, attributable directly to the nation's military involvements. This decrease has leveled off and anticipated enrollment for the coming year shows a substantial increase. The CMRP has assisted in the development of the Ph.D. program in Ceramic Engineering, a goal which NASA has continuously stressed. The overall increase in graduate enrollment appears to reinforce this claim.

The number of advanced degrees received by students participating in the CMRP is shown in Table 1. Disciplines from which the degrees were granted and the type of support involved in also shown.

Current student involvement in the CMRP is shown in Table 2. The majority of students are from engineering disciplines. The interdisciplinary aspect of the CMRP is reflected clearly in the allocation of projects within the CMRP.

Student participants also attend CMR seminars to discuss research activities and to interact with faculty, industry representatives, and visiting academicians. These seminars are held twice a month and attendance is mandatory.

Without question, the CMRP has greatly influenced its graduate student participants. Objectively, it appears that this influence has been substantial. Of equal importance, however, are the attitudes and opinions of the students--to be discussed later in this report.

Research Results of Program

Of all the objectives, those pertaining to scientific achievements seem most difficult to appraise. Attempting to place a relative degree of

Table 1

ADVANCED DEGREES RECEIVED BY STUDENTS SUPPORTED BY THE CERAMIC MATERIALS RESEARCH PROGRAM 1963-1968

Academic Discipline	M.S. Degrees Partial Support	M.S. Degrees Full Support	Ph.D. Degrees Partial Support	Ph.D. Degrees Full Support
Aeronautics and Astronautics	-	-	1	-
Atmospheric Sciences	-	1	-	-
Ceramic Engineering	6	12	3	1
Chemistry	-	-	2	-
Electrical Engineering	-	7	1	1
Mechanical Engineering	-	1	-	-
Metallurgical Engineering	1	5	3	2
Physics	-	-	2	-
Total	7	26	12	4

Table 2

NUMBER OF STUDENTS AND FACULTY INVOLVED IN RESEARCH SUPPORTED BY NASA GRANT AS OF MARCH 1, 1969

Academic Department	Categories						
	No. of Projects	Faculty	Research Faculty	Under-Graduates	M.S.	Ph.D.	Total Graduates
Ceramic Engineering	11	5	2	3	1	11	12
Chemistry	2	2	-	-	-	2	2
Civil Engineering	2	2	-	-	-	2	2
Electrical Engineering	2	2	-	-	-	-	-
Management and Organization	1	2	-	-	-	1	1
Mechanical Engineering	1	1	-	-	-	-	-
Metallurgical Engineering	3	2	-	-	2	1	3
Physics	3	3	-	-	-	3	3
Total	25	19	2	3	3	20	23

worth on the technical output of the CMRP is beyond the scope of this paper. True worth ultimately depends upon the utility the research has for science in general, and it is unrealistic to assume that all output of the CMRP is capable of being utilized immediately. However, as a contributor to scientific knowledge in general, and to specific aspects of materials research, the CMRP is certainly making valuable contributions.

If any research is to be useful, it must be available to other scientists for evaluation. Several vehicles exist for the publication and dispersement of the research findings of the CMRP. Student theses represent an integral part of the overall research effort. Faculty publications in respected professional journals and presentations at learned society meetings serve the function of making available to the entire scientific community the results of work supported by the CMRP. Table 3 identifies the various media through which research results have been presented since the CMRP was established.

The quantity of scientific output is impressive and represents a great deal of research effort. The value of this research depends to a large extent on the availability of scientific instrumentation for use by CMRP participants. Over $200,000 has been expended to purchase capital equipment for utilization in the CMRP. Without this equipment much of the research could not have been accomplished.

It should be emphasized that measurement of the research contributions of this program cannot be determined by the number of publications alone. There exists an informal communications linkage between researchers in the various scientific fields and much information is interchanged on an informal basis. We sensed that this was definitely true with the CMRP where faculty and

Table 3

SCIENTIFIC CONTRIBUTIONS AND SEMINAR ACTIVITIES
RESULTING FROM THE CERAMIC MATERIALS
RESEARCH PROGRAM

Contribution or Activity	Year					
	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
Thesis Completed	2	6	15	6	9	4
Papers Published	-	5	7	8	6	8
Papers submitted or accepted for publication	-	4	4	7	7	4
Papers presented or accepted for presentation	-	-	3	9	5	19
C.M.R. Seminars	20	23	29	27	27	15
Total	22	38	58	57	54	50

students interchanged research knowledge within the campus and with colleagues in other universities, government agencies, and industry. It is impossible to measure the volume of this information interchange but it does represent a substantial scientific benefit.

Interdisciplinary Aspects of the CMRP

A major goal of the CMRP has been to involve faculty members from as many disciplines as possible in ceramic materials research. This interdisciplinary effort appears to exist with at least eight academic disciplines represented in the overall program. Table 4 identifies the number of faculty from each discipline who have participated in the CMRP since it was established in 1963.

Current faculty involvement continues to reflect an interdisciplinary approach (see Table 2). Since the beginning of the CMRP, a total of twenty-nine different faculty members have been involved in the program. Four faculty members have participated since the CMRP's inception, giving the entire program needed experience and stability.

Several mechanisms exist to encourage and promote an interdisciplinary approach to research in the CMRP. The administrative policies of the Administrative Board and the recommendations of the CMR Committee have an obvious effect upon the selection of projects to be funded. It has been the policy of both of these groups to include as many disciplines as possible in the overall program. A concentration in one or several disciplines would completely disregard the stated objectives of both the CMRP and NASA.

Faculty members also participate in the CMR seminars, a doubly rewarding interchange because it encourages faculty interdisciplinary exchanges and provides an opportunity for student-faculty interaction.

Table 4

NUMBER OF DEPARTMENTAL FACULTY MEMBERS PARTICIPATING
IN THE CERAMIC MATERIALS RESEARCH PROGRAM

	Year					
Academic Department	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
Aeronautics and Astronautics	1	-	-	-	-	-
Atmospheric Sciences	-	-	1	-	-	-
Ceramic Engineering	4	5	5	5	5	5
Civil Engineering	-	-	-	-	-	2
Electrical Engineering	2	3	3	3	2	2
Mechanical Engineering	-	-	-	-	1	1
Metallurgical Engineering	-	2	4	3	4	2
Physics	-	-	1	1	3	3
Chemistry	1	1	1	1	2	2
Management and Organization	-	-	-	-	-	2
Total	8	11	15	13	17	19

Informal research area interaction also helps promote exchange between faculty members from various disciplines. Involvement in these informal discussions depends mainly upon professed interest, but the opportunity to interact is open to all participating faculty in the CMRP.

Responses from student and faculty participants in CMRP indicates substantial awareness and interests in the various research projects. They recognize that the CMRP has been an important vehicle for increased interdisciplinary interactions.

Interorganizational Communications

The final explicit objective of the CMRP, namely to develop and promote interaction between university personnel and interested representatives of NASA, other federal agencies, industry, and other scientific institutions is in part realized through accomplishments associated with the previously discussed objectives. In fact, all of the objectives associated with the CMRP are interdependent and mutually reinforcing.

Achievements relating to one explicit objective seems to assist in the realization of all others. For example, superior graduate students improve research endeavors, promote interdisciplinary interaction, and finally, help ensure program viability. Similarly, quality research equipment encourages and cultivates superior research results, attracts quality faculty and student participants, and helps to ensure an enduring program. However, to be successful, and to avoid entropic forces, the CMRP must extend beyond the immediate boundary of the University of Washington in order to obtain new ideas and inputs. Interacting with the external environment also generates feedback from the scientific community regarding the relative value of its product.

Such information can subsequently be applied to future courses of action in order to improve the overall program.

Although the CMR Seminars, designed primarily for intra-program communications, do include the inputs of visitors from outside institutions, the major vehicle for external communication is the annual Ceramic Materials Research Program Review.

The CMR Program Review was expanded to include outside participants in 1966 with the consent of the NASA technical representative assigned to the CMRP. It is designed to promote interaction between CMRP participants and others interested in the work being conducted in the program. Invitations are extended to appropriate individuals in federal agencies, to officials of Pacific Coast ceramic industries, to aerospace industries, and to non-profit research laboratories. The two-day program format includes a brief review of each project by the research supervisor in charge, followed by a discussion period. During the afternoon, attendees visit the various faculty members in their laboratories and are afforded the opportunity to discuss the research in detail.

Not unexpectedly, the majority of people attending the Review are from the Pacific Northwest. Most attendees represent ceramic or aerospace firms. However, the federal government, other universities, and non-profit institutes have been represented. A total of 21 visitors participated in the initial review in 1966. There were 17 visitors in 1967, and 18 in 1968. In addition to project supervisors and interested visitors, University of Washington administrators have also attended each Review. The major value of such a program appears to be the opportunity to experience intimate and in-depth scientific interaction, avoiding the normal delays involved in formal presentation and publication. Records show the response to the Program Review to be positive, although officials of the CMRP wish this enthusiasm were expressed in a larger number of attendees.

Another means of communicating with external institutions is the reciprocal faculty exchange seminars begun during the summer of 1965. Specialists from industry, research laboratories, and government agencies receive visiting appointments to teach and research in connection with the CMRP. In a similar manner, faculty supervisors in the CMRP have spent varying periods of time in a similar capacity at other institutions.

Finally, the CMRP provides travel funds to faculty participants for attendance at learned academic and professional meetings. In addition to the routine interaction which transpires at such meetings, many CMRP research results are made public via formal papers and presentations.

Views of Participants

Student and faculty participants directly involved in the CMRP are drawn from many distinct disciplines on campus. Table 5 identifies the classification of the various participants by discipline, and the number of projects currently being funded within each department via the CMRP.

Questionnaires were administered to every student and faculty participant currently involved in the CMRP. In addition, each faculty member was interviewed to obtain additional information on certain aspects of the CMRP not obtainable in questionnaire form. Another group involved either directly or indirectly with the CMRP were campus administrators, and they too were interviewed to ascertain their viewpoints regarding the CMRP.

Table 5

BREAKDOWN OF STUDENT AND FACULTY PARTICIPANTS
IN THE CMRP AS OF MARCH 1, 1969

	Academic Discipline								
Group	Ceramic Engr.	Elec. Engr.	Mech. Engr.	Civil Engr.	Meta. Engr.	Chem.	Physics	Mgt. & Org.	Total
Students									
M.S.	2	0	0	0	2	1	0	0	5
PH.D.	10	1	0	2	1	2	3	1	20
Total	12	1	0	2	3	3	3	1	25
Faculty									
Professor	1	2	0	1	0	2	2	2	10
Assoc. Professor	1	1	0	0	0	0	0	0	2
Assit. Professor	3	0	1	1	2	0	1	0	8
Research Ass.	2	0	0	0	0	0	0	0	2
Total	7	3	1	2	2	2	3	2	22
Projects	11	2	1	2	3	2	3	1	25

The following material briefly summarizes the significant results obtained from these three groups in this questionnaire and interview phase.[12]

Student Perspective. The general reaction of student participants regarding the impact of the CMRP is presented in Table 6.

Student response to academic considerations is shown in Table 7.

Student opinion suggests that the CMRP has had the following impact upon student participants: (1) it has provided the financial support to complete a graduate education; (2) it has provided equipment necessary for student research; (3) it has caused some interdepartmental interaction; (4) it has broadened students' knowledge in areas of materials research; and (5) it has influenced primarily the activities of students in the Ceramic Engineering Division.

Faculty Perspective. The faculty participants' reactions to questions concerning the impact of the CMRP upon research and interdisciplinary considerations are shown in Table 8.

Faculty members were asked to identify the goals which they felt the CMRP should strive to achieve. Although expressed somewhat differently, most responses were in agreement as to overall objectives. Faculty opinion suggests pursuit of the following goals:

(1) The development and promotion of research on ceramic materials;
(2) The development of an interdisciplinary approach to the study of ceramic materials;
(3) The education, training, and support of outstanding graduate students;

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[12] For a more complete presentation of these research results see, John W. Stockman, An Appraisal of the Impact of an Interdisciplinary Research Program: The Ceramic Materials Research Program at the University of Washington, Doctoral Dissertation, University of Washington, Chapter 5, pp. 93-126.

Table 6

GENERAL REACTION OF GRADUATE STUDENT PARTICIPANTS TO THE IMPACT OF THE CMRP UPON SELECT ISSUES

Issue	Positive	Neutral	Negative	Don't Know
Over-all Graduate Education	20	1	1	
Expanded Career Opportunities	14	4	1	3
Initial Decisions to Attend the U. of W.	12	8		2
Perceived Preferential Treatment	5	14		3
CMRP Student Support Adequate	18		4	
CMRP Student Support Equitable	21		1	

Table 7

STUDENT REACTION REGARDING THE IMPACT OF THE CMRP UPON ACADEMIC CONSIDERATIONS

Issue	Positive	Neutral	Negative	Don't Know
Improved Quality of Course Offerings	7	8		7
Education Responsive to "Real-World"	18		4	
Increased Freedom to Select Research Topic	8	9	4	1
Effect Upon Degree Program Duration	2	13	3	4
Creation of Pressure	8	12	2	
Increased Opportunity to Publish	11	9		2
Effect Upon Student-Faculty Relations	9	10	1	2

Table 8

FACULTY PARTICIPANT REACTION TO QUESTIONS REGARDING THE IMPACT OF THE CMRP UPON RESEARCH AND INTERDISCIPLINARY CONSIDERATIONS

Issue	Positive	Neutral	Negative	Don't Know
Importance of CMRP to Future at U. of W.	16	2	1	
Effect upon Interaction with Industry	7	11		
Effect upon Desire to Attend Off-Campus Meetings	13		5	
Importance of CMRP Funds to Current Research Projects	16	2		
Improved Interdisciplinary Interaction	17		1	

(4) The development of a long-range research program characterized by a stability of funding;
(5) The pursuit of both applied and basic research into the nature of ceramic materials;
(6) The development of a meaningful dialogue between industry, government, and other interested parties on ceramic materials research;
(7) The development of meaningful student-faculty interaction and;
(8) An overall maintenance of quality in all activities of the CMRP.

Faculty response suggests both personal and institutional benefits have resulted from the CMRP.

Administrative Perspective. Some new and interesting information resulted from these interviews and in order to protect the identify of the specific contributor, the data will be summarized and treated in a single presentation.

The administrators pointed out that a general problem often confronted in dealings with the federal government is the inconsistency and uncertainty of funding. This presents special problems such as initiating research for new faculty members and maintaining continuity in grants and projects in progress. Ultimately, the uncertainty affects output because often it takes from 4 to 10 years to achieve significant and meaningful results. The uncertainty surrounding funding prevents long-range planning and in turn forces a more fragmented approach to research projects.

NASA's step-funding approach to support was cited as an important hedge against uncertainty and a definite aid to the university. The CMRP apparently does not present any unique administrative problems other than the usual bookkeeping functions. It was noted that a block grant such as the CMRP, which is allocated on an individual project basis, does involve a multiple accounting problem. As it is now administered, the program entails more monthly reports and accounting manipulations than are probably necessary because individual project assessments must first be extracted from the total program budget and then brought back together for an overview of the financial status of the entire program. However, recent innovations in the university accounting system are anticipated to relieve such problems in the future.

It was acknowledged that the Principal Investigator should have ultimate control and be the sole individual responsible to both the University of Washington and to NASA for the activities of the CMRP.

In general, university administrators were favorably disposed toward NASA and the particular funding procedures of the agency. It was pointed out that the CMRP allows a great deal of flexibility in the allocation of funds and that anything that gives more autonomy to the university administration is viewed favorably.

It was also noted that until state governments assume a greater responsibility in supporting university research, dependence upon the federal government for support will probably continue.

Administrative interviews indicated that strong support exists for the CMRP. Most administrators expressed the belief that its primary goal should be the training and education of graduate students. Responses verified data obtained earlier from faculty and student participants. Unique problems associated with the CMRP are few and those which do exist appear to be known and are currently being dealt with.

Specific Conclusions

On the basis of the evaluation of historical data and the questionnaire and interview phases of this study we can draw the following conclusions:

1. Concerning student participants:

   a. The major impact for student participants in the CMRP has been the provision of financial support necessary to complete a graduate education.

   b. The CMRP has provided sophisticated equipment necessary for student research.

   c. The CMRP has exposed graduate students to the problems and techniques of other disciplines involved in materials research on a formal basis, but has initiated little informal interdepartmental interaction between the student participants.

   d. The graduate students in Ceramic Engineering have been the primary beneficiaries of the CMRP through the development of a sound Ph.D. program and a concomitant upgrading of faculty expertise and research capability.

2. Concerning faculty participants:

   a. The major benefit accruing from the CMRP has been financial support of research projects and graduate students.

   b. The CMRP has encouraged interdisciplinary interaction which otherwise would not have occurred.

   c. The CMRP has been an important source of travel funds and funds for summer employment.

   d. The CMRP has provided funds for the acquisition of expensive and sophisticated equipment which probably could not have been purchased otherwise.

   e. The CMRP has allowed maximum flexibility and discretion in the conduction of faculty research with minimal external constraints.

3. Concerning University Administration:

   a. The approach of CMRP in relating funds for research directly to a graduate academic program is most appropriate from the University's viewpoint.

   b. The CMRP has presented no unique problem of administration for the University of Washington.

c. The greatest benefit to the University is the step-funding approach of support which provides continuity and certainty of funds for a specified period of time.

d. The CMRP has not created any unusual interdepartmental conflict due to its existence, although a competitive spirit exists between the disciplines involved.

4. Concerning the Ceramic Engineering Division:

   a. The CMRP has been the primary impetus for the successful development of a Ph.D. program and for the development of a visible research program in ceramic materials.

   b. A withdrawal of funds would seriously handicap the Ceramic Engineering Division and would cause a significant retrenchment of all activities now being pursued.

   c. As one student expressed it, "The CMRP <u>is</u> the Ceramic Engineering Division."

5. Concerning the CMRP in general:

   a. The CMRP has been relatively successful in its development of an interdisciplinary research program at the University of Washington.

   b. Evaluation of research projects and the funding of new research endeavors associated with the CMRP have been conducted rather "loosely" in the past. It is felt that a more critical evaluation on an annual basis would strengthen the program.

   c. The primary group to be affected by a withdrawal or cutback in support would be the graduate students participating in the program. Secondary ramifications would be the inadequate utilization of equipment and the gradual falling away of disciplines interested in ceramic materials research.

   d. Finally, virtually all of the benefits previously cited would be substantially reduced or eliminated if the current financial support of the CMRP were discontinued by NASA.

In the following section we will present our analysis and interpretation of the research findings.

PART III

ANALYSIS AND INTERPRETATION OF RESEARCH FINDINGS

In this section the research team has gone beyond the specific conclusions set forth in Part II, and has taken substantial liberty in presenting its analysis and interpretations. These are based not only upon the evaluation of historical information and the questionnaire and interview program, but also upon the accumulation of more general information during the past 15 months. The findings also are influenced by the authors familiarity with NASA and its university programs, the structure and functioning of universities, and activities in other government agencies and in industry. These interpretations are based upon subjective analysis as well as objective data. It is anticipated that this section will serve as a basis for further discussion with NASA officials and university participants.

This section covers the following topics: (1) overall evaluation of the CMRP program; (2) creation, utilization, and administration of science and technology; (3) the university setting; (4) NASA-university interface; and (5) areas for further research.

Overall Evaluation of the CMRP Program

Our study indicates that the CMRP has had an overall positive effect upon (1) the Ceramic Engineering Division, (2) the College of Engineering, and (3) the University of Washington. Students, faculty participants, and university administrators all responded favorably to questions concerning the program. The number of graduate students has increased substantially during the period of the program and the contributions to scientific knowledge have been significant. There is evidence that the CMRP has satisfactorily achieved the objective of an interdisciplinary research program. Information from discussions with various officials suggests that the program has also been successful in accomplishing NASA's objectives.

If we appear too optimistic about the success of the CMRP, it should be recognized that we had limited absolute criteria for measurement of program effectiveness. Also, we were concerned only with this program and did not make a specific comparative analysis of similar government-university research programs, at the University of Washington or elsewhere. However, we did reach some general conclusions concerning why this program appears to have been successful. Related to program success are such factors as the nature of the stated objectives, the academic orientation of the program, the interdisciplinary nature of the activities, and the development of integrative mechanisms.

Objective Accomplishment

The stated objectives of the CMRP were (1) the education and training of graduate students in ceramic engineering and associated disciplines; (2) the development of an interdisciplinary interest in research on ceramic materials; (3) the accomplishment of fundamental research upon the nature and properties of ceramic materials; (4) the development of an enduring research capability at the University of Washington; and (5) the development of an information interchange between the CMRP and NASA, other federal agencies, the ceramics industries, and other universities and research institutes.

Underlying these specific objectives for the CMRP were some overall goals of NASA and the University of Washington. One of NASA's broad goals as defined by the Space Act is to expand and develop the Nation's scientific and technical capability to meet changing requirements and to take advantage of new opportunities in aeronautics and space. In accomplishing this goal NASA has sponsored research across a broad spectrum of the sciences and their technical applications with many universities. More specifically, NASA joined with other governmental agencies in 1959 in sponsoring university research in materials sciences. This program called for the establishment of a number of interdisciplinary materials research laboratories in various universities. NASA is currently funding three such laboratories at Rice University, Rensselaer Polytechnic Institute, and the University of Washington. The primary purpose of this federal interagency program was to increase the output of researchers trained in the science of materials and to expand the knowledge in these fields. Thus, the establishment of the CMRP fit within NASA overall objectives and within the specific framework of the interdisciplinary materials research laboratories program.

The University of Washington also has overall goals which set the framework for the establishment of the CMRP program. These are: (1) the dissemination of knowledge to students--primarily through the teaching of undergraduate and graduate students; (2) the creation and advancement of knowledge--accomplished through the research activities of the faculty and specialized staffs; and (3) service to society--a result which obviously is related to the first two goals. The University of Washington's participation in the CMRP was premised upon its contribution to the accomplishment of these three organizational goals.

Thus, the establishment of CMRP was based upon the meshing of the goals of NASA and the University of Washington and resulted in the more specific statement of the five objectives delineated above. It is evident that these overall goals are relatively compatible and that the specific objectives are complementary. However, it is difficult, if not impossible, to measure the relative degree of accomplishment of these five objectives. It became evident from our discussions with various participants in the CMRP that differing emphasis was placed upon these objectives. They were not completely compatible and might even be in conflict. Consequently, it is our view that the CMRP tended to achieve satisfactory accomplishment of multiple objectives rather than optimal satisfaction of a single, explicit objective. The diversity of interests of the various participants suggests that complete satisfaction of all objectives would be impossible. For example, from some faculty members' viewpoint a greater allocation of resources toward meeting the objective of creating new knowledge (and publication of findings) would have been desirable. However, graduate students thought more emphasis should be placed upon their specific educational program. University administrators envisioned possible conflict and advocated a more balanced effort toward objective accomplishment. In our discussions with NASA we also discerned differing emphasis upon the various objectives of the CMRP.

We therefore concluded that success in the CMRP depended upon satisfying the needs of the various participants in order to ensure their active and continuing contribution. This required a continual bargaining-negotiating relationship to ensure satisfaction of participants. However, the CMRP did adopt certain mechanisms for integration of objectives which reduced possible conflicts.

Academically Oriented Research Program

Many faculty participants and university administrators stressed the view that the CMRP was successful because it merged the research for knowledge with an academic program. Many requests for research to be undertaken by the university are difficult to accomplish in relationship to academic programs. While they may offer interesting research opportunities they do not tie in directly with the training of students. In fact, there is some feeling that they may detract from the teaching function. The current image of the high-priced professor engaged in research and consulting and neglecting his students is overemphasized, but the danger is present. Research programs which utilize the knowledge and energy of the faculty but have little or no relationship to an academic program can create substantial conflict within the university.

One of the major values of the CMRP is that it avoided this conflict. It provided for the clear integration of the research efforts with an academic program. One of the major objectives was to improve the academic program. A major usage of funds is for support of graduate students. Substantial effort is devoted to ensure that students are active participants in many phases of the program. They are encouraged to take part in many seminars and can tap the knowledge of many faculty members.

As we perceive it, the CMRP was specifically organized and administered to encourage the integration of the academic and the research efforts and this is one of the prime reasons for its success.

Interdisciplinary and Multidisciplinary Research

One of the objectives of CMRP was to develop an interdisciplinary interest in research on ceramic materials. This objective appears to have been accomplished to a fairly high degree. However, unavailability of comparable information on other such programs and the lack of a definition of the term "interdisciplinary" makes it impossible to measure accomplishment of this objective precisely.

The concepts of interdisciplinary and multidisciplinary team research convey a similar meaning to many people. Both terms imply bringing together divergent disciplines to study complex problems and often are used interchangeably to describe such an effort. However, a distinction appears to exist between them, and the ultimate success of team research may depend upon which approach is selected to confront a given problem area.

Approaches to scientific inquiry can be viewed from a two-dimensional perspective. First, it either involves only one scientist working predominately in isolation or it involves two or more scientists working in a cooperative manner. Second, the research method utilizes the perspective of a single discipline to approach the problem or combines the knowledge of two or more disciplines. These dimensions, as shown in Figure 5, can be combined to represent a continuum of possible approaches to research.

Many Scientists Many Disciplines	One Scientist One Discipline

Figure 5

CONTINUUM OF APPROACHES TO
SCIENTIFIC INQUIRY

The concepts of interdisciplinary and multidisciplinary research are somewhere to the left of the unidisciplinary position, but where? The distinction between these two approaches lies mainly in the amount of interaction or coupling that takes place among the individual researchers.

Multidisciplinary research involves several researchers working on a problem but from independent perspectives. There is little interaction between the parties regarding research progress, specific methodological approaches employed, or significant problems encountered in the process of the research. Dialogue between research team members is minimal, and the final product is represented by a series of individual research reports or by a single report that merely combines the individual efforts.

Interdisciplinary research, on the other hand, encourages interaction and dialogue among the participating researchers. Luszki defines it as follows:

> An interdisciplinary team is a group of persons who are trained in the use of different tools and concepts, among whom there is an organized division of labor around a common problem, with continuous intercommunication and re-examination of postulates in terms of the limitations provided by the work of the other members, and often with group responsibility for the final product.[13]

There appears to be several degrees of interdisciplinary effort that can be attained. In the extreme, an attempt is made to fuse the goals, values, and techniques of the representative disciplines into a single approach to a problem. This process leads to complex interrelationships and more time is probably spent on integrative and maintenance functions than is spent in actual research activities. Where a final product is in part dependent upon the ability of a group of scientists to compromise individual differences in order to reach agreement, large amounts of time are needed to mold a smooth functioning research team. It is questionable whether an interdisciplinary

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[13]Margaret Barron Luszki, Interdisciplinary Team Research: Methods and Problems (New York: National Training Laboratories, 1958), p. 10.

effort that requires the fusion of many disciplines and many scientists into a single, cohesive team can be achieved in the university setting.

On the other hand, a research program such as the CMRP does not attempt to achieve the extreme type of interdisciplinary team effort. Participants represent many distinct disciplines and all projects conducted in conjunction with the program relate to the general area of ceramic materials. However, no attempt is made to fuse the various efforts into a single team, nor are the results combined to form a single final product. Consequently, more time can be devoted to research and training of students, and less to the integration and maintenance functions. However, in the CMRP a great deal of attention was paid to the need for integration, primarily by the Ceramic Materials Research committee and the Principal Investigator. The point of emphasis here is that <u>all</u> members of the CMRP team--faculty and students--were not required to spend a great deal of time on integrative activities.

Mechanisms for Integration

There were a number of factors which did help to integrate CMRP into a team effort. As discussed in Part II one of the major devices providing for integration was the definition of certain areas of ceramics research for concentration. Initially, research activities were somewhat unstructured and unrelated, but over time these endeavors evolved into a structured and coordinated categorical framework. This delineation of specific research areas of major interest helped to provide integrative effort.

The organizational arrangements providing for overlapping groups and the linkages between the various administrative and research groups helped provide integration. The Principal Investigator and the research area representatives performed a vital role in linking the various disciplinary groups together.

Faculty members and students participated in CMRP seminars and program reviews. This encouraged interdisciplinary exchanges and provide an opportunity for student-faculty interaction. In our observations over the past 15 months we have noted many informal interactions and exchanges of ideas between the various participants. Both students and faculty are encouraged to seek advice from other disciplinary areas involved in the CMRP.

It is our observation that the degree of interdisciplinary integration in CMRP is not due to chance, but rather to the active efforts of the CMRP Committee, the research area representatives, and in particular, the Principal Investigator. We noted many informal persuasions to ensure that the individual researcher shared his ideas and communicated with others on the project.

Creation, Utilization, and Administration of Science and Technology

The National Aeronautics and Space Administration and universities have many features in common. In particular they are among the primary institutions in our society engaged in the creation, utilization, and administration of science and technology. Science denotes the systematic, objective study of empirical phenomena and the resultant bodies of knowledge. Technology relates to the application of knowledge for the performance of certain tasks or activities. Technology is much more than machines and relates to the utilization of all types of knowledge for the rational accomplishment of human objectives. Machines are merely the physical artifacts of technology.

Science and technology have become pervasive forces in modern society. In the Western world since the beginning of the industrial revolution, technology and its parent, scientific research, have had a profound impact upon social structure and culture.

Increasingly, the creation and effective utilization of science and technology requires the development of complex organizations. A phenomenon of modern industrial society is the development of large-scale, complex organizations for the accomplishment of specific purposes. This relatively new development has been pervasive over the past century. Throughout most of man's history, his social institutions were primarily on an informal face-to-face basis. The industrial revolution, with its demand for concentration of resources and greater scale, fostered larger economic and other organizational units.

The development of large organizations is closely related to scientific and technological advancements. "Large-scale organizations have evolved to achieve goals which are beyond the capacities of the individual or the small group. They make possible the application of many and diverse skills and resources to complex systems of producing goods and services. Large-scale organizations, therefore, are particularly adapted to complicated _technologies_, that is, to those sets of man-machine activities which together produce a desired good or service."[14]

Both universities and NASA have unique roles in our society for the creation and utilization of science and technology. Since their development in the late 19th century, American universities have continually expanded their boundaries and disciplines and have become a vital contributor to advancing science and technology. Although NASA was created little more than a decade ago, it has already achieved a position of great importance in this

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[14] James D. Thompson and Frederick L. Bates, "Technology, Organization, and Administration," _Administrative Science Quarterly_, December, 1957, p. 325.

area. Each of these institutional types faces rather new and unique managerial and organizational problems as a result of this growing role.

Scientists/Professionals in Organizations

Complex organizations are the primary means in our society for the specialization and utilization of knowledge. They are making increasing use of scientists and other professionals in accomplishing their objectives. NASA and universities are prime examples of complex organizations which employ large numbers of scientists/professionals and this creates many problems of conflict and accommodation.

The distinguishing characteristic of scientists/professionals is their high level of technical expertise and adherence to professional rather than organizational norms. There appear to be certain role definitions for scientists/professionals in our society. These are:

1. Professions have a systematic body of knowledge in which skill is achieved through a lengthy process of training. Preparation must have an intellectual basis as well as practical experience.
2. They have authority based on superior knowledge which is recognized by society. This authority is highly specialized and is related only to the professional sphere of competence.
3. There is broad social sanction and approval of the exercise of this authority.
4. There is a code of ethics regulating relations of professionals with clients and with colleagues.

5. There is a scientific/professional culture sustained by organizations.[15]

These role definitions indicate that the task of scientists and professionals is intellectual in nature. Their function is primarily one of providing knowledge. Increasingly, scientists/professionals are "organization men" affiliated with businesses, hospitals, governmental agencies, large law firms, and other complex institutions. Over the past several decades the number of "salaried scientists/professionals" has increased many times faster than has the number of independent scientists/professionals. More and more, they need the resources of complex organizations to accomplish their work.

There are characteristics of scientists/professionals which set them apart from other occupational groups. Many of these are related to inherent personality factors which are instrumental in the individual's selection of a particular life's work. Others are culturally determined by educational experiences. The values of the individual become, through the process of socialization, inextricably interwoven with the values and norms of the professional group. Rational methods, autonomy in the pursuit of work and the search for truths become a basic part of the value system. These are strongly influenced by collegial relationships with other members of the profession. These values are not discarded as the individual takes on an organizational role. They continually affect his behavior and attitudes regarding his work relationship. "These values are not characteristic of the ordinary submissive subordinate forced to look to the organization for his rewards in terms of

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[15] For a further discussion of the elements of professionalism see: Howard M. Vollmer and Donald L. Mills (eds.) Professionalization (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1966), pp. 9-19.

prestige, status and even power. Rather, the professional image conveys expectations of an environment of equality where knowledge reigns supreme."[16]

This group has a high need for achievement and self-actualization. They have a keen interest in their work and the development of knowledge for its own sake. They are motivated by problems which have an intrinsic importance to them. They tend to be inner directed rather than motivated through external rewards or punishments.

Many of these characteristics, values, and motivations of scientists/professionals are in conflict with role requirements in complex organizations. Scott suggests two primary reasons for this conflict. "First, professionals participate in two systems--the profession and the organization--and their dual membership places important restrictions on the organization's attempt to deploy them in a rational manner with respect to its own goals. Second, the profession and the bureaucracy rest on fundamentally different principles of organization, and these divergent principles generate conflicts between professionals and their employers in certain specific areas."[17]

All participants in a social system are subject to some form of control which ensures the proper integration of their activities into the total system. In the bureaucratic organization, administrative authority and control is the primary mechanism for ensuring this integration. For scientists/professionals, however, the primary means for achieving this integration are self-control, adherence to professional norms, and colleague surveillance. In addition there

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[16] Borje O. Saxberg and John W. Slocum, Jr., "The Management of Scientific Manpower," Management Science, April, 1968, pp. B-484-485.

[17] W. Richard Scott, "Professionals and Complex Organizations," in Howard M. Vollmer and Donald L. Mills, op. cit., p. 266.

appear to be a number of other areas of conflict between scientists/professionals and organizations.

> Autonomy versus Integration: The scientists/professional has a high need for autonomy. Yet his activity also must be integrated and contribute to the overall goals of the organization.
>
> Cosmopolitan versus Local Orientation: Basically the local is oriented toward the organization whereas the cosmopolitan is oriented to his science or profession. The local seeks advancement through the organizational hierarchy and wants recognition from superiors. The cosmopolitan seeks advancement and status in his profession through approval of colleagues, identifies with the profession's goals, and seeks external recognition.
>
> Conflict Between Technical and Managerial Role: The scientist/professional is dedicated to the creation and application of knowledge. However, the hierarchical organization usually provides rewards and status for the professional who moves away from his technical role performance into a managerial function.

The foregoing discussion of possible conflicts between the scientists/professional and the organization might lead one to believe that any accommodation is impossible. This obviously is not true, for an increasing number of them are working within organizations and are making important contributions. In essence, this accommodation has been accomplished through changes on both sides--modifications on the part of the professional in his desire for autonomy and modifications on the part of the organization away from strict hierarchical control and authority. "Organizations are increasingly governed by professional standards, and professions are increasingly subject to bureaucratic controls."[18] There is a reciprocal process of adaptation and accommodation between the professional and the organization. However, this has required substantial modifications in the organization and management of these groups.

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[18] William Kornhauser, Scientists in Industry: Conflict and Accommodation, University of California Press, Berkeley, 1963, p. 7.

Administration of Scientists/Professionals

The development of an effective managerial system is vital for the organization with a large number of scientists/professionals. Various studies suggest that the most effective pattern is democratic-participative leadership in which there are free communications and a high degree of collegial relationship. Evidently scientists and professionals do not like laissez-faire leadership where they are left completely alone. They prefer to have frequent interactions with the research administrator as well as with immediate colleagues. The democratic leadership style provides a more effective means for integrating scientists and professionals than does a laissez-faire approach. Scientists and professionals report the highest dissatisfaction under a strong, autocratic leadership pattern.

The administrator of research and professional activities frequently has many role conflicts. He is often in the middle between scientific/professional norms and values and organizational requirements. He is the moderator between the scientific/technical area and the organizational system. The managerial system for research and development administration requires substantial modification from the traditional bureaucratic-mechanistic approach.

Technology, Organization Structure, and Management

The foregoing discussion suggests that the organization dealing with advancing science and technology must substantially modify its structure and managerial approach from the traditional bureaucratic institution. There is increasing evidence that organizations operating in a turbulent environment and with rapidly changing technologies need structures and managerial systems different from those with a stable environment and technology. The highly structured bureaucratic organization is most appropriate for stable operations whereas the innovative organization with changing technology requires a more adaptive, less structured system. Instead of providing for permanent, structured positions as characteristic of the bureaucratic organization, the adaptive organization has less structuring, more frequent changes of positions and roles, and more dynamic interplay between the various functions. The adaptive organization requires more time and effort toward integration of diverse activities. At the risk of over-simplification we can suggest the following characteristics for the creative, adaptive organization.

1. In the creative organization, power is widely distributed and is based upon the knowledge of the various participants. Bureaucratic hierarchy and authority of position are deemphasized. It is not highly stratified and has structural looseness. The hierarchy is used as a source of information and communication flow in both directions. There is freedom to discuss new ideas upward as well as downward.

2. The relationship is such that individuals perceive the organization as a means of professional growth. The organization makes use of the motivations and aspirations of its knowledgeable members.

3. It has a diverse communications system which provides the inputs of information and knowledge necessary for the generation of ideas. It has effective external communications channels with its environment. It provides a climate where "cosmopolitans" can develop strong professional loyalties and contacts.

4. It has a general climate receptive to new ideas. This receptivity requires flexibility in the goals, structure, and managerial system. It has a high tolerance for "odd balls" and participants who deviate from established institutional norms.

5. It provides a high degree of autonomy for its scientists/professionals to choose problems of interest to them and to change directions to meet new unforeseen circumstances. It provides numerous incentives for creativity. One of the prime incentives may be the amount of "free time" to explore new and different ideas.

6. There is a substantial amount of slack so that all of its resources are not committed to the maintenance and production functions. Total emphasis on productivity tends to drive out opportunities for creativity and innovation.

7. There is a relatively high tolerance for uncertainty and ambiguity. The creative organization anticipates that its participants will not always be right and will frequently follow one-way streets. It has a risk-taking ethos.

8. It uses many group processes and assignments. It frequently has multiple group membership on a flexible basis. Quite often it uses the project approach which allows diverse interests and special skills to participate on a particular program or task.

9. The controls are substantially different from traditional bureaucratic control which emphasizes rigid adherence to established policies and procedures. There is a long feedback cycle and substantial flexibility and autonomy of operations within broadly established guidelines.

This listing suggests that an emphasis upon creativity and change is not an ideal for all organizations. The creative organization has many role conflicts and tensions. All organizations should not emphasize creativity. For some, adherence to the structured bureaucratic system, with its emphasis upon productivity, is more appropriate. The creative organization has a more flexible structure and managerial system and must pay a price in terms of greater uncertainty, ambiguity, and conflict. However, it is our view that both NASA and universities are geared to the development of organizations towards the creative end of the spectrum.

A further characteristic of NASA and universities, one which is closely related to the emphasis upon expanding science and technology, is that of boundary expansion. There appears to be a general phenomena of expansion of the domain of activities and boundaries of complex organizations to include more activities. Both NASA and universities, as institutions, have very wide boundaries. It is our view that this boundary expansion is due to several forces. Goal elaboration has caused these organizations to increase their scope, and the development of new knowledge and technologies have caused them to encompass additional activities. Organizations frequently respond to environmental uncertainties by expanding their domain and bringing into the system of internal control those forces creating uncertainty. The very fact that NASA and universities are creative, change-oriented organizations stimulates boundary expansion. Participants in these organizations seek to apply their newly developed knowledge and ideas through taking on new activities. The expansion of the boundaries of an organization creates many new and different problems for management. The number of interfaces with environmental units increases and the organization must be more responsive. Boundary expansion increases internal complexities and creates problems of control. As an organization expands its activities it cannot continue to use the tight bureaucratic form but must develop a more dynamic and less structured system.

The CMRP and Science and Technology

Much of the foregoing general discussion has direct relevancy to the CMRP, its organization and administration. CMRP is at the interface between two organizations with a strong scientific/professional orientation, NASA and the University of Washington. Many of the problems of creation, utilization, and administration of science and technology are seen in microcosm in this program. One of the major administrative problems is the integration, in an interdisciplinary team effort, of faculty members with strong and diverse scientific/professional orientations. The objectives of CMRP stress innovation in the creation and application of knowledge.

The University Setting

We have indicated that universities have been profoundly affected by advancing science and technology. They have also expanded their activities into many new and expanding fields. There are other forces in the university setting which relate to the development of interdisciplinary research programs, and in particular to CMRP.

Movement Toward Professional Training

During the second half of the nineteenth century there were major transformations in American higher education--the rise of the true university. This was a fundamental change from the traditional collegiate pattern. The American university took its form from the German universities which placed a strong emphasis upon scholarship, creation of knowledge, and training for the learned professions. There developed a new spirit of vocationalism with the incorporation of professional schools within the university. In fact, the universities helped redefine the concept of professions. Universities recognized the need for professionalized training in a wide variety of fields such as engineering and other applied sciences, teaching at the elementary and secondary level, and business administration. "In assuming responsibility for providing formal professional education, the university revealed the degree to which American higher education had now broadly entered into the life of the people."[19] The American university system, more than any other in the world, has provided professionally trained people for a wide variety of activities necessary in an advanced industrial society.

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[19]Frederick Rudolph, The American College and University (New York: Alfred A. Knopf, 1962), p. 3.

The support which the University of Washington has given to the development of the field of ceramic engineering is quite consistent with this general university role in our society. The CMRP also illustrates another facet of this issue. With the great expansion of science and technology, particularly since the end of World War II, universities have been hard pressed to develop new academic programs in many expanding areas. The need for expansion was great but the resources were limited. The utilization of federal funds to aid in development of new academic programs was vital. Universities simply did not have the resources to develop all the new fields. Thus such programs as the interdisciplinary materials research laboratories--and more specifically the CMRP--funded by federal agencies, are essential if the universities are to continue this function. Major cutback of federal funds in these areas will seriously depreciate this role.

Differentiation and Integration of Organizational Activities

With the development of the true university, the problems of structure became more important. The university model brought greater complexities due to increased specialization and the emphasis upon research and knowledge creation. There was also greater diversity of objectives. This process of specialization continued as universities expanded into the various disciplinary fields and added new subject matter.

It became necessary to develop a more complex and elaborate structure. Separate colleges or schools based upon academic disciplines were established. These were further divided into departments with even more academic specialization. This created a strong, specialized discipline orientation throughout the university system. Each discipline developed its own goals for academic and research endeavors. This often led to very closed and parochial viewpoints. Kennedy and Putt suggest the narrow discipline orientation of researchers:

> Research has come to be as ritualistic as the worship of a primitive tribe, and each established discipline has its own ritual. As long as the administrator operated within the rituals of the various disciplines, he is relatively safe. But let him challenge the adequacy of ritualistic behavior and he is in hot water with everyone.
>
> The first conviction of the research specialist is that a problem can be factored in such a way that his particular specialty is the only important aspect. If he has difficulty in making this assumption, he will try to redefine the problem in such a way that he can stay within the boundaries of his ritual. If all else fails, he will argue that the problem is not 'appropriate.' Research specialists, like all other living organisms, will go to great lengths to maintain a comfortable position. Having invested much time and energy in becoming specialists in a given methodology, they can be expected to resist efforts to expand the boundaries of the methodology or to wrap the methodology into an unfamiliar framework.[20]

This high degree of disciplinary specialization and the distinct subcultures of the various academic areas has created major problems of integration for the University. This is particularly true for research activities and academic programs which cut across traditional disciplines.

One of the primary means for achieving integration in the bureaucratic model is the hierarchical authority structure. The authority structure within the university is not similar to that of the bureaucratic model. There is no way of clearly defining scalar authority from top to bottom of the hierarchy. One university president has likened the university to a collegial partnership between himself and 2,000 faculty members. In the university there is a wide

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[20]John L. Kennedy and G. H. Putt, "Administration of Research in a Research Corporation," Administrative Science Quarterly, December, 1956, pp. 329-330.

dispersal of power. A major source of power resides with the holders of knowledge and pursuers of research--the academic staff. The authority of knowledge is a fundamental part of the system and does not rest exclusively in the scaler hierarchy. Thus, most of the decision making relating to research activities and academic programs rests at the departmental (disciplinary) level. Integration between disciplines must rely upon the development of effective horizontal interchanges and not upon the organizational hierarchy. The necessity for the development of mechanisms for the horizontal integration of activities across departmental lines becomes obvious when considering interdisciplinary programs.

Problems in Interdisciplinary Research Programs

The structural characteristics and disciplinary specialization within the university suggests that there are a number of inherent difficulties for interdisciplinary research programs. The following constraints by no means represent the full extent of such obstacles, but they do appear to be the most serious:

1. The university structure itself, based upon a hierarchy of Schools, Colleges, Departments, and Divisions often makes interdisciplinary efforts difficult. Further, the breakdown of knowledge into specialized subject matters often leads to competition and antagonism between disciplines. In many ways the tradition and politics encountered in the university environment do not provide the most beneficial climate for interdisciplinary research efforts.

2. Interdisciplinary and multidisciplinary research efforts, by design, involve many researchers. Problems associated with differences in styles of research, with the composition of the research team itself, and with variances in the time and energy commitments of the individual researchers are often encountered. Overt displays of competition and antagonism among the researchers often follow if the aforementioned problems are acute.

3. Project directors or principal investigators of team research efforts rarely have formal control and authority over the activities of the individual participants. Similarly, they have little or no control over the rewards and incentives that commonly serve as motivators to individual commitment and effort.

4. Goal determination is often a difficult task when imputs from many disciplines must be considered. Many times, the determination of the precise goals which interdisciplinary and multidisciplinary research are to achieve is the most formidable obstacle to be overcome. In the extreme type of interdisciplinary research especially, the goals may ultimately determine the disciplines involved and the methodological approach to be employed.

5. In some instances, the university administration represents a deterrent to interdisciplinary and multidisciplinary research programs by requiring excessive paperwork, by imposing budget constraints, and, in some cases, by influencing the direction and focus of the research effort.

6. The agency funding the research program may establish policies and constraints which deter interdisciplinary research efforts.

With these many obstacles to interdisciplinary research it becomes evident that such an effort will not occur spontaneously. <u>Integration requires effort and resources</u>. Some group or individual must be willing to devote the necessary effort to achieve integration. Unfortunately, this role is not fully recognized in most of our universities.

It is our view that these obstacles to interdisciplinary research have been substantially overcome in the CMRP program. The CMRP has responded to many of these problems successfully. Furthermore, it has accomplished this without excessive resources being allocated to the integrative function.

Project Team Organization

It is highly unlikely that the structure of a university could be changed to accommodate to the requirements of a specific interdisciplinary research program. Therefore, the organization of the program should be designed to transcend the barriers imposed by the university structure.

Program or project management in government and industry has evolved to accomplish objectives that are similar to the goals of interdisciplinary research. These experiences can serve as a model for interdisciplinary efforts within a university.

Project management has the major purpose of integrated management of a specific program on a systems basis. The project manager has the primary role of integrating the diverse activities required for program accomplishment. "The project manager acts as a focal point for the concentration of attention on the major problems of the project. This concentration forces the channeling of major program considerations through an individual who has the proper perspective to integrate relative matters of cost, time, technology, and total product compatibility."[21]

The project manager is usually superimposed upon the functional organization, creating new and complex relationships. This structural approach requires organizational modifications, emphasizes the integrative aspects, and requires the development of effective horizontal and diagonal information-decision networks. The manager cannot operate effectively if he relies solely upon the formal authority of his position. Success is likely to depend upon his ability to influence other organizational members. Because he is a focal point of the operation, he does have informational inputs which provide him with a strong basis of influence. The program manager's authority and

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[21]David I. Cleland, "Why Project Management?" Business Horizons, Winter, 1964, p. 83.

influence flow in directions which are different from hierarchical authority. They flow horizontally across vertical superior-subordinate relationships existing within the functional organization. Throughout the program, personnel at various levels and in many functions must contribute their efforts. For each new program lateral information-decision networks must be established which differ significantly from the existing networks based upon the established structure. The organization should be sufficiently flexible to allow for evolving relationships and networks as program requirements change.

In many ways there are similarities between the project management form and the administration of interdisciplinary research. Interdisciplinary research often requires that a hybrid form of organization structured be developed to compensate for obstacles inherent in the university setting. A flexible "free-form" structure allows a more responsive reaction to changes. The barriers of departmental lines should be minimized. Team members should have access to each other and must interact if interdisciplinary research is to be successful.

We see similarities between the role of a project manager and that of the Principal Investigator of the CMRP. The Principal Investigator is not in a superior relationship to the team members. He does not possess the formal authority to direct the activities of the participants to any significant degree. Only in rare instances does a Principal Investigator have control over the formal academic reward system; i.e., salary, promotion, and tenure. He does not have strong authority of position. In order to be effective he must develop a high degree of interpersonal influence with team members.

The Principal Investigator's primary function is integration of the efforts of scientists, using the norms of professionalism to provide a form of control. He should be able to rely upon the values and self-imposed standards of each participant to govern individual research activities.

He does have at his disposal certain indirect incentives. Access to funds for travel, for the purchase of equipment, and for graduate student support are important incentives within the academic environment. There is also the opportunity to gain national visibility within the academic community by publishing the results of individual research efforts. Used wisely, these incentives can motivate participants and reward excellence in research. Conversely, the withdrawal or withholding of such incentives can provide a deterrent to an indifferent research effort.

There is no doubt that much of the success of an interdisciplinary research effort depends upon the influence and integrative skills of the principal investigator. He must encourage interaction among the participants. He is the catalyst that makes things happen. He is a communication link between all the participants and it is his responsibility to channel information to those involved. He also serves as the most important interface between the research team and the sponsoring agency. He is a "boundary agent" whose activities span several organizations. Part of his function is to create a research climate that encourages interaction among the researchers. To do this he must gain the respect of the participants not only for his leadership and integrative abilities, but also for his technical expertise.

Given that the university has established research and academic competency in the necessary fields, it appears that the selection of the principal investigator and the establishment of an effective mechanism for coordination is one of the most critical decisions in the development of an interdisciplinary program. Just as the government and industry frequently have difficulty in finding the right person to perform the role of project manager, so also are there difficulties in finding an appropriate principal investigator for an interdisciplinary research effort. It seems apparent to us that this role and its requirements are not clearly understood either within the university or by the sponsoring agency. There are, however, certain pitfalls to be avoided. It seems unlikely that a person with an existing administrative position, such as a dean or departmental chairman could fulfill this role effectively. He frequently has so many diverse responsibilities that he could not devote sufficient effort toward achieving integration. He would not have the time nor the motivation to perform all the interface functions. Again, it is unlikely that someone in the central administration, such as vice president of research, could perform this role effectively. He has many research projects to monitor and could not give enough detailed attention to a specific program.

These limitations would seem to indicate that the most likely principal investigator would be a senior faculty member who is well-established in his disciplinary area and who has the respect of his colleagues in other departments. However, he would also need to be motivated toward substantial effort to make the team effort go. An overriding concern with his own research interests and academic discipline might prevent him from performing these vitally necessary integrative functions.

The CMRP was fortunate in developing a flexible group structure which allowed for communication and linkage of participants and in the selection of a Principal Investigator who had the willingness and ability to perform many integrative functions. He possessed the technical competence necessary to coordinate the program, but even more important was the interpersonal competence to integrate and encourage interdisciplinary interaction. He established personal relationships with every member of the team and his leadership style encourages participation. He also has another major function--maintaining the interface with the sponsoring agency, NASA.

NASA-University Interface

There are many problems associated with the interface between NASA and the universities within which it is sponsoring research programs. These problems relate to a broader issue in our society of interorganizational relationships. With the growing importance of complex organizations we should have greater awareness of the problems of interorganizational analysis. The lack of emphasis on the study of organizational interface is due primarily to the traditional emphasis in both organization and economic theory. Organization theory was concerned primarily with internal structural relationships and with problems of integration and improvement of task performance. Economic theory considered interface and coordination between organizations as being accomplished through the pricing mechanisms of the marketplace.

In the future there will be increasing emphasis on interorganizational relations. Administrative coordinating processes between organizations have been used as substitutes for or complements to marketplace coordination. This has occurred in relationships between the government and the national defense industries and in the NASA programs. In the future, even more administrative coordination between complex organizations will be necessary. Galbraith sees a closer interrelationship between business and government in the future, and the continued development of a complex industrial system based upon cooperation.

> Given the deep dependence of the industrial system on the state and the nature of its motivational relationship to the state, i.e., its identification with public goals and the adaptation of these to its needs, the industrial system will not long be regarded as something apart from government. Rather it will increasingly be seen as part of a much larger complex which embraces both the industrial system and the state.[22]

While we may not agree fully with Galbraith about the extent of the mergence of the industrial complex with the state, we do foresee a substantial increase in the interface between government and business. The same thing is true between government agencies and universities.

Again, we see this general problem of interorganizational interface represented in microcosm in the CMRP. We have two complex organizations, NASA and the University of Washington, which have to establish some means for integrating their activities related to CMRP. It is usually more difficult to achieve interface between organizations than it is to achieve coordination within a given organization. There are many barriers to interorganizational coordination and some means for bridging these is necessary. When faced with problems of interorganizational coordination, "boundary agents" are frequently used. In the CMRP the Principal Investigator serves as the primary boundary agent for the University of Washington and the Technical Monitor serves as the boundary agent for NASA. These two individuals have the primary role of interorganizational interface. It is vitally important that they establish effective interpersonal relationships and are able to "speak for" their perspective organizations. While they are supported by review committees within each organization, they must serve as the central point of interorganizational communications.

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[22] John Kenneth Galbraith, The New Industrial State (Boston: Houghton Mifflin Company, 1967), p. 392.

Communication of Findings

One of the evolving objectives of CMRP is related to the communication of research findings. The goal is to develop communications between university personnel and those interested in ceramic materials research at NASA research centers, other federal agencies, ceramic and aerospace industries, other institutions of higher learning, and research institutes. Formally, this is accomplished through the semiannual program reviews and the semiannual status reports. Many informal interchanges of information have developed. However, there remain barriers to the full accomplishment of this objective. One problem in an interdisciplinary effort is establishing communications between the individual researcher and the NASA technical personnel who have interests in his area. There have been numerous suggestions as to how this might better be accomplished. For example, the program reviews might be held at various NASA centers. Also, it was suggested by some of the participants that the current semiannual review provided only a brief and superficial opportunity for presentation of results and for interactions between interested parties. A more comprehensive annual review might be more appropriate. This issue of providing adequate communication of the results of the CMRP is one of the unresolved problems in the program.

Funding of Programs

There was general agreement of participants in CMRP and university administrators that NASA's step-funding approach was a hedge against uncertainty and a definite aid to the university in its planning. The CMRP approach of block grants as compared to individual contracts created less paperwork and concern over proposals. Seeking individual grants from a federal agency often leads to some "proposalmanship" in which a great deal of time and energy is devoted to getting funds, perhaps reducing the effort going into the actual research. On the other hand, block grants such as CMRP may make procedures for granting funds and reviewing work too easy.

It seems to us that the nature of the grant should be determined by the objectives. In a grant such as CMRP with multiple objectives and a strong academic program building focus, the long-term block grant appears most appropriate. Where the federal agency has a specific research goal and a primary interest in research results of a specific nature, individual, short-term grants are feasible.

The withdrawal of funds for the CMRP would have severe repercussions upon the materials sciences activities at the University of Washington. This would be particularly true for graduate students and faculty in Ceramic Engineering. This program has been effective in accomplishing its objectives and interests and activities as being sustained at a high level. Our observations suggest that creation of an effective interdisciplinary effort does take time, energy, and organization. Many of the benefits of this program would be substantially reduced or eliminated if the current financial support of the CMRP were discontinued by NASA.

Areas for Future Research

The research team for this study of the impact of the Ceramic Materials Research Program at the University of Washington has found participation in this program rewarding. We were searching in a relatively unexplored area and had to create a new research design. We emphasized that this was an exploratory study rather than one which tested specific hypotheses. We personally have learned a great deal concerning the organization and administration of interdisciplinary research programs within a university setting. However, we recognize that this report is just a beginning and raises many new issues which necessitate further, more intensive investigations. This study represents an initial phase which provides the framework for further research. The background of knowledge and insights which have accrued to the research team during this study can serve as the basis for future research efforts.

We perceive a number of specific research areas which can build upon the results of this study. Several of these are discussed below.

1. Comparison of CMRP with other NASA-University programs. NASA is sponsoring numerous university programs. It would be interesting to compare the organization and administration of these programs with our findings from study of the CMRP. Specifically, a comparative study of CMRP with the two other NASA sponsored interdisciplinary materials research programs at Rensselaer Polytechnic Institute and Rice University would be of interest. A comparative analysis of the goals, organization and administration, and overall results at these three institutions could provide valuable information.

2. A further extension of this approach would be a comparative study of the interdisciplinary materials research laboratories sponsored by the federal agencies participating in the interagency Coordinating Committee on Materials Research and Development (CCMRD). A comparison of the goals, organization and administration, and overall results of these programs could provide new insights in the area of government-university research programs.

3. Investigation of university organization and administration of government sponsored research programs. Specifically, this research would envolve a comparative analysis of other interdisciplinary research programs in the physical sciences at the University of Washington. In addition to the CMRP, there are four other interdisciplinary programs currently operating: (1) the Geophysics Research Program; (2) the Bio-Engineering Research Program; (3) the Sea-Grant Research Program; and (4) the Aerospace Research Program. A comparative study of the goals, organization and administration, and relative success of these programs could provide important information for future interdisciplinary research efforts on the University of Washington campus. The nature and complexity of today's research problems indicate that progress is increasingly dependent upon the skills and knowledge of many distinct disciplines. Information concerning effective organization and administration of interdisciplinary research would ultimately benefit every academic institution.

4. More detailed investigation of the NASA-university interface. We have suggested that there are major problems of coordination and communication between government agencies sponsoring research and universities. What channels exist to communicate the problems of NASA to universities and vice versa? What means exist to transfer research findings from the universities to the appropriate individuals within NASA? The development of more effective means for interorganizational communication and integration is important if research efforts are to be utilized.

5. Investigation of the project management form for university research teams. We have indicated that the role of a principal investigator is similar in many ways to that of a project manager in government and industry. However, there has been little recognition within the university of this function.

Success is often achieved by chance and the administrative causes of failure are not fully recognized. Investigation of this role in various universities would lead to greater understanding and could provide valuable normative guidelines.

6. Finally, we see major problems facing universities in organizing for many types of research and academic efforts. The strong disciplinary orientation (frequently on rather arbitrary bases) makes interdisciplinary efforts difficult. Universities must find more effective means for bringing together the various disciplines to deal with many of our scientific and social problems. Investigation of university organizations to determine what has been done and what might be done to create an environment more conducive to integrative interdisciplinary efforts could be of vital importance.