Science and Technology Centers: Principles and Guidelines

Panel on Science and Technology Centers, National Research Council

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SCIENCE AND TECHNOLOGY CENTERS

Principles and Guidelines

A Report by the
Panel on Science and Technology Centers

National Academy of Sciences
Washington, D.C. 1987

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PANEL ON SCIENCE AND TECHNOLOGY CENTERS

Richard N. Zare (*Chairman*), Stanford University
Norman M. Bradburn, University of Chicago
Praveen Chaudhari, IBM Corporation
Ernest G. Jaworski, Monsanto Company
Daniel Kleppner, Massachusetts Institute of Technology
Joshua Lederberg, Rockefeller University
Donald J. Lewis, University of Michigan
William Press, Harvard University
Leon T. Silver, California Institute of Technology
Larry Smarr, University of Illinois
Joseph E. Varner, Washington University

Staff

Norman Metzger, *Study Director*
Stephen Merrill, *Writer*
Gretchen Schneider, *Administrative Assistant*

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Donald H. Osterbrock, Professor of Astronomy and Astrophysics, Lick Observatory, University of California, Santa Cruz
Alexander Rich, Sedgewick Professor of Biophysics, Massachusetts Institute of Technology
Carroll M. Williams, Benjamin Bussey Professor of Biology, Harvard University

PREFACE

The nation's economy is driven increasingly by the development and commercialization of new technologies. Competition for creating and applying these new technologies is fierce and worldwide. In an effort to meet this challenge, President Reagan, in his 1987 State of the Union message, proposed several initiatives to enhance the nation's economic competitiveness, including the establishment by federal research agencies of Science and Technology Centers. The President described these centers as "new university-based, interdisciplinary 'Science and Technology Centers' that will focus on fundamental science that directly contributes to the nation's economic competitiveness."

The National Science Foundation (NSF) intends to begin supporting such Science and Technology Centers in fiscal year 1988. To accommodate this new program, as well as to provide increased funding for traditional research modes and for facilities, the President is requesting yearly budget increases that are intended to double the NSF budget by 1992.

In a letter to National Academy of Sciences (NAS) President Frank Press dated February 11, 1987, the Director of the Foundation, Erich Bloch, asked the NAS to provide guidance by June 1 for NSF's implementation of the President's proposal. A copy of this letter is appended to this report.

A panel was formed under the guidance of the Council of the National Academy of Sciences. This panel has taken a broad view of its charge to advise the Foundation. Aware that the President's proposal and the Foundation's response have caused some concern in the scientific community, the panel has considered how to ensure that centers encourage individual initiative and scientific innovation.

The panel has examined

— the role of the National Science Foundation in the President's program for Science and Technology Centers;

- the relationship between Science and Technology Centers and other modes of research support by the Foundation;
- essential and desirable features of NSF-funded Science and Technology Centers;
- mechanisms and criteria for soliciting and selecting proposals to encourage the most promising ideas;
- principles and methods of governance, including the relationships of the centers to their parent universities, the Foundation, and their scientific constituencies; and
- concerns raised within the scientific community by the proposed expansion of the center mode of research.

The panel met twice -- March 28 - 29, in Washington, D.C., and April 15 - 17, in Palo Alto, California. During those meetings it had the benefit of extended discussions with the Director and other senior officials of the National Science Foundation. Much of this discussion concerned the meaning of the concepts “science and technology” and industrial and state participation as a “prerequisite.” In neither case was the panel asked to adopt restrictive meanings. The panel agreed subsequently that, although the government-wide program for Science and Technology Centers should eventually embrace the entire spectrum from science to technology, the NSF portion of the program should focus primarily on basic science. Further, participation by industry, states, and other sectors, although possibly including financial support, should emphasize intellectual involvement.

Finally, the panel attempted to identify areas, suitable for the center mode, that seem most promising in relation to economic competitiveness. While in many cases is was possible to foresee evolutionary advances, the panel realized that revolutionary advances are often the most important; and, in this area, past experience shows that no panel or government agency can forecast with assurance which fields, or

combination of fields, will produce new discoveries of major importance to the nation's economy. Therefore, the panel quite deliberately chose not to prejudge which areas might be particularly relevant to economic competitiveness.

The panel sought the advice of the chairs of the National Science Foundation and the National Research Council advisory boards on various research disciplines and of W. Dale Compton, who chaired the panel of the National Academy of Engineering that, in 1983, provided guidelines for the Foundation's creation of Engineering Research Centers. The panel also examined the operation of various types of centers, including the Materials Research Laboratories, the Engineering Research Centers, and several centers in particular fields of science and mathematics. A subcommittee of the Council of the National Academy of Sciences reviewed the panel's report.

The limitations on the panel's work should be clearly understood. First, its recommendations were framed in terms of the National Science Foundation's program for Science and Technology Centers and do not necessarily apply to the companion programs of other federal agencies.

Second, the panel, in its brief lifetime, was unable to undertake a thorough examination and evaluation of the relative strengths and weaknesses of different modes of research support -- from individual investigator grants to group awards to centers in various forms. Such an examination is needed and is under way by a panel of the Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. That report is expected to be available early in 1988.

Richard N. Zare

Chairman

Panel on Science and Technology Centers

CONTENTS

EXECUTIVE SUMMARY

The National Science Foundation's proposed program for Science and Technology Centers at universities can have an important place in the Foundation's portfolio of research support and make significant contributions to science and to the nation's economic competitiveness. To accomplish this will require proper management, adequate resources, and, above all, the selection of programs for which the centers are the most effective form of organization. Great care will be needed to keep the Science and Technology Centers program in proper balance with other modes for supporting U.S. science.

Centers have advantages over other support modes for those areas of scientific inquiry that would benefit from formal, sustained collaboration in pursuit of an intellectual objective. Such work may involve one or more disciplines; it may depend upon research facilities or instrumentation large enough or costly enough that their use is best shared.

Centers can contribute to the nation's economic competitiveness by advancing the frontiers of knowledge; providing the opportunity for timely exploitation of new discoveries; educating young researchers at the highest professional level to fill university, government, and industrial positions; and accelerating the application of new knowledge to the resolution of economically important problems.

FEATURES OF NSF SCIENCE AND TECHNOLOGY CENTERS

The panel believes that centers should have the following features:

- Their primary goal is to exploit opportunities in science where the complexity of the research problems or the resources needed to solve these problems require the advantages of scale, duration, or facilities that can be provided only by the center mode of research.
- They have a set of related research objectives that may entail work across disciplines or within a single discipline.
- They are campus-based, led by regular faculty, and integrated into academic programs; there is a tangible commitment to the centers by their home universities.
- They provide education and research experience for undergraduate and graduate students, postdoctoral researchers, industrial fellows, and others.
- Through outreach activities, whose type and scope will vary with the mission of the center, they provide opportunities for intellectual exchanges with researchers in other scientific fields and in industry, government, and other sectors. They may have financial support from non-federal sources, but that should not be a prerequisite.
- They display diverse organizational structures, ranging from a center of activity at a single university to a linkage of several centers of activity.
- They may range widely in size. Typically, their annual cost to the NSF will be from $1 million to $5 million, but may be as low as $500,000 and, in some instances, as high as $10 million.
- They have a finite life with stable funding for a period not to exceed nine years.

NSF MANAGEMENT

The panel recommends that the Science and Technology Centers program be managed as follows:

— NSF should maintain a separate budget for Science and Technology Centers administered by a new program office for Science and Technology Centers. The panel assumes that the Foundation will receive proposals for this program annually.
— Proposals for centers should have a two-stage review -- an initial merit review of the quality of the proposed research, followed by a review that determines whether the work to be done justifies a center form of organization.
— Centers should be reviewed by outside visiting committees every three years.

CAUTIONS

The panel endorses Science and Technology Centers as one valuable mode of research support. At the same time, the panel cautions that

— There is a risk that a significant portion of federal funds and university resources will be diverted from the support of individual investigators, especially if the Foundation's budget remains static or declines. In those circumstances, the projected budget of the NSF Science and Technology Centers program should be reduced proportionately.
— The number of centers should not be increased unless existing centers have adequate resources to carry out their missions.
— Centers, like other organizations, may in time become resistant to new ideas and unreceptive to new members with different

perspectives and backgrounds. It is easily forgotten that scientific advances flow from dedicated researchers and their ideas, not from institutions.

— Interdisciplinary research, although essential for the solution of many problems, should be pursued only when there is a demonstrated need or opportunity, not because of current fashions or the enhanced likelihood of funding.
— No single type of center should be allowed to dominate the program relative to other types of centers.
— Science and Technology Centers are only a partial cure for deficits of facilities, staffing, and instrumentation in academic research.
— The work of centers should not focus on near-term commercial applications to the neglect of scientific advances of greater long-term economic significance.

Notwithstanding these cautions, the panel believes that Science and Technology Centers can make significant contributions to science and the nation's economic competitiveness with proper management, resources, and evaluation, provided there continues to be a balance among the principal modes of research support.

I. INTRODUCTION

ECONOMIC COMPETITION, RESEARCH, AND THE NATIONAL SCIENCE FOUNDATION

This nation's preeminence in scientific innovation is a major and durable strength. In looking to the future, however, many knowledgeable observers have raised serious concerns about our ability to sustain a high rate of innovation and to transfer new knowledge rapidly to industrial and social needs. The National Science Foundation has a crucial role to play in addressing these concerns.

In view of its mission “to promote the progress of science and engineering” and “to address the national health, prosperity, and welfare,” the Foundation has responsibility for the creation of new scientific knowledge and for providing students with the quality and breadth of instruction required to meet the changing needs of science and society. The Foundation must ensure that today's scientific frontiers are being explored vigorously and that the results of this research are made available to society as rapidly as possible. As many of today's new industries represent the harvest of research in former decades, today's basic research sows the seeds for new industries of future decades. Any strategy for economic competitiveness that fails to recognize the importance of a long-term commitment to basic research will be self-defeating.

GOALS

Viewed in the aggregate over the long term, the economic payoff of investment in education and research is enormous, but its sources and timing are uncertain. In some cases, science evolves along fairly predictable lines whose benefits can be largely anticipated; but

revolutionary discoveries of much greater long-term economic significance usually depend on knowledge whose utility was unforeseen. No one envisioned that basic studies in the microwave spectrum of ammonia would lead to the invention of the laser, whose contemporary uses range from printing documents to long-distance communication to ship welding to repairing detached retinas. Similarly, no one anticipated that research on magnetic moments and nuclear spin would lead to nuclear magnetic resonance, which today finds countless uses ranging from chemical analysis of compounds to medical diagnostics; or that work on the molecular biology of bacterial viruses and intestinal bacteria would create a new industry. And who would have predicted that research on perovskites, a common class of mineral insulators, would lead to the discovery of high-temperature conductivity, whose potential applications seem enormous?

The lesson of these and other examples is that the United States must continue to support a wide variety of research activities -- short and long term, basic and applied -- organized in the many different ways that are appropriate to the various research problems and opportunities.

The principal rationale for the NSF Science and Technology Centers is to ensure continued preeminence in science and an adequate base of trained scientists -- two ingredients essential to our success in economic competition. They should not be intended to respond to government or industry perceptions of what is required to remedy deficiencies in U.S. competitiveness in the short term.

BALANCING MODES OF RESEARCH

The major issue in inaugurating a new program of Science and Technology Centers is one of balance among modes of research support. The single investigator with a small research team remains the appropriate mode for many fields of scientific inquiry. This mode has the advantages of pluralism, decentralization, and flexibility to move in new directions as opportunities unfold. Individual investigator support has been enormously successful for the National Science Foundation and productive for the nation. Its preeminence must not be diminished.

Although not identified separately in the NSF budget, group projects receive a growing share of NSF research funding. They are concentrated in

the materials, physical, and biological sciences. Groups typically involve a few researchers collaborating or simply sharing equipment. They usually lack an administrative structure, an educational mission independent of university departments, and the ability to fund promising new projects; but they have many of the virtues of single investigator projects and should be treated as favorably.

The term “center” implies a larger scale activity with a formal management and organizational structure. Centers are not a new idea for NSF. On the contrary, they are already an important part of the Foundation's funding portfolio. In view of the need to support more collaborative research and build university infrastructure in many areas where progress is otherwise limited, centers should be expanded as one component of increased research funding.

It is in the context of the President's intention to double the NSF budget over five years that the panel supports the Foundation's Science and Technology Centers initiative. At the outset of its deliberations, the NSF Director assured the panel that, although he envisages a three-fold increase in the total number of NSF centers during that period, the centers will still represent only about 10 percent of the Foundation's budget. Awards to principal investigators for single and collaborative projects will continue to represent about 60 percent of the budget for research. In the event that the additional funds are not appropriated as anticipated, the panel believes that the Science and Technology Centers program should be reduced proportionately.

II. THE MISSION AND CHARACTERISTICS OF NSF-FUNDED SCIENCE AND TECHNOLOGY CENTERS

WHAT ARE SCIENCE AND TECHNOLOGY CENTERS?

The panel conceives a Science and Technology Center as a group of researchers who share common goals or common means such as a laboratory, an instrument or set of instruments, or a data base. Centers are on a scale between the single investigator or a small group of investigators and large national facilities such as the National Center for Atmospheric Research or the national laboratories. Centers contribute to science by enabling researchers to accomplish challenging, longer term projects that they could not undertake at all or as efficiently as individual investigators because of the need for stable support, large facilities or support teams, or simply the need to bring together diverse experiences and expertise. By involving external parties as well as students in their research activities, centers contribute to the more rapid transfer of new knowledge and to the training of professionals with an awareness of potential applications.

No single type of center fits the needs or exploits the potential of contemporary research in every field. The science should determine what a center is and does, not the reverse. Innovative researchers and their ideas, not institutions, drive science and, ultimately, economic progress. Thus, the general features of Science and Technology Centers should exhibit diverse forms of organization, participation, and operation.

Science and Technology Centers should have research as their major function. Their success should be measured by the quality of the science and the significance of the new knowledge generated. In addition, they should be judged for their effectiveness in transferring knowledge and educating a variable population of undergraduate and graduate students, postdoctoral fellows, and visiting scientists and other professionals.

THEME

A center's "theme," or intellectual focus, should emphasize important research opportunities. It may derive from a single discipline or several disciplines. In either case, centers should be effective in promoting active intellectual collaboration among researchers with varied backgrounds and perspectives acquired in different kinds of science (e.g., basic and applied), different modes of research (e,g., experimental, computational, and theoretical), and different sectors (industrial, government, and university).

The panel considered the request by the NSF Director for suggestions of promising areas for which the funding of a center might be the best mode of support. Recognizing that some of today's most exciting scientific opportunities were unknown a short time ago, the panel concluded that identifying a small number of candidate areas might inadvertently steer researchers away from areas of even greater promise or prejudice the review process. For these reasons, it would be unwise for the panel or the Foundation to pre-select a limited number of scientific and technological areas. Instead, the scientific community should define the range of research goals through the quality of the proposals it generates for Science and Technology Centers.

The panel points out that in recent years there have been a range of reports in which the scientific community described potentially explosive advances in many fields and subfields of science; for example, the research briefings by the Committee on Science, Engineering, and Public Policy and the disciplinary surveys in chemistry, physics, and other fields by the National Research Council. Many of the opportunities described in these reports could be facilitated by the Science and Technology Center mode of research.

Finally, the panel considered the balance between science and technology in Science and Technology Centers. It concluded that such a balance should emerge across the Science and Technology Centers programs of the Foundation and other government agencies but that the mix will vary considerably from one center to another. Some centers will emphasize basic research, while others will have a major technological component. The panel anticipates that NSF, by virtue of its traditional mission, will

concentrate its resources on activities involving basic scientific research.

EDUCATION

Centers can enhance educational opportunities for undergraduate and graduate students and postdoctoral researchers by increasing the resources available to universities and by providing exposure to leading-edge research that might not be undertaken otherwise. In some cases, centers will introduce students to large-scale collaborative ventures that characterize some industrial research organizations. The instructional mission of centers need not be limited to full-time students and postdoctoral fellows. Some centers will provide continuing education for industrial researchers, visitor programs for scientists from other institutions, personnel exchanges, and conferences and seminars. Where these occur, students will be better equipped to deal with practical problems if they move to industry. By the same token, industrial researchers will be better acquainted with new developments in science.

CENTERS AND THEIR UNIVERSITIES

The integration of a center into its parent institution is essential. The center's core leadership should comprise faculty belonging to one or more departments of the host university or other participating universities.

The intellectual and administrative home of a center should be on or contiguous to the campus, although a major facility of the center may be located elsewhere. Further, in any proposal for a center, there should be a tangible demonstration of the university's support in the form of space, faculty positions, capital equipment, or access to existing facilities and instrumentation.

MODELS FOR SCIENCE AND TECHNOLOGY CENTERS

Although no current program has precisely the characteristics envisioned for the President's Science and Technology Centers initiative, the National Science Foundation has experience in several closely related activities. Among these are Materials Research Laboratories (9 facilities currently funded at a total of $26 million annually with 15 years of experience); Industry-University Cooperative Research Centers (39 centers currently funded at $3.2 million annually with 7 years of experience); Engineering Research Centers (13 centers currently funded at $30 million annually with nearly 3 years of experience); and several specialized centers not part of larger programs. Finally, beginning in fiscal year 1987, NSF will support several new Biological Facilities Centers at an aggregate level of up to $8 million. Together, support for these and other existing centers totals approximately $115 million in fiscal year 1987. *

These NSF centers exhibit a diversity of structures, missions, and modes of operation that may be reflected in the Science and Technology Centers program, but none can be considered a perfect model for the new centers. The panel anticipates and encourages wide variation in the design of center proposals, limited only by the imagination of the scientific community.

Possible models for Science and Technology Centers include:

— Centers organized around an intellectual theme that requires drawing together a critical mass of researchers from within a single discipline or from several disciplines. The focus may be experimental, theoretical, or computational; the organization may be within a single university or it may draw researchers from several institutions. For example, theoretical institutes focusing on a single discipline might be characterized by topical programs of limited duration, small permanent staffs, a large

* Figures provided by the Office of the Comptroller, National Science Foundation.

number of short-term visitors, and broadly attended conferences on topics of current research.

— Centers organized around a common facility, set of experimental techniques, a common data base, or research instruments. The latter may be existing techniques and instruments, or the center may be designed to develop new tools of research. The facility need not consist solely or primarily of hardware; multiple uses of a common data base may provide the focus of a center's activities.

— A “center without walls,” a network of research scientists at several institutions who interact frequently by electronic or other means. Such a center could stimulate cooperative research when no single institution has the resources to form a center. Furthermore, it could avoid what might be an undesirable concentration of effort and talent at a single institution or, alternatively, a duplication of activities and investment at several institutions.

OUTREACH AND PARTICIPATION

The resources available to centers should enable them to undertake a variety of outreach activities to transfer new knowledge to researchers in disciplinary subfields or other sciences or to industry and other sectors. The most effective way to transfer knowledge generated by research is through direct intellectual exchanges -- seminars, conferences, visitor programs, and exchange visits. Knowledge transfer is a “body contact sport.” Such activities must be commensurate with the size of the center and appropriate to its research theme.

External participation by industry, government, and other sectors can facilitate knowledge transfer, bring different perspectives to research problems, and augment resources. The nature of the problems and opportunities selected for support should govern the form and extent of such participation. It is to be expected that the role of participants and the extent of their involvement will vary greatly among centers and

over time. Participants may be state governments, national laboratories, foundations, and non-profit research institutions as well as industrial enterprises. Opportunities for continuing intellectual exchanges that acquaint academic researchers with practical problems and convey new knowledge and techniques to researchers elsewhere in the public and private sectors are more important than financial support.

III. SOLICITATION AND SELECTION OF PROPOSALS

GENERAL GUIDELINES

The Foundation's solicitation of proposals should impose as few constraints as possible on the subject matter, size, and organization of proposed centers. NSF should accept proposals in any field. Universities and departments with diverse capabilities should be encouraged to submit more than one proposal. Researchers should be able to work within a center while also receiving individual investigator grants.

In view of the large scale and long duration of centers, thorough merit review is critical. External reviewers should evaluate the scientific quality of the proposed research and the capabilities of the institution and investigators to meet the criteria of a successful center. There should be face-to-face and on-site reviews of the leading candidates among competing proposals.

The creation and operation of a center is a major undertaking, requiring not only research, education, and facilities development within the parent institution, but also outreach to the scientific community and, in many cases, to industry. To realize their potential, centers selected for support must be adequately funded, even if the consequence is the creation of fewer centers than the Foundation has projected.

Following the initial selection, new centers should be created only to the extent that funding is available without detriment to the support of individual investigators or existing centers. If the projected budget increases are not approved by Congress, the Science and Technology Centers program should be reduced proportionately so that a balance is maintained among modes of research support.

FUNDING, REVIEW, AND SELECTION

NSF should maintain a budget for Science and Technology Centers separate from current program and division budgets and administered by a new program office for Science and Technology Centers. The panel assumes that the Foundation will receive proposals for the program annually.

Authors of proposals should, at an early stage, consult with a program officer within one of the existing NSF research directorates or in the new office. Proposals should be submitted to existing program offices or directly to the program office for Science and Technology Centers. The latter should be charged with serving as an advocate and ombudsman for proposals that do not fall into current program areas. NSF should ensure that all of the program offices involved in evaluating proposals are adequately staffed to perform these functions.

The selection of proposals should proceed in two stages. First, under the direction of the Science and Technology Centers office, program officers responsible for fields in which applications are submitted should participate in setting up an initial merit review of the scientific quality of the proposed research. Program officers from the discipline-based directorates are the most knowledgeable people in the Foundation to select reviewers for scientific quality. The first round of review may be conducted by mail ballot or by convening panels of reviewers.

For proposals judged to have significant scientific merit, there should be a second level of review, addressing:

- whether a center is needed to do the proposed work,
- whether the preconditions of an effective Science and Technology Center are likely to be met, and
- what should be the balance of awards among scientific fields to meet the goals for the NSF Program for Science and Technology Centers, including enhancing the nation's economic competitiveness.

This second review should be conducted by a single multidisciplinary committee reflecting the full spectrum of NSF research activities and

composed of scientists from universities, industry, and national laboratories, selected for their broad perspective on science, education, and knowledge transfer. The committee might convene ad hoc panels of specialists to interview applicants at a central location or to conduct on-site visits. Site visits are essential, although they may be practical only for those few proposals tentatively selected for awards. The review committee should advise the NSF Director on the final selection.

CRITERIA FOR SELECTION

Scientific Quality

The principal selection criterion will be the scientific quality of the proposal. The proposed center should enable new science or the application of new techniques or instruments to important scientific problems. The proposal may be cross-disciplinary or limited to a single discipline, as appropriate for its objectives.

Intellectual Theme

A proposal should have a unifying research theme and should demonstrate that the proposed center can accomplish significant results more effectively and in a more timely manner than its participants could achieve as individual investigators. A center's theme should be sufficiently long term to justify a center form of organization and broad enough to permit changes in focus and approach as the research proceeds, but it should have sufficient focus to have definable goals. In some instances, the theme may derive from various uses of a common facility or piece of equipment, but the center must be more than merely a provider of services.

Education and Training

The proposal should include plans for the education and training of a mix of undergraduate and graduate students, postdoctoral and industrial fellows, and faculty of undergraduate institutions and secondary schools. The instruction plan should indicate how the center's activities will be integrated into the university's structure and academic programs.

Staffing

Science and Technology Centers can succeed only with outstanding leadership. It was apparent from the panel's examination of existing centers that the presence of one or two highly effective administrators often makes a critical difference. The usual mode should be a single director with strong scientific qualifications and administrative skills.

The university should demonstrate its willingness to provide regular teaching faculty who meet university and departmental standards to constitute the core research staff of the center. Where interdisciplinary research activities are contemplated, the university should demonstrate how its academic departments will recognize and reward faculty, research fellows, and students for their accomplishments within the center.

Additional scientific staff may occupy non-tenure track positions. Proposals should anticipate the career and career development opportunities that will be available to scientific staff who do not hold faculty appointments; and they should address the kinds of interaction expected to occur among a center's principal investigators and other research staff.

Size and Cost

The purpose of a center is to achieve greater productivity and inventiveness in an important area of science. The size and cost of a center derive from the demands of the subject matter. The annual NSF investment might be as low as $500,000 and as high as $10 million, with the cost of most centers falling in the range of $1 million to $5 million.

The number of personnel associated with centers also may vary widely. Lower limits are set by the center's objectives. Upper limits are set, in addition, by the need to maintain focus and coherence and by the availability of specialists. The size of a proposed center should be commensurate with the size of the field; the majority of research talent in a field or subfield should not be concentrated in a single center.

Outreach and Participation

Center proposals should include plans for involving the relevant research community beyond the sponsoring university -- at other universities, colleges, and non-profit research organizations and in industrial and government laboratories. This outreach can take many forms, including timely publication of research results, visitor programs, personnel exchanges, computer linkages, conferences and seminars, institutional affiliations, work-study programs, consulting arrangements, continuing education programs, contract research, student placement in summer jobs, and academic-year cooperative programs.

Although leveraging the NSF investment is desirable, it should *not* be the primary reason for attracting the participation of industry, state governments, or other sectors. Rather, the goal should be to encourage intellectual exchanges on a scale and with a frequency that do not ordinarily occur between the university and outside communities. Larger centers should have proportionately greater external participation and outreach efforts. Foreign participation with reciprocal arrangements should be encouraged where appropriate.

Industry. An important mode of industrial cooperation is the exchange of personnel to help develop and transfer new knowledge. Although it should not be a prerequisite of science-based centers, corporate participation also may include direct financial contributions or equipment donations. It is to be expected that such participation will be small during the start-up phase of a center and increase over time; in some instances it may not develop during the lifetime of the center. Center research activities should be open to the maximum extent.

States. Although the benefits of Science and Technology Centers are national, state governments increasingly perceive advantages in supporting local centers of scientific research and training to provide additional jobs and revenue, attract out-of-state talent and industrial investment, and produce research on areas of state responsibility or interest. State participation might include providing sites, financing construction, matching funds for instrumentation or equipment, enabling the host institution to create new faculty positions, and facilitating knowledge transfer to state agencies and local industries.

Foundations and Private Donors. Foundations and private donors differ from states and corporations in having fewer local or proprietary interests. Their participation in centers is likely to be primarily financial, except in the case of operating foundations with in-house research activities.

IV. GOVERNANCE OF SCIENCE AND TECHNOLOGY CENTERS

RELATIONSHIP TO UNIVERSITIES

Centers must be located at a university or affiliated with a consortium of universities. Centers should be partners in their parent institutions' educational, research, and service missions. In view of the outreach function of centers, host universities should create an external mechanism for obtaining advice on center activities and regular evaluation of their performance.

Beyond these general prescriptions, the details of administration should be left to the universities' discretion with a minimum of federal involvement.

NSF REVIEW

The panel recommends a nine-year funding cycle to provide centers a reasonable opportunity to achieve their scientific objectives. Typically, this period should include three years of funding growth, three years of stable funding, and a terminal three years.

Because Science and Technology Centers are privileged to receive substantial funding over a relatively long period, they should be subject to periodic review of the highest standard. The Foundation should evaluate a center at three-year intervals to determine the funding level to follow. After each review, the center should be given either a three-year renewal or a three-year period in which to terminate its activities. Thus, barring evidence of gross mismanagement or poor performance, each center that does not itself propose an earlier termination will be assured of funding for at least six years from its start-up. At the end of nine years the original grant should be terminated.

Because the three-year start-up period is necessarily one of organization, exploration, and adjustment of original plans to new or unanticipated circumstances, the first evaluation should focus more on scientific promise and administrative progress and less on research accomplishments. All reviews should be conducted by external committees of scientists appointed by the Foundation. NSF should require written administrative reporting by the centers no more often than once a year.

Finally, separate from the process of reviewing individual centers, there should be a mechanism to monitor and evaluate the Foundation's entire Science and Technology Centers program in the context of all programs supporting basic science. This function might be assigned to a standing committee external to the Foundation.

V. SOME CAUTIONARY OBSERVATIONS

The panel agreed that centers as a mode of research support can produce significant scientific accomplishments. By assembling where they are needed the critical number of researchers, scale of facilities, and types of instrumentation, centers can accelerate the generation of new knowledge and its application.

Thus, if implemented wisely, the Science and Technology Center program will strengthen the Foundation's role as the nation's premier agency for the support of basic science. In acknowledging the potential value of such centers, however, the panel recognizes several potential problems:

— Science and Technology Centers may divert funds from individual investigator grants, which continue to be the best means of supporting research and training in many scientific fields. The panel envisions increasing support for centers only in the context of a rising NSF budget and has received assurances that the Foundation's leadership is of the same view.

In particular, the panel cautions strongly against a repetition of the experience with the Defense Department's University Research Initiative (URI) program. Supporting the URI program without providing for an increase in total basic research (6.1) funds has weakened not only the existing basic science programs of the military services but also the URI program in its formative stages.*

* See the February 26, 1987, memorandum of Dr. Cornelius J. Pings, Co-chair of the Department of the Defense-University Working Group on Engineering and Science Education, to Hon. Chapman B. Cox, Assistant Secretary of Defense, Force Management and Personnel.

Further, it is unavoidable that, within universities, Science and Technology Centers will compete with individual investigator projects for such university resources as land, building construction, and tenured faculty positions. This problem is real but not unique to programs supported by the Foundation. Although acknowledging that universities labor under severe constraints in funding instrumentation and facilities, the panel believes that it is the responsibility of each research university to face this issue squarely. The centers program should be evaluated periodically to inform NSF of the cumulative effect of the program on the universities.

— There is a risk that centers will in time become unresponsive to new ideas and unreceptive to new people. The administrative apparatus and size of centers may become obstacles to innovation. The review procedures outlined above are designed in part to guard against this danger, but university administrations must also be alert to it.
— Cross-disciplinary research, which is one of the rationales for centers, must have natural reasons for its existence. Sometimes the best science can be done at the interfaces of disciplines, sometimes not. It would be unfortunate if the Science and Technology Centers program induced able scientists to abandon important problems simply because they are not regarded as sufficiently cross-disciplinary to be funded under the program.
— No single type of Science and Technology Center should become so predominant that other kinds of centers are excluded from receiving support. For example, the likely popularity of facility-based centers that furnish instrumentation and related services should not preclude centers devoted to experimental or theoretical work in single disciplines or across disciplines.
— The objective of accelerating technology transfer could lead to a narrow focus on near-term commercial applications in center activities. There should be no requirement that Science and Technology Center applicants have the prior assent or support of

industry. Academic laboratories have a special responsibility to furnish leadership in breakthrough science and to call attention to new opportunities for commercial exploitation. There may be some lag between a discovery and recognition by business that it warrants investment. A related danger is over-emphasis on outreach activities to the point that they detract from research efforts.

— The funding of one or two centers in a relatively small scientific field could concentrate a large fraction of the talent, weakening other institutions and reducing healthy competition. The decision to create a center should take into account the need to maintain institutional diversity in the field.

Finally, the panel believes that the entire continuum of size and scale of NSF research funding should be addressed by experts outside the Foundation. Not only large-scale activities but also individual and small group research suffer from insufficient funds, support of too short duration, obsolete equipment, and inadequate staffing. These are problems that the NSF Science and Technology Centers program will not solve but that urgently need attention.

Notwithstanding these cautions, the panel believes that Science and Technology Centers can make significant contributions to science and the nation's economic competitiveness if they have proper management, resources, and evaluation and if the Foundation maintains a healthy balance among the principal modes of research support.

APPENDICES

NATIONAL SCIENCE FOUNDATION
WASHINGTON. D.C. 20550

February 11, 1937

OFFICE OF THE DIRECTOR

Dr. Frank Press
President
National Academy of Sciences 2101 Constitution Avenue, N.W. Washington, D. C.20418

Dear Frank:

The National Science Foundation intends to issue later in the year a solicitation to implement the Science and Technology Centers presidential initiative.

Just as the National Academy of Engineering played a pivotal role in shaping the approach NSF used to establish and administer the Engineering Research Centers, a similar contribution can be made by the National Academy of Sciences with regard to this initiative. I would be most grateful if under your auspices such an effort could be undertaken.

I would suggest that the National Academy of Sciences assemble an ad hoc policy group consisting of a broad representation of its members to address the following issues:

a) What is the group's view of the most promising areas of science where these centers can make a significant difference?
b) What are the the defining characteristics of science and technology centers and how do these characteristics relate to economic competitivenes?
c) Since industry and state participation is a prerequisite, what form should this participation take and how is it best utilized?
d) What support is required and over what period of time?
e) Governance of the centers.
f) The centers' contribution to education, including precollege, undergraduate, graduate and postgraduate education.
g) Monitoring mechanisms and sunset rules.
h) Ground rules for the solicitation.

Timeliness of the study is important. I would hope that the ad hoc group can be assembled soon, with a report available by June 1, 1987, so that its conclusions can be folded into the NSB strategic plan review later that month.

Sincerely,

Erich Bloch
Director

Panel on Science and Technology Centers

PANEL BIOGRAPHIES

RICHARD N. ZARE (*Chairman*) is Professor of Chemistry at Stanford University.

From 1975 to 1977, Dr. Zare served as Higgins Professor of Natural Science at Columbia University before joining Stanford University as Professor in the Department of Chemistry. In 1985, as a recipient of the National Medal of Science, he was cited "for his seminal contributions to molecular spectroscopy, photochemistry, and chemical reaction dynamics, especially for his incisive theoretical methods and the development of the experimental technique of laser induced fluorescence." He serves in an editorial and advisory capacity for the journals of *Chemical Physics Letters, Chemical Physics, The Journal of Molecular Spectroscopy,* and *Chemical and Engineering News.* Dr. Zare holds both a B.A. in Chemistry and Physics (1961) and a Ph.D. in Chemical Physics (1964) from Harvard University.

NORMAN M. BRADBURN is Provost of the University of Chicago.

Dr. Bradburn joined the faculty of the Graduate School of Business, University of Chicago, in 1960. He served as Chairman of the Department of Behavioral Sciences from 1973 to 1979 and is Tiffany and Margaret Blake Distinguished Service Professor (1977-). In 1984 he became Provost. He was also Director of the National Opinion Research Center, Chicago (1967-1971; 1979-1984). His publications include *The Structure of Psychological Well-Being* (1970), *Side by Side, A Study of Integrated*

Neighborhoods (1971, with S. Sudman, G. Gockel), and *Asking Questions, A Practical Guide to Questionnaire Construction* (1983, with S. Sudman). Dr. Bradburn is a Fellow of the American Association for the Advancement of Science and the American Statistics Association and a member of the International Statistics Institute, the American Sociological Association, and the American Association for Public Opinion Research. Dr. Bradburn received a B.A. from the University of Chicago (1952) and Oxford (1955) and a M.A. (1958) and Ph.D. in Social Psychology (1960) from Harvard University.

PRAVEEN CHAUDHARI is Vice President for Science and Director of the Physical Sciences Department, Thomas J. Watson Research Center, IBM Corporation, Yorktown Heights, New York.

Dr. Chaudhari served as a member of the IBM Corporation research staff from 1966 to 1980, during which time he became Director of the Physical Sciences Department. Dr. Chaudhari is a recipient of the Leadership Award of the Metallurgical Society of the American Institute of Mechanical Engineering and the George E. Pake Award of the American Physical Society. He is a Fellow of the American Physical Society and a member of the American Association for the Advancement of Science. He serves on a number of committees and advisory boards and in several editorial positions. His research interests are in amorphous solids, defects in solids, superconductivity, quantum transport, magnetic monopoles, and neutrino mass localization. Dr. Chaudhari received a B.A. (1961) from the Indian Institute of Technology, Kharagpur, and Sc.D. (1966) from the Massachusetts Institute of Technology.

ERNEST G. JAWORSKI is Director of Biological Sciences at the Monsanto Company, St. Louis, Missouri.

Dr. Jaworski began his professional experience in chemistry at the University of Minnesota. Beginning in 1952, he held several positions with Monsanto Company, including Resident Biochemist (1952-1954), Resident

Group Leader (1954-1960), Scientist (1960-1962), Senior Scientist (1962-1970), and Distinguished Science Fellow (1970-). Concurrently, he is a member of the Frasch Foundation Awards Committee of the American Chemical Society (1969-); he has served as Chairman, Gordon Conference on Plant Cell and Tissue Culture (1973-1975) and was a Trustee (1975-1981) and later Chairman of the Board of Trustees (1978-1979) for Gordon Research Conferences, Inc. He serves in an editorial capacity with *The Journal of the American Society of Plant Physiologists* (1973-), *Trends in Biotechnology* (1984-), and *BioScience* (1984-). His research interests are in plant growth regulation, hormones and metabolism; plant chemotherapeutic investigations; mechanism of action of herbicides; radioisotope techniques; biosynthesis of chitin; plant cell and tissue culture; plant organogenesis; cell biology, and molecular biology. Dr. Jaworski holds a B.S. (1948) from the University of Minnesota and a M.S. (1950) and Ph.D. in Biochemistry (1952) from Oregon State University.

DANIEL KLEPPNER is Lester Wolfe Professor of Physics and Associate Director of the Research Laboratory of Electronics, Massachusetts Institute of Technology.

Dr. Kleppner joined the Department of Physics at the Massachusetts Institute of Technology in 1966. From 1976 to 1979, he was Head of the Division of Atomic, Condensed Matter and Plasma Physics, Department of Physics. He is a member of the National Academy of Sciences and the American Academy of Arts and Science and a fellow of the American Physical Society and the American Association for the Advancement of Science. He has served as Chairperson of the Division of Atomic, Molecular and Optical Physics of the American Physical Society and is currently a Councilor of that society. In 1986, Dr. Kleppner was awarded the Davisson-Germer Prize of the American Physical Society. His research interests are in experimental atomic physics, high-precision measurements, and quantum optics. Dr. Kleppner received a B.A. from Williams College (1953) and from Cambridge University (1955); he has a Ph.D. in Physics (1960) from Harvard University.

JOSHUA LEDERBERG is President of Rockefeller University, New York City.

Dr. Lederberg moved from Assistant Professor to Professor of Genetics at the University of Wisconsin (1947-1958) and became Professor of Medical Genetics and Chairman of the Department in 1955. He became Professor and Chairman of Genetics in the Medical School at Stanford University in 1959 and in 1978 joined Rockefeller University. He also held an appointment in the Computer Science Department at Stanford University. Dr. Lederberg has served as a consultant to the Syntex Corporation, Cetus Corporation, Celanese, and many government agencies. His research interests are in microbiology, molecular genetics and evolution, science policy, and computer science. Dr. Lederberg received a B.A. (1944) from Columbia University and a Ph.D. in Microbiology (1947) from Yale University.

DONALD J. LEWIS is Professor of Mathematics at the University of Michigan, Ann Arbor.

Dr. Lewis advanced from Assistant Professor to Associate Professor at the University of Notre Dame (1953-1961); he moved to the University of Michigan in 1961 and became Professor of Mathematics in 1963 and Chairman of the Department in 1984. He was concurrently NSF Senior Fellow at Manchester and Cambridge universities (1959-1961); Senior Visiting Fellow at Cambridge University (1965-1969); Visiting Fellow, Brasenose College, Oxford (1969); and Guest Professor at Heidelberg University (1979-1980, 1983). He was awarded the Humboldt Stiftung Senior Award in 1980 and 1982. He is a member of the American Mathematics Society and the Mathematics Association of America. Dr. Lewis was Chairman of the Editorial Board for *Mathematical Reviews* and currently serves on the editorial boards of *Zentralblatt für Mathematik, Acta Arithmetica,* and *Journal of Number Theory.* His research interests are in Diophantine equations, finite fields, and algebraic number theory. Dr. Lewis holds a B.S. (1946) from the College at St. Thomas and a M.S. (1949) and Ph.D. (1950) in Mathematics from the University of Michigan.

WILLIAM PRESS is Professor of Astronomy and of Physics at Harvard University.

Dr. Press is a member of the Center for Astrophysics and former Chairman of the Department of Astronomy at Harvard (1982-1985). He was Tolman Research Fellow in Theoretical Physics at the California Institute of Technology (1972-1973) and Assistant Professor of Physics at Princeton University (1973-1976). Dr. Press concurrently is a consultant for the Lawrence Livermore National Laboratory (1973-), Mitre Corporation (1977-), and Los Alamos National Laboratory (1984-). He won the Warner Prize of the American Astronomy Society in 1981. Dr. Press has served in a number of advisory positions with the National Aeronautics and Space Administration, the National Academy of Sciences, the Alfred P. Sloan Foundation, and the National Science Foundation. He is Chairman of the Advisory Board to the National Science Foundation Institute for Theoretical Physics and is a member of the Defense Science Board. Dr. Press's research interests are relativistic astrophysics, theoretical astrophysics, cosmology, galaxy formation, general relativity, and numerical methods. Dr. Press received an A.B. (1969) from Harvard University, and a M.S. (1971) and Ph.D. in Physics (1972) from the California Institute of Technology.

LEON T. SILVER is the W. M. Keck Foundation Professor for Resource Geology, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena.

Dr. Silver has been an educator with the California Institute of Technology since 1955. He was a geologist with the United States Geological Survey from 1947 to 1975; a Guggenheim Fellow (1964-1965); a member of the Subcommittee on Geochronology, International Union of Geological Sciences (1970); and Chairman (1984-1985) of the Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. He is currently a consultant with the National Aeronautics and Space Administration (1971-), from which he received the Exceptional Science

Achievement Medal 1971. He is a member of the National Academy of Sciences, the Mineralogical Society of America, Geochemical Society, American Geophysical Union, American Association for the Advancement of Science, and American Academy of Arts and Sciences. He has served as President of the Geological Society. His research interests are in igneous and metamorphic petrology; geochemistry of uranium, thorium, and lead; geochronology; regional geology of the southwestern United States; tectonic history of North America; and mineralogy and petrology of meteorites and lunar materials. Dr. Silver received a B.Sc. (1945) from the University of Colorado, a M.S. (1948) from the University of New Mexico, and a Ph.D. in Geology and Geochemistry (1955) from the California Institute of Technology.

LARRY SMARR is Director of the National Center for Supercomputing Applications and Professor in the Departments of Astronomy and Physics, University of Illinois, Champaign.

Dr. Smarr was a lecturer in the Department of Astrophysics, Princeton University (1974-1975), and subsequently a Junior Fellow in the Harvard Society of Fellows (1976-1979). While at Harvard, he was also a research affiliate with the Department of Physics, Yale University (1978-1979). He has been on the faculty of the University of Illinois since 1979. He was Visiting Fellow, Cambridge University (1978) and Max Planck Institute for Physics and Astrophysics (1981-1983). He has been consultant with the Smithsonian Astrophysics Observatory (1979-1981), and currently consults with the Los Alamos National Laboratory (1983-) and Lawrence Livermore National Laboratory (1976-). Dr. Smarr is a member of the American Association for the Advancement of Science, the American Physical Society, and the American Astronomy Society. He was associate editor for the *Journal of Computational Physics* (1977-1980) and currently serves on the editorial board of *Science*. His research interests are in relativistic astrophysics, radio galaxies, numerical relativity, and numerical hydrodynamics. Dr. Smarr holds a B.A. and a M.S. (1970) from the University of Missouri, a M.S. (1972) from Stanford University, and Ph.D. in Physics (1975) from the University of Texas at Austin.

JOSEPH E. VARNER is Charles Rebstock Professor of Biology, Department of Biology, Washington University, St. Louis, Missouri.

Dr. Varner was a chemist with Owens-Corning Fiberglas Corporation (1943-1944); research engineer with Battelle Memorial Institute (1946-1947); research associate with the Research Foundation (1949-1950) and Assistant Professor of Agricultural Biochemistry (1950-1953), Ohio State University; Research Fellow, California Institute of Technology (1953-1954); and Associate Professor and Professor at Ohio State University (1954-1961). He was scientist of the Research Institute of Advanced Study, Martin-Marietta Company (1961-1965), and Professor with Michigan State University (1965-1973). Concurrently, Dr. Varner was National Science Foundation Fellow at Cambridge University (1959-1960) and at the University of Washington (1971-1972). He is a member of the National Academy of Sciences, American Academy of Arts and Sciences, American Society of Biological Chemistry, American Society of Plant Physiology, and a Fellow of the American Association for the Advancement of Science. His research interests are plant biochemistry, biochemistry of aging cells, action mechanism of plant hormones, and cell wall glycoproteins. Dr. Varner received a B.Sc. (1942), a M.Sc. (1943), and Ph.D. in Biochemistry (1949) from Ohio State University. He holds an honorary doctorate from L'Université de Nancy (1977).