A Study by a Panel of the

NATIONAL ACADEMY OF PUBLIC ADMINISTRATION

National Science Foundation's Science and Technology Centers:

Building an Interdisciplinary Research Paradigm

NAPA

National Academy of Public Administration

A Study for

THE SENATE APPROPRIATIONS COMMITTEE

Subcommittee on VA, HUD, and Independent Agencies

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National Science Foundation's Science and Technology Centers:

Building an Interdisciplinary Research Paradigm

NATIONAL ACADEMY OF PUBLIC ADMINISTRATION

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FOREWORD

The National Academy of Public Administration welcomes the opportunity provided by the Senate Appropriations Subcommittee on VA, HUD, and Independent Agencies, and the National Science Foundation to address the complicated issues raised in managing and assessing our nation's scientific resources.

Two important institutional challenges to the scientific research community are:

- The increasing need for collaboration among disciplines, and among research, industrial, and educational institutions to solve complex scientific and technological problems; and

- The increasing focus on management processes designed to deliver better value to citizens which include goal setting, performance measurement, and regular review to track progress toward goals and drive program revision.

In an age of rapid scientific and technological change, research is central to our national health and prosperity. Because federal funding plays an important part in strengthening the university research-capability that enables that progress, federal funds must be managed to yield the greatest possible scientific progress in the most efficient way possible.

Managing, measuring and monitoring scientific performance raise complex questions. How are research goals set? How do scientists reach those goals? How is progress defined? How is it measured? What areas of research should be assessed? How can researchers in these areas be held accountable? All these questions are at the frontiers of the performance and assessment arena.

They also point toward a common problem in governance: a complex and demanding purpose that must be executed in an era of financial limitations. As was the case with the Academy's studies of the Global Positioning System of the Department of Defense and the U.S. Trustee Program of the Department of Justice, the Academy panel sought, in this instance, to balance the value of scientific research with the need for public accountability.

The National Science Foundation's Science and Technology Centers add still more complexity to the questions. Collaboration among scientists from different disciplines and institutions requires more organizational structure and management than does traditional, single-investigator research. Thus, management and organizational issues are intricately woven into the patterns of the science practiced at these centers.

The Academy is pleased to present its assessment of NSF's management of its Science and Technology Centers and to contribute to the important debate on the value and means of science in helping attain national goals.

R. Scott Fosler
President

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PROJECT CHARGE AND DESIGN

The Senate Subcommittee on HUD, VA, and Independent Agencies requested that the National Academy of Public Administration (NAPA) review the management of Science and Technology Centers funded by the National Science Foundation.

To do so, NAPA selected five Science and Technology Centers. (See Exhibit 1 for an overview of the chosen centers.) NAPA then assembled an advisory panel comprising experts in research management, finance, education, public management and in the scientific research areas of each center chosen for review. A NAPA team conducted a literature review, made two-day visits to each of the five centers, and interviewed NSF staff and others interested and involved in the STC program.

The study focuses on four elements:

- The degree to which the centers exhibited interdisciplinary collaboration, a university base, knowledge transfer to industry, and educational outreach;
- The value of the center concept of management in the science and technology areas;
- The management approaches taken by each center; and
- The National Science Foundation's approach to the management of the Science and Technology Center program.

EXECUTIVE SUMMARY

Since 1989, The National Science Foundation (NSF) has established 25 university-based, collaborative, and interdisciplinary Science and Technology Centers (STCs). In addition to providing homes for long-term, federally funded research projects, the centers are to extend the benefits of government research to industry and to the K-12 educational community. The STCs are funded and supervised by the individual, discipline-oriented NSF directorates, and by the Office of Polar Programs. NSF's Office of Science and Technology Infrastructure (OSTI) serves as the general coordinator of the centers and of the program. Through NSF's matrix management system, technical coordinators familiar with appropriate areas of scientific research, along with OSTI, coordinate and oversee the operations of the individual centers.

Although the internal management of the individual centers visited by the NAPA team varies, all of them provide the opportunity for scientists to establish research communities and to develop entrepreneurial and leadership skills. Collaborative, interdisciplinary scientific research augmented by strategies for knowledge transfer to industry and educational outreach constitute the value added by these STCs. In a time of increasing budget restrictions, NAPA concludes that STCs provide a good return on federal funds which is in the national interest.

The centers visited have the characteristics of those centers envisioned in the legislation and regulations through which they were established, are valuable contributions to NSF's research portfolio and to national research goals, and are managed in a manner appropriate for their purposes. The centers are assessed effectively by NSF's technical coordinators, by their own external advisory boards and steering committees, and by periodic in-depth peer reviews.

Consistent with the program's original goals, these five centers are university-based, interdisciplinary, basic-research efforts. The collaboration among individually recognized scientists evident at the STCs provides examples for university administrators encouraging such synergism in other areas. In return, universities support the STC efforts with space, faculty salaries, equipment, and funding. The expert scientists involved in the program benefit both the centers as researchers and universities as teachers, thus helping to educate a new generation of scientists trained in the interdisciplinary methods necessary to solve increasingly complex technological and scientific problems.

Special value is added by the centers' attention to knowledge transfer and educational outreach. Research in each center can be used as a base for more-applied research in its particular field. It has, however, more immediate applications, as evidenced by participation in center governance by the industrial members of individual external advisory boards, by personnel exchanges among centers, and by placement of students in related industries after graduation.

A unique aspect of the centers is funding to support outreach activities for K-12 students, teachers, and the general community. Centers exhibited an impressive variety of activities designed to enrich scientific education for young students and for the community. Although they acknowledged being skeptical of contacts with young students at first, center scientists exhibited genuine excitement about their outreach activities once they began.

Individual center management techniques, including systems of feedback cycles, vary according to the nature of the disciplines involved and the vision with which each center was established. The directors of the STCs have developed a wide range of management styles. In each center, governance has evolved through interaction and a growing sense of community among the members. The only significant management weakness the NAPA team found was that NSF does not have a clear method for removing a weak center director or replacing a director who leaves.

The Science and Technology Centers are valuable to NSF's research portfolio, leveraging NSF funding by supporting the coordinated scientific research necessary to solving complex problems that transcend individual disciplinary approaches. The center mode is an effective way to invest federal resources to maximize returns, and to provide center scientists with the flexibility to respond rapidly to innovate research opportunities. Communities of scientists promote synergism and reduce duplication of research activities. Center members credit this collegial interaction with increasing their enthusiasm for pursuing new avenues of research and technology transfer, as well as with their own surprising interest in performing community outreach projects.

RECOMMENDATIONS

- NSF, Congress and the administration should recognize the good return on federal government expenditures through the STC program as being in the national interest and worthy of continued support.

- NSF should continue the current matrix method of managing the centers, with funding through the responsible directorates and Office of Polar Programs, and coordination through the Office of Science and Technology Infrastructure.

- The National Science Board should form a subcommittee, including – when and where appropriate – representatives of industry and other stakeholders, to:

- Act as a monitoring body and inform Congress and other stakeholders of the goals, activities, and value of the STC program;

- Advise NSF in establishing processes and criteria to assess management of the STCs without adding to the current oversight burden;

- Advise NSF in establishing criteria to replace weak center directors or directors who leave.

EXHIBIT 1

THE FIVE SELECTED CENTERS

- **The Center for Biological Timing**, at the University of Virginia in Charlottesville, draws from the fields of plant and animal biology, and medicine to conduct research in biological timing. The work has important implications for agriculture, health, and industrial safety. The scientists bring laboratory activities to local K-12 classrooms.

- **The Center for Molecular Biotechnology**, at the University of Washington in Seattle encourages physicists, biologists, chemists, computer scientists, engineers, physicians and mathematicians to develop and commercialize new biological research technologies. Center scientists give lectures at local schools and provide research internships to high school students.

- **The Center for Research on Parallel Computation**, at Rice University in Houston seeks to make parallel computing truly useable. Computer scientists, applied mathematicians, and engineers participate in that effort. In addition, they advise on science curricula in local schools and historically minority colleges, and mentor minority undergraduate and graduate students.

- **The Center for Quantized Electronic Structures**, at the University of California at Santa Barbara, involves researchers in developing and studying the behaviors of quantum structures with as few as ten to as many as 100 atoms. More efficient data transmission and storage may result from this research. Center scientists are drawn from physics, chemistry, and electrical and computer engineering. They advise on school science curricula and offer laboratory internships to high school students and science teachers.

- **The Center for Analysis and Prediction of Storms** at the University of Oklahoma in Norman is developing a mathematical model to predict small-radius, severe thunderstorms through the work of mathematicians and meteorologists. Center scientists provide research opportunities for undergraduates, have developed a weather instruction-kit for local schools, and produced an educational radio program.

EXHIBIT 2: CONCLUSIONS

Center Characteristics

- The characterization of research as long- or short-term, or as basic or applied varies among centers, depending on the maturity of the discipline and the preciseness of its definitions. Research at those centers NAPA visited can be used as a base for more applied-research in the relevant fields.
- The nature and degree of interdisciplinary and multidisciplinary collaborations among individual-center members vary, but such collaborations are evident in all centers visited, and are opening new avenues for cooperation.
- Interdisciplinary collaboration in centers can provide strategic beachheads from which university administrations can encourage further collaborative efforts.
- Universities provide substantial support in technical and administrative space, equipment, and faculty salaries.
- Since many center members are regular university faculty, center activities are well integrated into their university's educational function.
- Most of the centers visited had excellent, innovative educational outreach to many age groups in their communities and beyond. It is those outreach activities which are most likely to be curtailed if center funding ceases.
- The centers' collaborative nature and the mandate that they have external advisory boards extend knowledge transfer both to and from industry and government.
- Some centers are building a critical mass of scientists and equipment which will continue interdisciplinary activity after NSF funding ceases, while others have designed programs to conclude at the end of the 11-year grant period.

Value of the Center Concept

- Centers represent an organized approach to quality science-projects managed by capable scientists.
- NSF funding has a strong effect in the centers and provides flexibility that leads to rapid response capability when opportunities for innovative research occur.
- With reductions in industry support of research, STCs are even more important to accomplishing national goals.
- NSF funding allows center members to address research that individual researchers cannot address because of scale, complexity, cost, or interdisciplinary requirements.
- NSF funding is highly leveraged. The center mode is an effective way to invest federal resources in this time of budgetary pressures.

- Centers foster collegial groups and new interdisciplinary approaches to complex problems.

- Although considerable time may be spent on center activities, scientists involved in centers report that they and their work benefit from the collegial interactions and from the exposure to the community and industry.

Center Management

- Centers benefit from being directly managed by the NSF technical coordinators who have knowledge of the research.

- Centers evolve over time, developing research focuses, management practices, collegial relationships, and outreach and technology transfer programs.

- Centers are subject to more oversight than are individual investigators.

- Center management varies in character depending on the nature of the center, the expertise of the center director, and the institutional setting, although all centers share management responsibilities within a collegial group to some extent. The vision and direction of the center director is a driving force in developing intra-center relationships and in maintaining the focus of the research.

- A change of center director brings a critical period during which the collegial relationships may be realigned and center purposes refocused. With a new director, a center may have to repeat some of the evolution of building collegial relationships.

- Since centers' budgets are maintained largely in complex university budget systems and include funding from several sources, some centers are not able to fully demonstrate the degree of leverage of STC funding.

NSF Management of the Centers' Programs and NSF's Environment

- NSF's mission and the national goals are broad. STC goals contribute to achieving NSF goals while NSF goals contribute to achieving national goals.

- A wide variety of research is supported by the STC program. The most critical decision made by NSF concerning the STCs is which initial projects to support.

- One disadvantage of management being dispersed among the various NSF directorates and OPP is the lack of an advocacy body for the center concept.

- The OSTI STC database provides valuable material which can be used to demonstrate the value of the program as a whole to Congress and other constituents.

- OSTI-sponsored periodic meetings for center directors, center administrators, and outreach coordinators contribute to the program by facilitating information exchange among members of these groups. Even greater exchange and coordination of research would be beneficial.

- OSTI-sponsored training and guidelines for peer reviewers contribute to progress toward equity in the STC peer-review process.

- NSF has not defined a clear method for removing a weak center director or replacing a director who leaves.

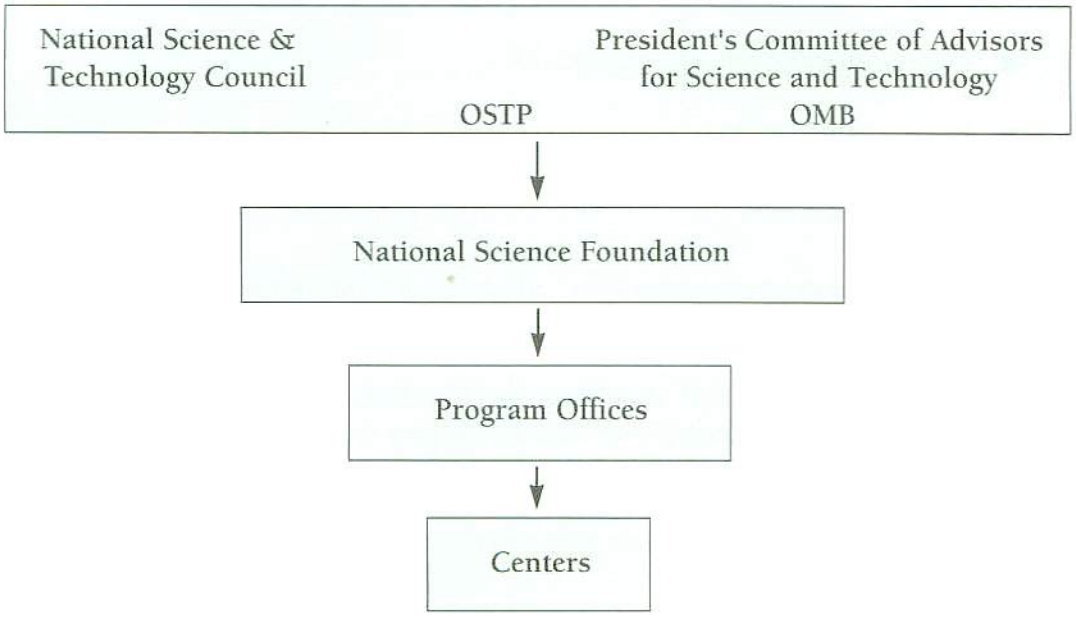
BACKGROUND

This study of the National Science Foundation's (NSF) Science and Technology Centers (STC) was requested by the Senate Appropriations Committee subcommittee on VA, HUD and Independent Agencies. For this project, the Subcommittee specifically asked the National Academy of Public Administration (NAPA) to consider peer-review techniques in center evaluation, the centers' performance in promoting interdisciplinary activities and ties with the educational and industrial communities, and NSF's management of the STC Program. (See Appendix A.)

STCs function within a four-level management system: internal center management; NSF management of centers in the field: internal NSF management of the centers program; and NSF's niche in the management of science research within the government. (See Exhibit 1.)

EXHIBIT 1: MANAGEMENT STRUCTURES AFFECTING STCS

Science Research Within the Federal Government



To describe management of the STCs effectively, all of these areas must be included. To answer the subcommittee's concerns, information was gathered in relation to center:

- Characteristics,
- Contributions to NSF's portfolio of research, and
- Management at all four levels, including evaluation processes.

For the funds and time available for the study, NAPA agreed to review five STCs by conducting literature reviews, site visits, and interviews. NAPA also reviewed, but at a significantly lower resource level, NSF management of center programs, and their context within the federal research infrastructure.

STC HISTORY

President Reagan's reference to the NSF in the 1987 State of the Union message highlighted the critical importance of knowledge to our economic well being and the concern that US leadership was at risk in several technological areas. Three books describing the US education system, *A Nation At Risk*[1], *Educating Americans for the 21st Century*[2], and *A Renewed Partnership*[3] brought the situation into focus, calling for innovative approaches to science research which would encourage large-scale, long-term research on complex problems, and coordination between academic, industrial, and government sectors. The STC Program is one experiment in encouraging such scientific research.

At NSF's request, the National Academy of Sciences prepared a report known as the Zare Report which became the model for the STC program. The report suggested several major elements which the NSF included in the definition of the center concept. Centers should:

- Carry on research in basic science;
- Include interdisciplinary collaborations;
- Be university-based;
- Be involved in education and outreach in the community; and
- Be involved in knowledge transfer and collaboration with industry and government.

The report emphasized that NSF should not specify research areas for the centers so the most promising proposals could be selected by the peer review process. The report did not specify the centers' day-to-day management structure, except to note that each center should have criteria for evaluation, and those criteria should be appropriate to the research. At the NSF level, the report recommended that the STC program should be

managed by a separate office rather than through the various directorates, and that funding should be for a limited period.

More than 300 proposals for STCs were submitted to the Office of Science and Technology Infrastructure (OSTI). They were subject to an intense peer-review process which included site visits and a multidisciplinary panel review. Eleven STCs were established in FY 1989 and 14 were established in FY 1991. (See Appendix A for a list of current STCs.)

Although NSF does not impose specific criteria for day-to-day center management, it does specify oversight strategies. Each center's governance structure must include an external advisory board with appropriate representatives from academia, industry, and government. Most centers also have an internal steering or executive committee. Criteria for center evaluation are designed by directors of the individual centers in cooperation with OSTI staff and technical coordinators, and are an important part of the third and sixth year renewal evaluations. For the first three years of a center's existence, NSF conducts annual site-visits and requires the center to submit annual reports to the relevant technical coordinators. Following that three-year period, visits and reports decrease to every 18 months. Peer reviews are conducted at the end of the third and sixth years for funding renewal.

STCs are managed by OSTI, the directorates, and the Office of Polar Programs (OPP). Although total center funding represents only about 7% of NSF's budget, an early concern was that STC funding would decrease funding for individual researchers through NSF's discipline-related directorates. To answer that concern, STC funding was initially a separate line-item in NSF's budget. At this time, STC funding is through the directorates and OPP, while OSTI coordinates center program activities, including organizing meetings for center directors and outreach coordinators and maintaining a database on the centers program. (See Appendix B.)

PERFORMANCE MANAGEMENT IN FEDERAL PROGRAMS

In the current context of federal budget cuts and performance measurement, government programs are coming under increasing scrutiny; research is no exception. The House and Senate Reports on the National Science and Technology Policy, Organization, and Priorities Act of 1994 outlined principles and modes of implementing a coordinated national science policy infrastructure, including the development of central policy and planning elements. The reports recognized the responsibility of the federal government to support beneficial science research that cannot be supported by the private sector. They noted that setting research priorities in terms of broad national goals represents a change in the nature of congressional and executive oversight and in current management practice within the scientific community. These coordinating policies are recent and their eventual effect on STCs is not yet clear.

In addition, there have been a number of initiatives to improve accountability in federal government programs, such as the Chief Financial Officer Act (CFO) and the Government Performance and Results Act of 1993 (GPRA). While the CFO Act aimed to

control government managers, GPRA encouraged experimentation in developing strategic planning and performance indicators. The purpose of the performance indicator system is to enable managers to compare data obtained about their programs to establish benchmarks, and to use the information to improve program management and performance. The performance indicator system also gives managers a tool for communicating the value of their programs to Congress and to the public.

A MANAGEMENT PARADOX

STCs, therefore, operate within the context of two streams of thinking about the use of federal funding. Centers are both:

- A resource to promote experimentation in developing new methods to reach national goals of industrial and human health, high educational achievement, and international competitiveness; and

- An asset to be accounted for in terms of specific outcomes based on strategic plans, mission, goals, and objectives.

This constitutes a paradox for managers of interdisciplinary scientific research: their outcomes often cannot be predicted, but they must also attend to short-term requirements of current national concerns. This study describes five STC management systems which have evolved in response to these requirements.

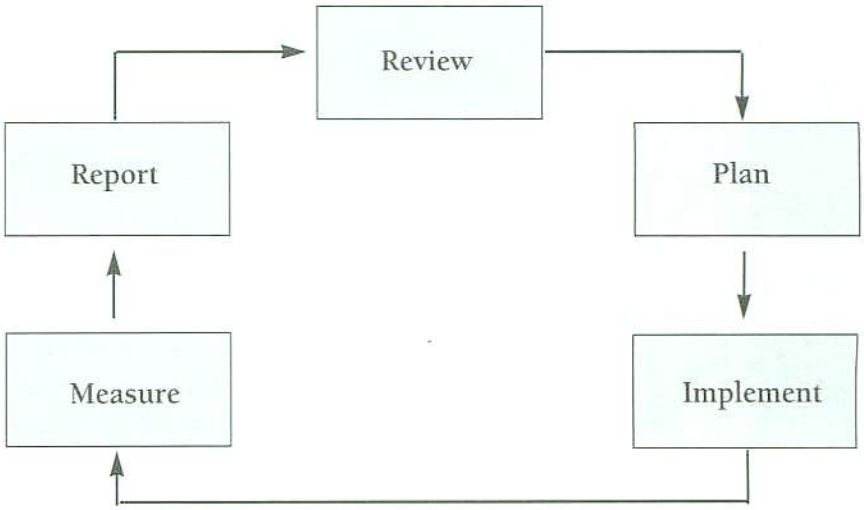
NAPA'S APPROACH TO THE STUDY

NAPA's approach to the study was to examine the extent to which the centers reflected the concepts in the Zare Report, included the essential elements of an effective management system, and promoted high-quality research. NAPA's approach is distinctive from the peer reviews used by NSF in the third and sixth year STC renewal process in an important way. For periodic evaluation of scientific research at the centers, NSF's review teams include scientists familiar with the disciplines practiced at the individual centers. Although the results of the peer reviews were included in NAPA's findings relative to the quality of science practiced at the centers, for this management study NAPA's team included specialists in the management of scientific and other research, in finance, and in education, as well as scientists familiar with the work of the individual centers.

A MANAGEMENT MODEL

Management of different types of activity may take different forms. Management efforts generally assume that managers can focus their programs to produce specific outcomes. By its nature, the outcome of scientific research is not known. Recognizing that there is a wide spectrum of opinion on what "management" is in a research enterprise, this study adopted a center of gravity at an elemental level. In the most basic form, the essential elements of a management system were defined to include a process for defining goals, allocating resources, directing activities to goals, reviewing results, and revising goals and processes to reflect new data in successive cycles. These cycles are different lengths and occur at different intervals depending on program managers' and policy makers' needs and data availability. (See Exhibit 2.)

EXHIBIT 2: THE MANAGEMENT CYCLE



The study addresses three basic management issues at each of the four levels:

1) Are the key elements of a management system as defined above evident?

2) Does the management system promote high-quality, basic scientific research, educational accomplishment, knowledge and technology transfer, and cooperation among government, academia, and industry?

3) Are the centers contributing quality research to achievement of national goals in which individual scientists cannot? Is NSF funding leveraged in STCs?

CHALLENGES IN ASSESSING RESEARCH CENTERS' PROGRAM PERFORMANCE

Research is an activity whose essence in some respects runs counter to the general management model. As noted above, the management model assumes a known goal, while research activity moves toward an unknown goal. Program assessments generally determine how much progress is being made toward the known goal. The assessment task is demanding for any type of program, but experts generally concede that assessing the performance of science research programs is especially complex, in part because:

- The returns to society from the performance of research are diverse;
- The returns are often in the form of benefits whose value can be only partially computed in economic terms;
- The quality or value of research benefits is a subjective determination;

- The value of the return on an investment in research may not be evident for years or even decades; and

- The relation of research programs to eventual impacts is complex, not well understood, and subject to many intervening variables.

RESEARCH QUESTIONS

NAPA research included examining several questions at each of the four levels in the management system. At the individual-center level the review team considered the following questions (See Appendix C for more detailed questions.):

- **Are the characteristics of a center as described in the Zare Report evident at the center?** Is the STC university-based? Is the STC research interdisciplinary or cross disciplinary? Does the STC focus on fundamental research? How does center activity contribute to technology transfer to industry and to educational outreach? Do STC plans included phasing out NSF funding after eleven years?

- **Is the center concept valuable to NSF's portfolio of research?** Why is this research best served by a center form of organization? Is the research at the center of such scope or complexity that it could not be carried out by individual researchers? Does the research require costly instrumentation or facilities which could not be made available to individual researchers? Does the research program include competent scientists?

- **How is the center managed?** What is the center's organizational structure? What are its processes? How is the center budget handled? How are the STCs as a whole and individual projects evaluated?

At the level of NSF's management of the field the team asked (see Appendix D for specific research questions on NSF management of the field and of the STC Program, and NSF's environment):

- **How does NSF manage the STC program?** What is the organizational structure under which the STCs are managed? How are the STCs evaluated and how are those evaluations used?

At the NSF central office level and at the NSF environment level the team asked:

- **How does the STC program relate to NSF's mission?** What is NSF's mission? What is the history of centers programs in NSF? How much of NSF's budget is devoted to centers? How much of NSF's budget is devoted to STCs? How do STCs relate to other NSF funded centers? How does NSF management act as a link between congressional and administration policy makers and the STC program? How is science and technology research policy managed?

METHODOLOGY

The subcommittee requested a study of five STCs' characteristics, management and oversight, and NSF's management of the STC program. NAPA viewed these centers in the context of a broader system including individual center management, NSF management of the field, NSF headquarters management of the STC program, and the management environment in which NSF functions. Research concentrated on center characteristics, the value of the center concept, and center management.

In order to understand the NSF centers programs within which the STC centers exist, NAPA began by reviewing the four groups of centers in NSF's programs. These included Engineering Research Centers (ERC), Science and Technology Centers (STC), Super Computing Centers (SCC), and Industry/University Cooperative Research Centers (I/UCRC). Since the ERCs have the most experience with the centers concept, the largest share of effort was spent during this phase on the ERCs. The staff reviewed documents, conducted interviews, and visited three centers. (See Appendix H.)

Preliminary study questions were based on the materials obtained in this research. Research on STCs included review of official documents such as related legislation and committee reports, the Zare Report, program solicitation notices, data on STC activities, funding, and evaluation, and related material on national goals in science and technology. In addition, NAPA staff reviewed a broad variety of materials presenting varying perspectives on evaluation of long term research programs.

In addition, NAPA staff collected data from

- Interviews with NSF policy makers and STC program staff;
- Interviews with congressional and administration staff involved with science and technology policy;
- Surveys of STCs that include the research questions listed above, and
- On-site research at five STCs. (See Appendix I for persons interviewed.)

On-site visits. NAPA's site-visit team made two-day visits to each of five STCs during the period from December 1994 to February 1995. The centers visited were chosen to include STCs managed by each of the four directorates, distributed over a wide geographical area, and funded at various levels. All centers visited have been funded since 1989, except for the Center for Biological Timing, which has been funded since 1991. Although the five centers exhibit a wide variety of characteristics, they are not a representative sample of program participants. NAPA visited the following centers:

- Center for Biological Timing, University of Virginia, Charlottesville, Virginia
- Center for Molecular Biotechnology, University of Washington, Seattle, Washington
- Center for Research on Parallel Computation, Rice University, Houston, Texas

- Center for Quantized Electronic Structures, University of California, Santa Barbara, California

- Center for Analysis and Prediction of Storms, University of Oklahoma, Norman, Oklahoma

The NAPA site-visit team included persons with expertise in science research management, management and performance measurement, finance, and education. Each site-visit team included a scientist who was familiar with the particular center being studied. A recorder accompanied the team to compile extensive notes of all presentations and interviews. (See Appendix E for site-visit personnel.)

Data were obtained from a number of sources before, during, and after the site visits. The team reviewed literature on each center, including previous site review presentations and evaluations, and answers to a questionnaire sent prior to the visit. They heard presentations from center directors, scientists, outreach coordinators, and internal and external advisory board members, and received answers to specific follow-up questions. The scientists involved in the site visits, technical coordinators, and OSTI staff also contributed significant data based on their knowledge of the science practiced at the centers and management of research.

LIMITATIONS

Although there are important similarities among the five centers visited, conclusions about them cannot necessarily be generalized to other STCs because of numerous variables: differences in leadership, demographics, disciplines, maturity of the research, institutions in which they are housed, funding, support from NSF personnel, and rapidly changing technologies. Likewise, the various centers programs vary widely in history, duration and size of funding, NSF management, disciplines and objectives addressed, and structure. Therefore, conclusions about the STC program may not be applicable to the other centers' programs. The focus of the research concerns the validity of the concept of center-based research as one of the components of federally funded research and management at five centers. An evaluation of the STC program or individual centers is beyond the scope of this study.

Scientific research at the centers is extremely broad and complex. Although scientists familiar with the activities of the centers were part of the site-review teams and there is a body of data available on the quality of science practiced at the centers, only general conclusions relative to the scientific research as it relates to center management are included in the report. A detailed evaluation of specific research activities is beyond the scope of the study.

CONCLUSIONS

The center concept as envisioned in the Zare Report is achieving its objectives. Centers provide opportunities for long-term, basic, complex, interdisciplinary research that cannot be carried out by individual investigators. Both internal center management and NSF management of the individual centers has contributed to the centers' evolution from groups of individual investigators to cohesive units with shared goals, and ultimately to communities which commit some of their resources to knowledge transfer to industry and educational institutions. Center funding provides flexibility to support projects of emerging interest and often leverages substantial contributions from universities, industry, and other government programs.

CENTER CHARACTERISTICS

The Zare Report suggested several major elements that should characterize centers. According to the report, centers should:

- Perform basic research;
- Foster interdisciplinary collaborations;
- Be university-based;
- Provide educational experiences and community outreach;
- Support knowledge transfer and collaboration with industry and government; and
- Be funded for a finite period. (This is now interpreted as 11 years).

In addition, the report included the suggestion that NSF not specify areas in which it would accept proposals, but allow a wide variety of proposals and judge them on individual scientific merit without regard to distribution among the various scientific disciplines. All of the centers visited displayed these characteristics to varying degrees. (See Appendix J.)

- **The characterization of research as long- or short-term, or as basic or applied varies among centers, depending on the maturity of the discipline and the preciseness of its definitions. Research at the centers visited can be used as a base for more applied research in the relevant fields.**

Research is often classified in two different ways: *basic* versus *applied* research, or *curiosity-driven* versus *strategic* research. Basic research is distinguished from applied research by the extent to which a contribution is made to fundamental knowledge in a field. Strategic research is focused on overcoming a particular impediment to a specific goal. Categorizing research projects in these classifications depends on individual perspectives.

The five centers reviewed included a wide variety of research, all of which can be used as the base for further applications and research. Data from the University of Virginia on mutant timing- patterns in mice may eventually be used in industrial safety research. On the other hand, the mission of the Center for Research on Parallel Computation (CRPC) at Rice University is to make parallel computation more useable, which has more immediate application to industry. Both efforts, however, facilitate further research in relevant fields, providing technology basic to the work of other researchers.

- **The nature and degree of interdisciplinary and multidisciplinary collaborations among center members vary, but such collaborations are evident in all centers visited, and are opening new avenues for cooperation.**

University research-efforts generally are divided quite strictly along disciplinary lines, and NSF itself is divided into directorates representing the major divisions of science. On the other hand, industrial research-labs often require the collaboration of scientists and engineers from several fields to bring technologies to market. Each center visited reflects a blending of the industrial and academic model. The Center for Molecular Biotechnology at the University of Washington includes scientists from physics, chemistry, biology, engineering, and mathematics, many of whom are competent in more than one field. In addition, the University of Washington has formed a multidisciplinary Department of Molecular Biotechnology. The Center for Biological Timing and the Center for Analysis and Prediction of Storms (CAPS) focus in their respective fields of biology and meteorology though collaborations of mathematicians and computer scientists.

- **Interdisciplinary collaboration in centers can provide strategic beachheads from which university administrations can encourage further collaborative efforts.**

Some university administrations are breaking down traditional boundaries between academic departments. At both the University of Oklahoma and the University of California at Santa Barbara (UCSB), STCs serve as models of a new paradigm of research. These centers are helping to overcome the barriers that keep some from recognizing interdisciplinary work as "serious" science. Rice's dedication of funding to a new building to house the CRPC along with the electrical engineering, applied mathematics, and computer science departments is material evidence of the university commitment to broadening the paradigm of interdisciplinary research.

All five STCs visited had situations in which doctoral committees have members from more than one department. Two meteorologists from CAPS have taken sabbaticals to develop their own skills in computer science. The University of Washington's new Department of Molecular Biotechnology offers an interdisciplinary degree which helps to extend the paradigm of interdisciplinary or multidisciplinary research to universities throughout the country.

- **Universities, including those involved in distributed centers, provide substantial support in technical and administrative space, equipment, and faculty salaries.**

Each STC visited had relatively new office and technical space, with new buildings under construction for the STCs at Rice and the University of Washington. Administrative space for the centers is clearly identified as "center" space. The labs used by center members may not clearly be identified as "center" labs, but space and equipment have been made available for center-focused research. UCSB provides costly equipment which is shared by the Center for Research on Quantized Electronic Structures (QUEST), the departments, and the Materials Research Lab.

All centers include members who are not located at the home institution, but whose institutions also provide space, equipment and salaries to center efforts. For example, CRPC's efforts are distributed across Rice, Syracuse University, the University of Tennessee, California Institute of Technology (Caltech), and the national laboratories, all of which provide space, salary support, and computer equipment. Universities have supplied the faculty salary-lines to fill needs for additional center faculty. Universities have also supplied support for graduate research fellowships. The University of Washington supplied faculty positions for many faculty to move from Caltech.

- **Since many center members are regular university faculty, center activities are well integrated into the university educational function.**

An important goal of the STC program is improving education. There is strong support in the industrial community and somewhat less support in the academic community for interdisciplinary or multidisciplinary training as a new paradigm. STC activity includes enhancing students' educational experiences. At the University of Virginia and at Santa Barbara for example, students were involved in multiple research in the labs, in presenting interdisciplinary research results at informal "brown bag" discussions, in summer research programs, and were advised by faculty members from more than one department. As noted above, the University of Washington has developed a new department based on the STC from which students will receive multidisciplinary degrees.

- **Most of the centers visited had excellent, innovative educational outreach to many age-groups in their communities and beyond. It is those outreach activities which are most likely to be curtailed if center funding ceases.**

Center directors indicated that early outreach efforts often included only financial support for lab assistants and graduate fellowships. With NSF encouragement, they have expanded to include programs for all age and background levels, facilitated by outreach

coordinators with backgrounds in the field of education. Principal investigators indicated their enjoyment of work with young students, and that satisfaction was mirrored in the enthusiasm of the students and teachers with whom they worked. However, NSF support for these efforts is a prime driver, and most center personnel indicated without that support maintaining outreach would be difficult.

Although there are innovative twists to each, there are four programs that form the basis of the educational outreach efforts:

- Financial and mentorship support for graduate and undergraduate lab assistants;
- Summer research opportunities for university and high school students and for teachers;
- Curricula, lab kits, and training for K-12 teachers based on research at the centers or in relevant fields; and
- Lectures on center research to the general community.

National educational goals include exposing more students to quality science-experiences. When science teachers have been in elementary, middle or secondary classrooms for several years, the opportunity to work in university labs is particularly important to maintain their enthusiasm for lab science. This enthusiasm, in turn, fosters quality instruction and enthusiasm for science among students, as do student summer lab opportunities. It is in this area that STCs can make an important contribution.

All of the centers emphasize enriching the science experiences for minorities and women. One such activity is working with science teachers and students in inner-city schools. In addition, CRPC at Rice also has an outreach program to historically minority colleges which includes helping faculty at these colleges improve mathematics and computer sciences curricula. It also involves an active mentorship program in which CRPC graduate students work with minority-undergraduate summer-researchers, encouraging them to attend graduate school. Systemic changes as a result of center activities, however, are not evident.

- **Centers' collaborative nature and the mandate that they have external advisory boards extend knowledge transfer both to and from industry and government.**

The centers' external advisory boards all comprise representatives from relevant industries, government, and academic areas who are familiar with needs and developments in relevant fields. Their input helps shape the research focus. In some cases, personnel exchanges take place between STC and industrial labs. For example, industrial scientists work in QUEST's project, even though QUEST's research on quantum structures is far from having industrial application. The STC at the University of Virginia is using a large industrial database to investigate the relationship between human internal-clock mechanisms and industrial safety.

In other cases, industrial affiliates are active in applying STC outcomes. At CRPC, affiliates pay $15,000 annually to receive research updates from the center. The Center for Molecular Biotechnology has spun off several businesses related to manufacturing and marketing center technologies, with some royalties returning to the center. In addition to having close research relationships with the large Norman weather research community and with NOAA, CAPS has begun negotiations for application of its storm prediction model in South Korea.

- **Some centers are building a critical mass of scientists and equipment which will continue interdisciplinary activity after NSF funding ceases, while others have designed programs to conclude at the end of the eleven-year grant period.**

Research at some centers, such as QUEST and CRPC, depends on access to complex and expensive equipment and a critical mass of research talent. The STC at the University of Washington is building financial backing from private sources, the university, and royalties from its technologies. It is the scientists' intention to continue their collaborations indefinitely, changing focus as the needs of the science community change.

The project at CAPS will be complete at the end of the STC funding period. Although center members may become part of other nearby research efforts, they do not intend to continue as an STC. The STC at the University of Virginia was the only second round center in this study and members have substantial funding from other sources. It is still building a critical mass of scientists and has just begun to consider its future beyond STC funding.

VALUE OF THE CENTER CONCEPT

A primary value added by the center program is that it enables local control of substantial amounts of funding for an extended period, a situation which is very rare under current research funding standards. When STCs were created, they were controversial because it was feared funding for centers would decrease funding for individual principal investigators, and that center activities would detract from scientific research, lessening research quality. Center management does require commitment of time to center activities, but those activities enrich, rather than impinge upon, individual researchers' efforts. STC funding is highly leveraged, complementary to individual researcher grants, and is often used to develop projects for competition for individual-researcher grants.

- **Centers represent an organized approach to quality science projects managed by capable scientists.**

Technical credibility of the center leaders is essential, both in defining the focus and quality of center research and in attracting quality researchers to the center. At all of the centers in the study, center directors and members who are involved in identifying potential projects and allocating resources have sustained and recognized expertise in relevant disciplines. In most centers, principal investigators and the center directors hold consider-

able funding from other sources. This is a strong indicator that their qualifications and projects are recognized as of high quality by their peers. It is important that active research-scientists manage the centers, and that management does not take their full time.

- **NSF funding has a strong effect in the centers and provides flexibility that leads to rapid response capability when opportunities for innovative research occur.**

STC funding is used for industrial and educational outreach, purchase of new equipment, graduate-student funding, faculty salaries, travel, and center administration, including the costs of the review process. Center directors value the flexibility to provide "seed" money for new projects until they can be sufficiently developed to merit individual grants. Of particular value to the center directors is the ease and speed with which they can allocate resources to an unexpected and promising area of inquiry. At the University of Virginia, for example, center funding is helping support the initial stages of a mathematical project on biological timing and industrial safety.

At the Center for Analysis and Prediction of Storms, STC funding has been a larger portion of the researchers' total funding, enabling them to develop their model and to develop in-house computer skills. Considerable research preceded the "proof of concept" necessary to convince other agencies and industry to invest. As the CAPS model reached the data integration and testing stage, the center began negotiations with the U.S. military and other entities for support.

- **With reductions in industry support of research, STCs are even more important to accomplishing national goals.**

Research from all of the centers studied can be related to the national goals. For example, scientists at the Center for Analysis and Prediction of Storms at the University of Oklahoma are developing and testing a mathematical model for prediction of severe thunderstorms which could have tremendous impact in the airline industry. Since many airlines are currently in financial difficulty, funding is not available for the early part of this research from that sector.

The Center for Quantized Electronic Structures at the University of California at Santa Barbara is addressing a situation that may soon become a problem in communication and data storage: the structures on which computer data are stored are small, but the amount of data generated is increasing at such a rapid rate these structures will become inadequate. At QUEST, scientists are studying the properties of quantum structures which may result in more efficient data storage for the information society. Other nations recognize this as leading edge technological research. For example, according to QUEST members, the Japanese government is funding more than twenty large research projects, while in the U.S. there are few such projects funded either by the government or by industry.

- **NSF funding allows center members to address research that individual researchers cannot address because of scale, complexity, cost, and interdisciplinary requirements.**

STCs address problems which require interdisciplinary approaches not commonly used in academic department settings and which are often so complex that traditional three-year grants could not possibly yield results, and individual grants – which average $80,000 – could not purchase the necessary equipment. At QUEST, the problems of the behaviors of quantum structures require complex equipment and may take many years to solve, since the research involves learning how to build the structures before they can be studied. Without the stability of long-term funding and the ability to bring together a large number of people provided by STC status, such research could not be undertaken.

- **NSF funding is highly leveraged. The center mode is an effective way to invest federal resources in this time of budgetary pressures.**

Center funding stimulates discovery and activity to a much greater degree than is represented by its percentage of the funding to center members. The center director at the University of Virginia indicated that STC funding averaged about 10% of the totals in the various labs involved, indicating a high level of leveraging of NSF funding. Collaborations among center members speed up research and eliminate duplication, leveraging NSF funding. Centers are often not able to clearly report this degree of leverage accurately because boundaries between center and other research are not clearly drawn.

The center at the University of Oklahoma is located in an area in which weather conditions and weather data infrastructure are particularly strong. Federal money is highly leveraged because the research at CAPS is enabling the use of a large amount of weather data obtained by other federal resources.

- **Centers foster collegial groups and new interdisciplinary approaches to complex problems.**

Personnel at all of the centers reported a growing sense of collegiality crossing disciplinary, organizational, and institutional boundaries. Their enthusiasm for the center community and interest in each others' research were immediately evident even in casual conversation. One center director gave the following example: He had for some time known of researchers at other schools working on similar problems but had hesitated to discuss his work with them. Since he has worked in the center, he is willing to share his research and has benefitted from others' research. In another case, members from two institutions that had a long-standing professional rivalry surprised members of their professional organization by delivering a joint paper based on center collaboration.

One member told of a case in which he submitted a proposal to NSF's Biology Directorate and was told it contained too much applied physics. He then submitted it to the physics area and was told it contained too much biology. Eventually, the project was funded as part of center activity allowing an interdisciplinary approach which would not have been allowed under either of the directorates.

- **Although considerable time may be spent on center activities, scientists involved in centers report that they and their work benefit from collegial interactions and from exposure to the community and industry.**

Center directors report that they spend as much as half of their time on center activities, while other center members spend less. Several members indicated that center activities took less time than the administration of their individual grants, because center personnel handle administrative details. The value of center time in intellectual exchange with others, in sharing research results through "brown bag seminars", in interactions with the external advisory boards, and in planning research for long-term funding greatly benefits the quality of the research.

A well-known scientist at CRPC takes time from his research for center-sponsored programs for minority students in colleges, high schools, and an experimental K-8 school. This outreach activity gives him personal satisfaction, more pride in his work, and the ability to recruit promising students to the CRPC program. He feels it is well worth the time taken from his research. The center directors and other personnel from both University of Virginia and University of Washington reported personal satisfaction and more enjoyment of their work because of the opportunities to lecture to large groups of young students on center research.

CENTER MANAGEMENT

The management structures of the centers are flexible, evolving, appropriate to facilitate scientific research, and in keeping with basic management models of cycles of goal setting, prioritization, implementation, review and revision based on program data. (See Appendix K.)

- **Centers benefit from being directly managed by NSF technical coordinators who have knowledge of the research.**

The Zare Report recommended NSF manage and fund STCs through an office separate from the discipline-oriented directorates through which individual grants are funded. However, funding and management of the STCs has been "main-streamed" into the directorates. As noted above, general management theory assumes known outcomes, while scientific research is aimed at unknown outcomes. The center directors feel technical coordinators are capable of advising them – even on management matters – since they are familiar with specific science research areas. This is particularly important since the existing peer-review process on which continued funding depends is based primarily on the quality of science practiced at the centers, in addition to educational outreach and knowledge transfer activities.

The cultures of the research communities in the various disciplines also differ, largely due to the type of research appropriate to that discipline. For example, in areas like quantum structures, very basic research with little industrial application is appropriate. In others, like molecular biotechnology, commercialization is more important today. Center directors feel it is valuable for technical coordinators to be familiar with the disciplines practiced at the centers to correctly evaluate their progress in areas such as outreach and technology transfer.

- **Centers evolve over time, developing research focus, management practice, collegial relationships, and outreach and technology-transfer programs.**

Centers evolve at different rates depending largely on the previous experience of the center director and other members. The most mature of the centers visited was the Center for Molecular Biotechnology, whose leader had been involved in interdisciplinary study and development of biotechnology for over 20 years. Less mature was the Center for Biological Timing, the only visited center funded in the second round of STC grants.

The evolution of the centers visited followed a consistent path as center directors came to grips with management structures and issues. The original concept of each center visited was based on the vision of a leader or small group of leaders experienced in cooperative work. In the first years, centers recruited a critical mass of staff and began interdisciplinary collaborations, still with a high degree of individual-project focus. As the external advisory boards became involved, they encouraged center members to focus research on center goals. The first review brought the center together, building a true sense of community and strengthening the center director's leadership role. Once the community was established and research progress was made, members turned more strongly to industrial and educational outreach and to building an interdisciplinary educational component at their universities. Center members eventually began to consider avenues for funding after the 11-year grant.

- **Centers are subject to more oversight than are individual investigators.**

Centers were funded on the basis of competitive grants that included site visits. Site visits are conducted periodically by technical coordinators, and in-depth peer reviews are part of third and sixth year renewal funding. In addition, centers' external advisory boards review their activities annually. If a center director or location changes, it is subject to an additional peer review and site visit. Most centers have been reviewed by the inspector general. Individual investigators' projects merit site visits infrequently and are generally not required to have advisory bodies.

Since centers are perceived as a new concept, they have also been subject to numerous additional reviews, such as the NAPA review. Since the grants are much smaller and more numerous, individual investigators generally are subject only to annual report cycles rather than extensive site visits and outside reviews.

- **Center management varies in character depending on the nature of the center, the expertise of the center director, and the institutional setting, although all centers share management responsibilities within a collegial group to some extent. The vision and direction of a center director is a driving force in developing those relationships and maintaining the focus of the research.**

The leadership ability of the center director is a primary element in center evolution. Leaders of the centers visited varied in management style but each had a vision of

research collaboration, enthusiasm for his or her discipline and for center activities, concern for the welfare of center members, creativity, and a willingness to let others lead where appropriate. While the qualities of leadership are important, experiences both before and after center funding resulted in distinct management paradigms.

For example, the original center director at QUEST had many years' experience at Bell Labs. Using that experience, he was able to develop a unique group of experienced scientists that works together much like an industrial research-unit. The center director at the University of Washington has many years' experience in an academic environment. That center has expert scientists and scientists who wish to build their capabilities in multidisciplinary research.

The Center for Research on Parallel Computation is distributed among several institutions. The center director makes major decisions with the advice of senior members at each location. The center director at the University of Virginia regards himself as one of a group of equals and leads by example.

- **Change of center directors brings a critical period during which the collegial relationships may be realigned and center purposes refocused. With a new director, a center may have to repeat some of the process of evolution common to building collegial relationships in the centers' early stages.**

Two of the centers the study team visited have new directors. In both cases, the original center director was involved in negotiations with the university and with NSF on appointment of a new center director, and in both cases an existing center member was appointed as director. Leadership at QUEST passed to a scientist who is acknowledged as an expert in her field, and an assistant director was added to assist with daily administration. The center continues to have strong collegial relationships typical of a university department and strongly supports the new director. In turn, she is developing her own vision for future institutional and community outreach in addition to basic research.

At the University of Oklahoma, the original center director's expertise was more scientific than managerial. He has retired and been replaced as director by a former associate director. The original director had recruited a group of very competent scientists with the basic goal of developing a mathematical model of storm prediction. The new director has developed a strong model of center management geared to testing and marketing that model. His management techniques include time schedules and benchmarks. He is turning additional attention to NSF's requirements for outreach and knowledge transfer.

- **Since the centers' budgets are maintained largely through complex university budget systems and include funding from several sources, some centers are not able to fully demonstrate the degree of leverage of STC funding.**

The center concept creates some situations that make budget reporting difficult. Center funding tends to be only a small portion of the funding available to the members. It is not always possible to draw clear distinctions between center projects and others and to

determine what percentage of personnel time is devoted to center activities and what percentage is devoted to other activities. It is, therefore, difficult to determine which results and consequent income, royalties, or additional funding are generated by center activities.

Center funding is often used as "seed money" to develop other projects which are subsequently "spun off" when funded individually. Centers are concerned that they will not receive "credit" for those projects, or that in claiming "credit" will be accused of claiming more than is their due. Consequently, many of the financial structures presented to the team were not clear. This does not indicate that funds are badly managed; it does indicate the complexity of university structures for funding research.

NSF MANAGEMENT OF THE CENTERS' PROGRAMS AND NSF'S ENVIRONMENT

NSF does not direct daily STC management or prioritization of specific projects or resource allocations, but depends upon the initial process of grant competition and ongoing reviews to assure competent management of the centers program. This is consistent with the STC program purpose as an experiment in linking interdisciplinary scientific research with industry and education. Recently, however, emphasis has been put on linking national science research goals and establishment of strategic plans with appropriate goals and performance measurement processes. As mentioned above, this represents a management paradox within which NSF and the STCs must operate, and may require some changes in NSF management strategies.

- **NSF's mission and the national goals are broad. STC goals contribute to achieving NSF goals while NSF goals contribute to achieving national goals.**

Individual center goals are appropriately narrowly focused on specific issues. The five centers visited focused on genetic research, and developing technologies for advanced computer applications, biological research, quantum structures applications, and weather prediction. Goals of each of these centers can be linked to NSF's mission "to promote the progress of science: to advance the national health, prosperity, and welfare: to secure the national defense"

NSF has defined three broad goals:

- Enable the United States to uphold a position of world leadership in all aspects of science, mathematics, and engineering.
- Promote the discovery, integration, dissemination, and employment of new knowledge in service to society.
- Achieve excellence in U. S. science, mathematics, engineering, and technology education at all levels.

STCs promote these goals by enabling collaborative practices in scientific research, technology transfer to industry, and outreach to educational institutions ranging from kindergarten to graduate school, and to diverse groups including women and minorities.

NSF's mission and goals are closely related to broad national goals of fostering a healthy economy, promoting foreign policy objectives, facilitating health research and improving communications. Strategies include promoting cooperative relationships and technology transfer, both of which are also an important part of the national goals concepts.

- **A wide variety of research is supported by the STC program. The most critical decision made by NSF concerning the STCs is which initial projects to support.**

The Zare Report position on areas of research to fund was that NSF should not specify eligible research areas but should award funding on the basis of merit. The result has been the selection of a wide variety of projects which might not have been eligible if research areas had been specified. For example, one center focuses research on cement, which at first consideration seemed to NSF staff a mundane construction element perhaps not worthy of advanced scientific research. The selection committee, however, recognized the importance of investment in this area, particularly since the Japanese had invested in development of high quality cement products. The center is key in maintaining US competitiveness in this area.

By its nature, scientific research includes discoveries that could not have been planned prior to the onset of investigation. Studies show that the results of much scientific research may not be marketable for more than 20 years after they are made public. If NSF is to be able to fund research in areas that will contribute to the national goals in the next century, funding should not be limited to fixed percentage across certain disciplines, or to meet the needs of specific short-term goals.

- **One disadvantage of management being dispersed among the various NSF directorates and Office of Polar Programs is the lack of an advocacy body for the center concept.**

The Office of Science and Technology Infrastructure organizes the STC review processes and gives guidance to peer reviewers, but technical coordinators based in the directorates oversee the STCs. Although center directors expressed appreciation for the expertise of the various technical coordinators in their fields, they also perceived uneven support for the centers concept among the technical coordinators. Having technical coordinators who are experienced in collaborative research would be one way of establishing equitable treatment of centers within NSF. In some cases, technical coordinators have changed too frequently to gain this valuable experience.

Center directors expressed concern about an absence of general advocacy for centers which could be filled by a center-focused subcommittee of the National Science Board including members of the industrial and educational communities when appropriate. In contrast to the lack of an advocacy group for STCs, Engineering Research Centers bene-

fit from the support of industry. One effect of this lack may be that funds have not been made available for future STC competitions.

- **The OSTI STC database provides valuable material which can be used to demonstrate the value of the program as a whole to Congress and other constituents.**

The OSTI database includes a wide variety of information on STC personnel, funding, expenditures, research, industrial knowledge transfer, technology development, and outreach activities. These data can be used to indicate the contributions of STCs to NSF and national goals. The data base serves as a source of information within NSF and in providing information to Congress.

- **OSTI-sponsored periodic meetings for center directors, center administrators, and outreach coordinators contribute to the program by facilitating information exchange among members of these groups. Even greater exchange and coordination of research would be beneficial.**

OSTI-sponsored meetings of center directors and outreach coordinators facilitate sharing of ideas on management, research focus, and outreach programs. Most center directors said they had benefitted from the experiences of others shared at the meetings. In addition, some noted that they had gotten valuable ideas for further coordinating scientific research from the meetings. For example, the Center for Analysis and Prediction of Storms and the Center for Research on Parallel Computation are collaborating on some applications of parallel computing technologies on storm prediction.

Center scientists could be even more well informed about the activities of other centers and provide for more coordination. For example, there is work being done on biological computation at the University of Virginia and University of Washington centers and at the Center for Research on Parallel Computation. It is not clear that there is significant coordination among these groups, and there may be some duplication of effort.

- **OSTI-sponsored training and guidelines for peer reviewers contribute to progress toward equity in the STC peer review process.**

Although there is some concern among center directors about uneven treatment among the directorates of the centers, OSTI is working to improve the situation. OSTI personnel believe that understanding and appreciation of the program are increasing within NSF.

Prior to the third-year and sixth-year peer reviews, OSTI hosted meetings for technical coordinators and peer reviewers to further increase understanding of the purpose of the STC Program and uniform evaluation. The workshops included efforts to standardize STC presentations to reviewers and increase understanding of the criteria for excellence.

- **NSF has not defined a clear method for removing a weak center director or replacing a director who leaves.**

NSF feels that the merit of a center director is established in the original competition process. It especially stresses the notion that preparation of the competitive proposal, organization of the site visit and interactions of prospective center personnel and evaluation by those personnel during that visit provide a clear picture of the management capabilities of the center director. STCs are managed through a cooperative grant procedure with the parent universities. The universities are directly responsible for maintaining strong center management, although their external advisory boards and NSF peer reviews provide valuable input to the university administration. Center directors are also responsible to their peers on the steering or executive committee.

NSF needs to have a better understanding of what its role and the role of the university are in replacing a weak center director. In at least one case, differences arose between the center director and NSF personnel on reporting and outreach requirements. NSF, center members, and the university cooperated in naming a replacement when the original director retired. Several other center directors have been replaced due to death or retirement. In most cases, technical coordinators, center personnel, departing directors, and the university administration have cooperated in naming a new director.

RECOMMENDATIONS

- NSF, Congress and the administration should recognize the good return on federal government expenditures through the STC program as being in the national interest and worthy of continued support.

Some of the most important aspects of the STC Program cannot be effectively funded through individual grants. In addition to collaboration on scientific research, STCs facilitate knowledge transfer to industry through the external advisory boards and knowledge transfer to the community through educational outreach programs in schools and colleges and public presentations. These elements are the value-added which was the goal of the program as established by the Zare Report and which would be difficult to maintain without STC funding.

- NSF should continue the current matrix method of managing the centers, with funding through the responsible directorates and the Office of Polar Programs and coordination through the Office of Science and Technology Infrastructure.

Funding and oversight through the directorates and OPP allows STC research to be considered within the mainstream of NSF funded programs. OSTI provides necessary coordination for assessment and management purposes. OSTI's data base is available to provide information to interested stakeholders.

- The National Science Board should form a subcommittee, including -- when and where appropriate -- representatives of industry and other stakeholders, to:

  - Act as a monitoring body to inform Congress and other stakeholders of the goals, activities, and value added by the STC Program;

  - Advise NSF in establishing processes and criteria to assess management of the STCs without adding to the current oversight burden;

  - Advise NSF in establishing criteria to replace weak center directors or directors who leave.

It would not be appropriate for such a subcommittee to increase center assessment, but it would be appropriate for it to supply advice on matters specific to the centers program. The subcommittee could give support to the STC program both within NSF and the community of federally supported research programs and to external stakeholders such as Congress and the industrial and educational communities. Such a subcommittee could also provide additional links to scientific, industrial and educational communities.

ENDNOTES

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3. White House Science Council, Panel on Health of U.S. Colleges and Universities, David Packard and D. Allan Bromley, Chairs. *A Renewed Partnership*. Washington, DC. February 26, 1986.
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APPENDIX A

SCIENCE AND TECHNOLOGY CENTERS ESTABLISHED IN 1989

NAME	LOCATION	BASIC RESEARCH FOCUS	POSSIBLE APPLICATIONS	EDUCATIONAL OUTREACH
Center for Molecular Biotechnology	University of Washington Seattle	Genetic engineering–DNA/protein–change in molecular biology	Instrumentation for DNA fingerprinting super computer hardware for large data base analysis	Courses and briefings, teacher summer institutes, lecture series
Center for Parallel Computation	Rice University Texas	Parallel systems for supercomputers, programs, software, algorithms	Making parallel systems useable	Model curricula, short courses, graduate programs, teacher training
Center for Superconductivity	University of Illinois-Champaign-Urbana	Superconductivity of crystals; thin films	Industrial production of thin films	Graduate and post-doc education, summer undergrad institutes, workshops
Center for High-Performance Polymeric Adhesives and Composites	Virginia Polytechnic Institute and State University	Systematic methods for creation of new polymeric adhesives	Automotive, chemical, electronic, construction industries	Advanced seminars, undergraduates, teacher training
Center for Quantized Electronic Structures	University of California, Santa Barbara	Quantum structures	High speed integrated circuits, small lasers	Graduate students, K-12 teacher research, videotaped lectures, high school internships, undergraduate internships, elementary manipulatives.
Center for Particle Astrophysics	University of California, Berkeley	Dark matter and the geometry of the early and current universe; evolution of the universe	Advanced sensor technologies	Public scientific literacy, undergraduates, graduates, on-line telescopes in high school classes, planetarium show
Center for Advanced Cement-Based	Northwestern University, Illinois	Properties of cements at atomic levels Materials	More efficient use of cement based materials for strengthening infrastructure, building components, waste disposal, heat and abrasive resistant parts for tools	Workshops, graduates, undergraduates, summer seminar

NAME	LOCATION	BASIC RESEARCH FOCUS	POSSIBLE APPLICATIONS	EDUCATIONAL OUTREACH
Center for Photoinduced Charge Transfer	University of Rochester (New York)	How light drives a broad range of chemical reactions	Photoconductive polymers with industrial potential —chargetransfer from molecule to molecule —controls and materials	Graduate, Undergraduate, short courses, visiting speaker, symposia, visiting scientist, low cost scanning microscope for use in high schools
Center for Analysis and Prediction of Storms	University of Oklahoma	Prediction and modelling of weather patterns	Display of data; prediction of thunderstorms models, parallel data processing	Daily radio program on NPR high school competitions, mentorships
Center for Microbial Ecology	Michigan State University	Micro-organisms in their habitats	Groundwater quality, hazardous waste disposal, plant pests, fermentation, soil nutrients	Teacher training, undergraduate, graduate, workshops, symposia, lectures, Detroit City schools outreach
Center for Discrete Mathematics and Theoretical Computer Science	Rutgers (New Jersey)	Discrete mathematics and theory of computer science. One-year focus with visiting scholars on full-year research programs in different areas	Telecommunication transportation, robotics, computer software design, CAD	Workshops, summer high school programs, teacher training

SCIENCE AND TECHNOLOGY CENTERS ESTABLISHED IN 1991

NAME	LOCATION	BASIC RESEARCH FOCUS	POSSIBLE APPLICATIONS	EDUCATIONAL OUTREACH
Center for Biological Timing	University of Virginia Virginia	Timing systems and biorythms at the molecular level	Molecular biology, mathematical modelling, biorhythm research, worker safety	Symposia, summer courses, seminars, undergraduate, minority high school outreach
Center for Engineering Plants for Resistance Against Pathogens	University of California, Davis	Interactions of plants with pathogens	Genetic engineering	TV, K-12 outreach, Native Americans, seminars, short courses, summer apprentice
Center for Magnetic Resonance Technology for Basic Biological	University of Illinois-Urbana/Champaign	Magnetic resonance imaging for study of living organisms	Applications to brain research	Courses, seminars, summer research, elementary students
Center for Light Microscope Imaging and Biotechnology	Carnegie Mellon Pennsylvania	Light microscope research stations; software for biological applications	Microscopes, software	Careers programs, faculty
Center for Research in Cognitive Science	University of Pennsylvania	Acquisition of knowledge through perception, action, language	Computational models, artificial intelligence	University minor, K-8 mentoring, teacher enrichment, K-12 curriculum project
Center for Computational Graphics and Science Visualization	University of Utah	Geometric modelling, rendering, light reflective models, visualization	Software for modelling, chemical research, creation of better computer graphics	Summer program for high school students
Southern California Earthquake Center	University of Southern California	Integration of geologic, geodetic, geophysical, and seismological data	Data center, hazard mitigation, GPS strain monitoring	K-12 earthquake hazard education; funding with FEMA
Center for Clouds and Chemistry and Climate	University of Chicago	Data gathering concerning clouds and their chemical causes and effects	Climate and global warming research	Summer research, teacher training, video materials, graduate workshops
Center for Astrophysical Research in Antarctica	University of Chicago	S. Pole observatory for investigating far reaches of the universe, evolution of elements, theories of universe	Development of equipment for astronomical research, chemistry and physics of the origins of the universe	Outreach to inner-city students

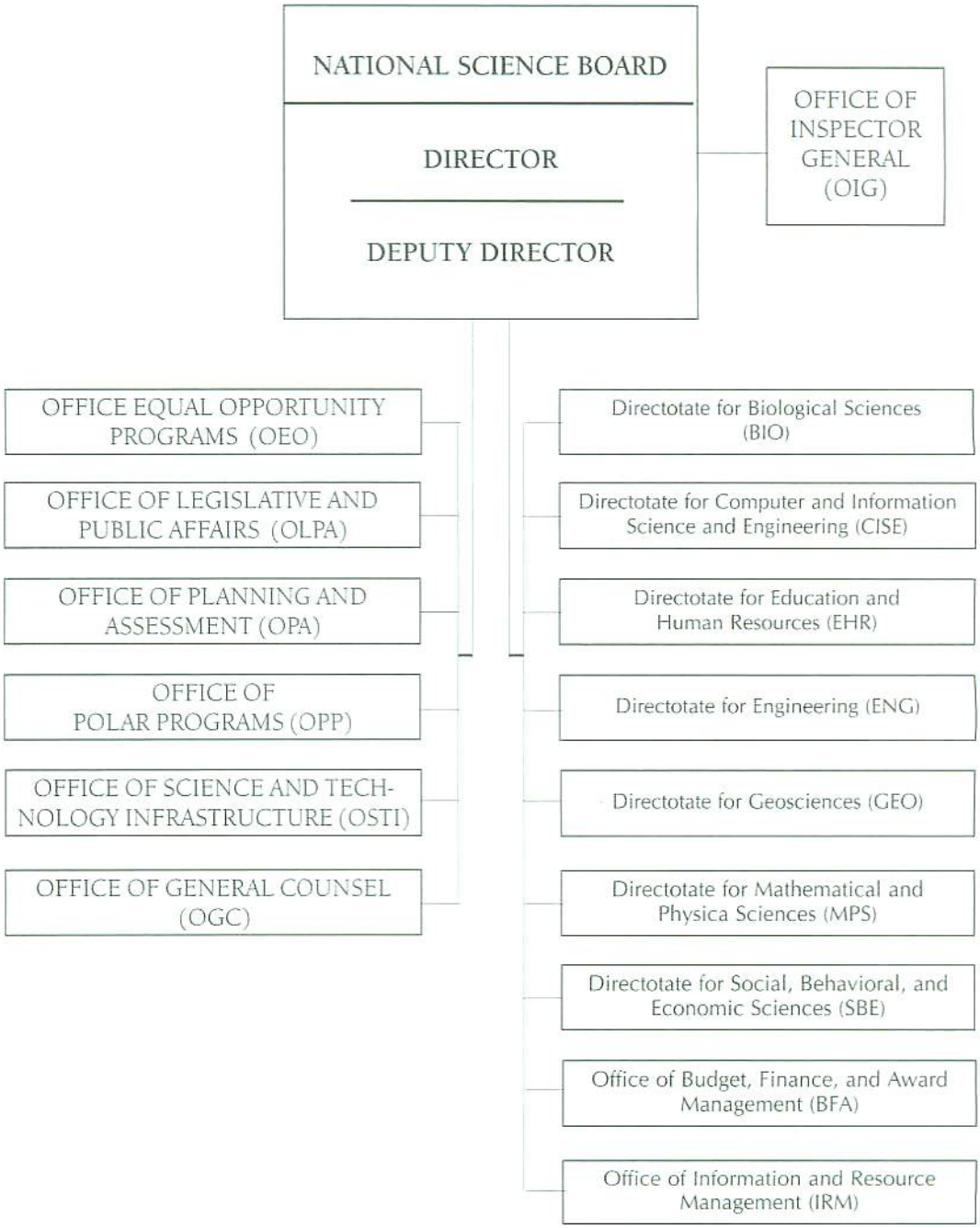
NAME	LOCATION	BASIC RESEARCH FOCUS	POSSIBLE APPLICATIONS	EDUCATIONAL OUTREACH
Center for High Pressure Research	University of Illinois–Champaign/Urbana	Understanding of high pressure and temperature effects on related to the interior of the earth and evolution of the universe	Development of devices for synthesis of new materials	One high school student elements–especially researcher, one PhD on another faculty, summer undergraduate program, multimedia package for high school
Center for Advanced Liquid Crystal Optics Materials	Kent State Ohio	Liquid crystalline materials synthesis, study	Production of optical materials	Stimulation of K-12 basic science, teacher training, graduate students
The Geometry Center	University of Minnesota	Tying together different subtopics in geometry such as topology, fractals, computational graphics, optimization	Software development	Summer course for high school, college, teachers, video, Minn Mathematics Mobilization
Center for Ultrafast Optical Science	University of Michigan	Ultrashort optical pulses, reaching the limits in duration and intensity	Physics, chemistry, biology, electronics, photonics, imaging, lasers, antenna structures.	Summer Science for Girls, high school after-school activities, summer research for undergraduates and graduates, fellowships
Center for Synthesis, Growth, and Analysis of Electronic Materials	University of Texas, Austin	Compound semiconductors and silicon based materials	Industrial applications such as thin film epitaxy, semiconductors, modelling, porous silicon production	Seminars, high school, graduate, undergraduate, elementary students, teacher training

APPENDIX B

NSF ORGANIZATION AND MANAGEMENT OF THE STC PROGRAM

The National Science Foundation's governing body is the National Science Board, a group of prominent scientists appointed to aid NSF in its primary purpose of promoting a coordinated national science agenda. The National Science Board approves NSF's resource allocations and advises NSF's administrator on national science priorities and development in the various fields of scientific research. Under the administrator, NSF is organized into seven directorates representing the disciplines of biology, computer and information science and engineering, geosciences, mathematics and physical sciences, social sciences, engineering, and education and human resources. There are also departments for education and separate offices for specific functions. One such special area is the Office of Science and Technology Infrastructure by which the original STC proposals were reviewed. (See Exhibit B-1 for NSF's organizational chart.)

EXHIBIT B-1: NATIONAL SCIENCE FOUNDATION



SOURCE: NSF

The Zare Report advised NSF in two areas of management of the STC program:

- Funding should not detract from individual investigator funding; and
- STCs should be managed from an office outside of the discipline-oriented directorates.

This recommendation was designed to protect the STC Program from the danger of loosing funding because of concern among the research community that they would supplant individual researcher funding. According to NSF personnel involved in the beginning of the program, however, it was always intended to "main-stream" the STC Program.

MANAGEMENT OF STCs WITHIN THE DIRECTORATES

Today, STCs are managed through the various research directorates and OPP. (See Appendix A for a detailed list of STCs.) Technical coordinators within the directorates manage both the STCs to which they are assigned and a variety of related individual research projects. Technical coordinators report that one main advantage of this system is their ability to facilitate coordination among related research projects. Some directorates have a subdivision which coordinates management of the several types of NSF centers,including the STCs.

Technical coordinators report STC management takes no more time per dollar expended, and in some years substantially less time, than does individual researcher funding. On the other hand, technical coordinators generally have more contact with center projects than with individual research projects. STCs submit extensive annual reports which contain information about the progress and focus of the research, center management and budget, and outreach and commercialization efforts. Following review of these reports, the technical coordinator and a group of scientists make a site visit to the center. Site visitors make recommendations where improvement is needed.

Major reviews of center progress are made during the third and sixth years. In each of these years, the review committee uses criteria prepared by the centers in cooperation with OSTI and the technical coordinators. The review committee includes the technical coordinator and several scientists familiar with the research done at the center. The review focuses largely on the quality of science practiced and the research possibilities, with lesser focus on budget and management. Based partially on the results of these reviews, the technical coordinators recommend to the National Science Board the level of funding which they feel should be given to the centers. Initially all STC funding was approved by the board. Currently it need only approve those exceeding $300,000 per year. Twenty-four of the original STCs have been renewed. One STC is being closed at the end of 1995.

In FY 1994, STC funding including interagency transfers and supplements was $60.6 million. This represented about 31% of NSF centers' programs funding, but less than

3% of total NSF funding by NSF for science research. How this funding was distributed by percentage of total spending over the directorates is not clear, although when STCs were chosen no effort was made to distribute funding evenly across the directorates. (See Exhibit B-2 for distribution of NSF funding across the types of centers.) Following the recommendation of the Zare Report, STC funding was decreased when NSF's total funding was decreased, so that a disproportionate share of the decrease was not absorbed by individual grants.

EXHIBIT B-2

SOURCE: NSF

(Millions of Dollars)

	Year of Program Initiation	FY 1995 Number of Centers	FY 1995 Estimate
Engineering Research Centers	1985	21	$51.73
Science & Technology Centers	1987	25	60.47
Industry/University Cooperative Research Centers	1973	53	4.13
State Industry/University Cooperative Research Centers	1991	10	3.72
Minority Research Centers of Excellence	1987	8	7.98
Materials Research Science & Engineering Centers	1972	29	44.41
Center for Ecological Analysis and Synthesis	1995	1	2.00
Long-Term Ecological Research Sites	1980	18	12.20
National Center for Earthquake Engineering Research	1988	1	4.00
National Center for Environmental Decision-Making Research	1995	1	1.00
Research Centers on the Human Dimensions of Global Change	1995	NA	5.00
National Consortium for Research on Violence	1995	1	2.00
National High Field FT-ICR Mass Spectrometry Center	1994	1	1.00
Critical Technologies Institute	1993	1	2.00
TOTAL		**170**	**$201.64**

THE OFFICE OF SCIENCE AND TECHNOLOGY INFRASTRUCTURE

The Office of Science and Technology Infrastructure (OSTI) was the original area of responsibility for the STC program. Today, it acts as a coordinator for specific STC activities, attempts to promote an even approach to management of STCs through the directorates, and maintains a data base on STC activities. OSTI also acts as an advocate for STC programs.

OSTI was responsible for administering the original STC proposal-review process. Proposals underwent stringent reviews both for scientific merit and for management

capability of center personnel. The first part of this process was much like that of any competitive grant, including written proposals of the scope of the work, resumes of center members, explanations of institutional expertise, and budget. The proposals were evaluated on the basis of merit of the research, research performance competence, effect of the center on the infrastructure of science and engineering, rationale for the center, utility and relevance of research, and the institutional support and management plan. Following the review of 343 proposals, 50 were chosen for site visits. Site visitors included prominent scientists, and NSF technical personnel, as well as representatives of OSTI. According to OSTI personnel, one of the important indicators of a center director's skills as a manager was the management of this extensive site visit. Following these visits the STCs were chosen—14 in the first round, and 11 in the second.

One of the primary responsibilities of OSTI is organization of training for center directors, center business managers, and center outreach coordinators. These meetings offer an opportunity for center personnel to share lessons learned in research, center planning, management and budget, university and community relationships, and outreach methods. Center personnel report the meetings are very valuable to their management. In addition, center personnel report they have used ideas presented at these conferences successfully at their own centers, especially in the areas of center management and outreach.

OSTI also coordinates the STC review process. Of particular importance to the continued success of the program is consistency of management of the centers by the technical coordinators from the various directorates. OSTI gives particular attention to this situation for the third and sixth year reviews. Since turn-over among technical coordinators is relatively high, OSTI has had several conferences on the nature and management of site visits.

OSTI manages an extensive database of information from the STCs. Obtaining and reporting information for the database, according to center personnel, requires nearly two person-months of time per center. The data base includes such information as research focus, funding, scientists' principal fields, students' status, and tracks students and faculty. Also included in the data base is information on industrial and university financial support for the centers and other budgetary matters. Data are used to inform Congress, the public, managers, and center personnel.

Although OSTI has a great deal of contact with the centers, and remains the advocate for the centers to the public and Congress, it has only persuasive abilities. It lacks the power to enforce specific requirements for the centers because funding comes directly through the directorates under which the centers are governed.

APPENDIX C

SURVEY QUESTIONS FOR INDIVIDUAL CENTERS

Is the STC university-based?

- Is it at one or several locations?
- Does it include tenured university faculty?
- Does the university host or hosts support it with services, space, equipment, or funding?
- Are students at all levels–undergraduate, graduate, and post-doctoral–included in both research and educational opportunities produced by the center?

Is the STC research interdisciplinary or cross disciplinary?

- From what departments or scientific disciplines are the faculty and students?
- Before the STC came into being, how was this research conducted?
- What communication channels are used among the researchers?
- What are the foci of the major projects and how are they linked?

Does the STC focus on fundamental research?

- How is "fundamental" research defined at the center?
- Is similar research being done elsewhere?
- To what extent is the research theme based on national goals and to what extent is it based on the need to produce knowledge which can be used in further research?
- Have new fields of research or courses of study been identified through this center?

Does the STC contribute to U. S. economic competitiveness?

- Do industry researchers work with the STC? How?
- Do STC students work with industry? How?
- Have STC students found employment with related industries?
- How many new technologies have resulted from the STC?
- How many patents have resulted from STC research?
- How many articles have been published on STC research by faculty, staff, students, or industrial partners?
- How are industrial partners linked to the STC?
- Have any technologies been marketed that arose from the STC?

Why does is this research best served by a center form of organization?

- What is the nature of the formal collaboration among the investigators?
- How long have these researchers collaborated?
- What types of facilities or instrumentation are needed for the research?
- How do the complexity of the facilities or instrumentation support the argument that a center is needed for this research?
- How are the STC's industrial partners involved in decision-making, funding, equipment, or other support?
- Are other federal institutions or state institutions involved in support of the STC? If so, what is that support?

What is the center's organizational structure?

- What are the past management experiences of the STC's managers and administrative staff members, including the center director and assistants?
- Who contributes to goal setting? How?
- Who contributes to prioritizing use of resources? How?
- What are the formal and informal methods used for reporting progress?
- What would precipitate a change in priorities?
- Has the structure of the center changed as the result of NSF funding under this program?
- What does STC management consider the criteria for success?

How is the center's budget handled?

- What is the amount of funding?
- What are the sources of income?
- To what is the income allocated? In what amounts? By what methods?
- What plans have been made to sustain the center financially after NSF funding under this program ends?

What is the nature of the STC outreach program?

- Who are the beneficiaries?
- How are resources allocated to these programs?
- What percentage of resources are used on outreach programs?
- Who designs the outreach programs?
- What are the purposes of the outreach programs?
- What are the criteria for success of the programs?

What processes are used to evaluate the STC as a whole and individual projects?

- Do the review processes give an opportunity for all parties to participate?
- To what extent do the members of the external advisory board participate in the evaluation process?
- To what extent does the NSF technical coordinator participate?
- How are the data from the reviews used?

APPENDIX D

STUDY QUESTIONS FOR NSF PERSONNEL

What processes are used to evaluate the STC as a whole and individual projects?

- Do the review processes give an opportunity for all parties to participate?
- To what extent do the members of the external advisory board participate in the evaluation process?
- To what extent does the NSF technical coordinator participate?
- How are the data from the reviews used?

How has NSF organized its management of the STC program?

- What are the relationships among the directorates, the STC program office, and the centers? What are the areas of expertise of the persons involved?
- Who participates in the site visits and reviews?
- Who determined the criteria for center success?
- How are those criteria used?
- What is the mission of the program? How is that communicated to the centers? How is it included in center evaluation?

How does NSF management act as a link between congressional and administration policy-makers and the STC program?

- What is the NSF mission? How is it linked to the national goals? How is it linked to the center goals?
- How is that mission communicated to the centers?
- What priorities does NSF use to allocate funds?
- Does NSF has a balanced portfolio of research including long and short term, basic and applied, throughout a variety of fields, and individual and center-based?
- How is progress toward the goals measured? How are these data used?

STUDY QUESTIONS FOR STAKEHOLDERS

A large number of stakeholders affects NSF and its programs. In addition to congressional and administrative offices, stakeholders are national science, industry, education,

and environmental groups, state agencies, and higher education agencies and advocacy groups. Questions posed to representatives of some of these groups include:

How does NSF management act as a link between congressional and administration policy-makers and the STC program?

- What is the NSF mission? How is it linked to the national goals? How is it linked to the center goals?
- How is that mission communicated to the centers?
- What priorities does NSF use to allocate funds?
- Does NSF has a balanced portfolio of research including long- and short-term, basic and applied, throughout a variety of fields, and individual and center-based?
- How is progress toward the goals measured? How are these data used?

How is science and technology research policy managed?

- What are the goals and priorities?
- How are they set?
- How are they communicated to the field?
- Are national science and technology research budgets coordinated across departments and agencies? If so, how and by whom?
- How is progress toward national goals measured? How are these data used?

APPENDIX E

SITE-VISIT PERSONNEL

James E. Colvard* is a senior fellow at the Center for Naval Analyses. He is also a former director of Johns Hopkins University Applied Physics Laboratory, and deputy director of the U. S. Office of Personnel Management. He also served the U. S. Navy as director of Civilian Personnel Policy, deputy chief of Naval Materiel, and technical director, Naval Surface Weapons Center.

Patrice Keough Gibson has contributed to a number of NAPA projects, including studies of programs at the Environmental Protection Agency, National Aeronautics and Space Administration, and the Federal Aviation Agency, as well as implementation of the Government Performance and Results Act. She has a special interest in educational programs, and has served as a teacher of mathematics and science, and a curriculum planner.

Gerald Riso* is a former president and CEO of Phillips Colleges, Inc. He served as special advisor to the secretary for Financial Management, HUD, and as deputy assistant secretary for Student Financial Assistance at the Department of Education. He also served at the Office of Management and Budget, and the Department of the Interior, and was a deputy commissioner of the Immigration and Naturalization Service.

Christopher Wye is the director of NAPA's Program on Ethics and Performance. He has a career-long interest in improving government performance through the use of information, research, performance monitoring, program evaluation, and inspections. He directed policy analysis and evaluation offices in the Department of Housing and Urban Development for 20 years before coming to NAPA in 1991. He has published several books and many articles and has directed the production of a large number of studies.

Richard A. Anthes President, University Corporation for Atmospheric Research, University of Oklahoma. Former professor of meteorology at the Pennsylvania State University; Former director of atmospheric research, National Center for Atmospheric Research.

Donald F. Hunt University professor, University of Virginia. Former assistant and associate professor of chemistry, and professor of chemistry, University of Virginia. Postdoctoral fellow, Massachusetts Institute of Technology.

Site-Visit Team

Waguih S. Ishak Manager, Phototonics Technology Department, Hewlett-Packard Laboratories; Former scientist, project leader, and project manager of Sources and Signal Process Group, Hewlett-Packard Laboratories.

Robert I. Moore Professor of psychiatry, neurology and neuroscience; Director, Center for Neuroscience; Co-director, Center for the Neural Basis of Cognition, University of Pittsburgh.

Steven J. Wallach Co-founder and senior vice-president, Convex Computer Corporation. Former product manager, ROLM Corporation. Manager, advanced development of Eclipse Systems, Data General Corporation.

*Fellow of the National Academy of Public Administration

APPENDIX F

SUMMARY DESCRIPTIONS AND CONCLUSIONS FOR INDIVIDUAL CENTERS

CENTER FOR BIOLOGICAL TIMING

University of Virginia
Site Visit Report
December 20-21, 1994

The Center for Biological Timing at the University of Virginia was funded in 1991 as part of the second round of National Science Foundation Science and Technology Centers. It currently includes participants from Northwestern University, Rockefeller University and Brandeis University, as well as the University of Virginia. Scientists from the areas of plant and animal biology, mathematics, and medicine, as well as engineers participate in center activities. The center also has an outreach program aimed at educational levels from corporate scientists to elementary school children.

The purpose of the center is to bring together investigators in a cooperative effort to solve major problems in biological timing and to provide exceptional breadth in the training of graduate and postdoctoral students. The center's stated goal is to be able to elucidate molecular, cellular and system-level processes involved in physiological oscillations in organisms. The strategy to achieve that goal involves research in three areas:

- The molecular and cellular basis of biological oscillations;
- The systems-level analysis of interrelationships among elements in the timing system; and
- How the timing system regulates rhythmic processes and behaviors.

Based on data from site visits and literature, the review team believes the center fulfills the characterization of an STC as a university-based, cross-disciplinary facilitator of basic research. Center findings may have important applications to industry, agriculture, and medicine in the future. Its management and leadership is grounded in a collegial culture of competent scientists. The combination of internal management, the external advisory board, and NSF technical coordination provides for cycles of goal setting, implementation, feed back, and revision. This facilitated the center's development and its effective leveraging of NSF funding.

CENTER ACTIVITIES

The center focuses on three major research areas: the Clock Genome Project, the Pacemaker Mechanism Project, and the Frequency Modulation Project. They are supported by the Biomathematical Analysis Project and the Technology Development Project. (See Exhibit F-1.)

- The Clock Genome Project involves location of the genetic sources of specific oscillations through screening and characterization of mutant rodents, arabidopsis, and drosophila.

- The Pacemaker Mechanism Project involves investigation of cellular rhythms and their sources in identified pace maker mechanisms.

- The Frequency Modulation Project involves research on the interactions between circadian and ultradian rhythms, and the impact of frequency coding on gene expression, primarily in mice.

- The Biomathematical Analysis Project facilitates the above research by developing computer models and the necessary data manipulation and analysis programs to study large groups of cases.

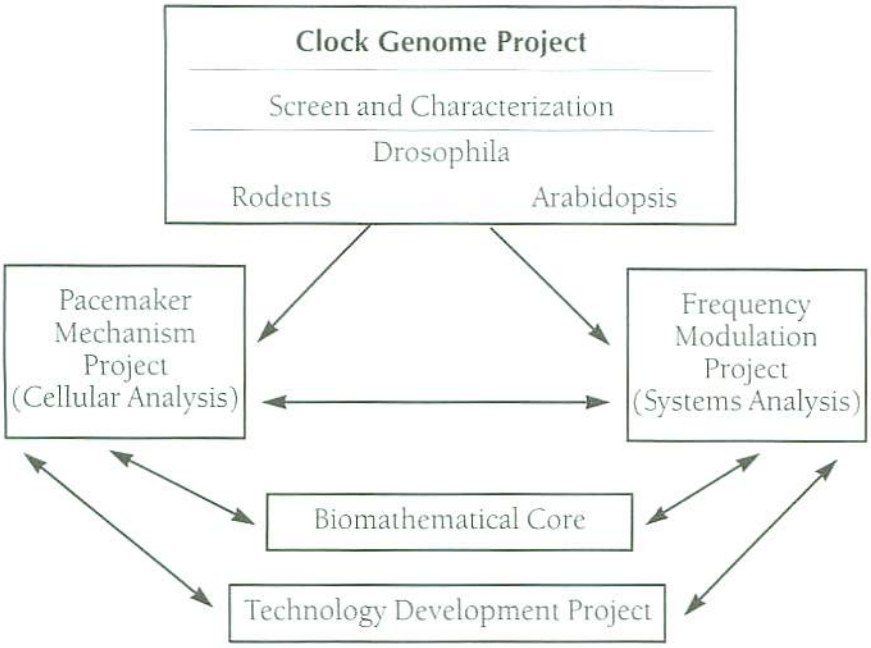
- The Technology Development Project supports the others in developing new technologies that allow the investigation of biological processes in real time in living organisms. One project goal is to develop imaging techniques to monitor gene expression in single living cells using the light-producing quality of luciferase.

In addition to its research program, the center has an educational and outreach program. Within the center and research community, educational and outreach programs include visiting scholars, new technology tutorials, special consultants, weekly seminars, symposia, meetings, undergraduate summer research programs, special courses, and a videotape library. Outreach programs include workshops and summer research opportunities for high school teachers, a visiting lecturer program, a biotiming bulletin board, and museum and travelling exhibits.

Recently, the center has begun some research in conjunction with heavy industry on safety factors involved with biological clock mechanisms, and has participated in developing of kits for teaching basic genetic engineering techniques to high school students.

EXHIBIT F-1 SOURCE: Center for Biological Timing

Center Research Program



CENTER DESCRIPTION AND FUNDING

The center includes nearly 30 senior research faculty, most of whom are individually funded primarily by grants other than those from NSF for the STC program. Faculty are from plant and animal biology, and medical schools, and are from the University of Virginia, Northwestern University, Rockefeller University, and Brandeis University. Recently faculty from engineering departments have become involved. In addition, research and industrial fellows, graduate and undergraduate students, and high school teachers involved in summer research programs contribute to research. In addition to providing interdisciplinary research for principal investigators, the center provides opportunities for students in university departments the opportunity to work in labs in other areas.

The center has administrative and technical space in newly renovated space provided by the University of Virginia on its campus. However, the center "owns" a very small amount of lab space and specialized equipment. Use of lab space in university departments facilitates center integration into the total university program.

The center director and associate director are assisted in general center coordination and priority setting by a steering committee composed of eleven center members which meets monthly to discuss research progress and priorities. An external advisory

committee composed of persons from industry, medical schools, and other institutions meets annually. The committee assesses the center plans for projects and use of resources. Together, these groups specify the mission, goals, and specific objectives of the center based on collegial assessment of research progress and needs. (see Exhibit F-2.)

NSF oversight has involved annual visits by the technical coordinator and peer reviewers and an in-depth peer review in 1993. In addition to support in completing documents, developing budgets, and obtaining funding, the technical coordinator visits the center annually and comments on needed improvements. The peer-review process, as designed by OSTI, was based on standards for evaluation designed by center personnel in cooperation with OSTI and the technical coordinator. The center presented written materials on its research efforts and results, as well as on funding, university support, and knowledge transfer and outreach programs, to members of the peer-review team. After written comments on this presentation, the peer review team visited the center and interviewed center members. The focus of the peer review is on the quality of the science. The research at the Center for Biological Timing was assessed as essential, innovative, basic-research. As a result, funding has been continued through the second three-year cycle, with some suggested program revisions.

NSF Science and Technology Center funding has been supplemented by additional grants from NSF, the university, and private sources. In addition, the university has supplied in-kind support in the form of space, accounting assistance, and faculty salaries. (See Exhibit F-3.)

EXHIBIT F-2: CENTER INCOME AND EXPENDITURES

(In thousands of dollars)

	1991	1992	1993	1994	1995
Income:					
NSF STC	958	980	1,001	1,134	1,141
NSF (other)		215	390	429	143
University	460	500	490	368	150
Other		55	55	83	83
Total	1,418	1,750	1,936	2,013	1,517
Expenditures:					
Admin. & Renovation	490	707	845	595	214
Research	850	879	942	1,291	1,161
Outreach	95	153	120	134	122
Total	1,435	1,739	1,908	2,020	1,497

STC funding is used to support the salaries of nine full-time and one half-time persons. Three of the full time persons and the half time person are in administrative positions. One of these persons develops and manages the outreach program, including symposia, seminars, and opportunities to cooperate with local secondary schools. The research positions funded are primarily lab technicians.

MANAGEMENT HISTORY

At the Center for Biological Timing at the University of Virginia, the director characterizes himself as one who was chosen from among a collegial group for what was perceived as an "administrative position." The center has its roots in the Biodynamics Institute established in the Biology Department at the University of Virginia. Scientists there recognized the NSF STC funding as a possibility for gaining funding for research which they felt would link the Biology and Medical Departments. As related by the center director, other senior scientists, feeling burdened with administrative responsibilities, suggested that he become the center director. They viewed the director's role as one of complying with NSF's requests for information and completing budget forms.

In the beginning, center members viewed funds as being shared to supplement existing substantial individual research grants and to recruit needed expertise in specific areas to supplement their already strong departments. Center structure was extremely informal, with few scheduled meetings. Research continued as usual in the center with slowly growing collaborative efforts building trust. While building their own relationships, center members did not take seriously NSF's criteria that centers make definite efforts at developing educational and industrial outreach programs.

Program criteria require the center to host site visits by its external advisory committee and NSF technical coordinator and peer reviewers annually during the first years. Center members, confident they had been proceeding along the right track, were surprised by the first review. In the January 1992 review, NSF suggested significant management changes to evolve greater focus on a unified research program, broader participation by other universities, expansion of the external advisory board and management structure, and greater industrial and educational outreach. In May, the external advisory board met and confirmed NSF's principal suggestions and added the suggestion that the center leadership be strengthened by more active participation of the steering committee. The board judged the educational outreach to be excellent and recommended postponing efforts at industrial outreach until the center was more firmly established.

The center members considered the criticisms and suggestions of the two site-visits. One of the first steps taken was to develop a more formal structure for center governance. They recruited an assistant director and developed a structure and policies which they felt would be formal enough to ensure participation but still congruent with a collegial university atmosphere. They began to schedule regular steering committee meetings with advance notice, formal agendas and a policy for settling issues in those meetings by vote or consensus. The steering committee, along with other members rapidly undertook a restructuring of the research program. They developed the Clock Genome

Project as the center's unifying theme. The budget system was reorganized to one in which individuals propose project budgets and discussed and funding is allocated by the steering committee. The director implements the budgetary decisions of the steering committee.

The second NSF site-visit in January 1993 noted progress in management and budget, technology transfer, and educational outreach but noted that center outreach should be widened to include the areas of agriculture and human performance. Specific suggestions included the need to justify all projects in terms of center goals, to build connections on a national level, and to distinguish more clearly between center research and individual investigator research. The following July, the external advisory board confirmed the suggestions of NSF in the areas of distinguishing between center and other funding, and the need to make center elements available as national research tools.

Center members and the steering committee again met several times to determine steps to implement NSF and external advisory committee recommendations, as well as to make changes they had noted. They adopted the following implementation plans:

- Development of additional plans to distinguish center and other research;
- Development of national resources by publishing research results, providing a video tape library on research results, and adopting a policy on making mutant mice available to the research community to be used in further studies in the field;
- Recruitment of several female and minority center members;
- Recruitment of an agriculture representative to the external advisory board and rotation of membership; and
- Improvement of technology transfer by beginning a large scale study of shift work and worker safety in a steel mill, and by planning a symposium on agriculture.

With these and the first year implementations, steering committee members and the director felt they had addressed all major concerns. They had strengthened governance and administration, revamped research to a more coordinated focus, more fully included all participating institutions, and increased technology transfer and outreach. In addition, center members had begun to develop a very sound sense of community. Evidence of sharing of research results among projects which formerly had been competitive was beginning to be evident, and researchers were beginning to develop cooperative projects for which NSF funding could act as "seed" money for development until individual grants could be developed.

The August, 1993 site visit confirmed the successes of the center. Center management and leadership were deemed excellent. The major research projects were judged strong. educational outreach was also deemed excellent.

Management of the center remains very much in the hands of the steering committee with the director taking an increasingly active role in both leading by example, particularly in the areas of research collaboration and outreach, and in directing the deliberations of the steering committee by taking stronger control of the agenda. New concerns of the advisory board focus on increasing industrial outreach and perpetuation of the center research focus. This will require increasing the "marketing" role of the director and center members. The center director reports that center members have recently become active in developing strategies to continue their collaborative efforts after the 11-year NSF funding expires.

CONCLUSIONS

The center is characterized by simple, effective management and leadership, close collegial relationships among scientists which allow them to maintain strong identities as individual researchers while collaborating across disciplines, and effective ties to the university at which it is based, to the community, and to industry. Center funding, although not a large portion of the scientists' expenditures, provides a catalyst by which interactions among researchers provide fresh outlooks and an enjoyment of and enthusiasm about continuing enquiry.

Although it was not within the charge of the NAPA team to judge the quality of science practiced at the center, it appears that it is valuable, leading research in its field. According to the recommendation to the National Science Board based on the 1993 peer review, the center is characterized by activities that rapidly advance research in the field. In addition, most of the labs are primarily funded by other sources on the basis of the quality of science practiced.

MANAGEMENT AND LEADERSHIP

In designing the Science and Technology Centers program, NSF followed the recommendation of the Zare Report in allowing for a broad variety of management techniques. The management and leadership that have emerged in this center are appropriate for promoting the collegiality which results in stimulating research through exchange of scientific information. They also provide for systemic use of a management feedback loop to revise goals, programs and processes.

- **The center has defined goals which are narrowly defined in a manner appropriate to scientific research, but are broadly related to industrial safety and efficiency, agricultural productivity, and human health.**

Center goals are appropriate to long-term, basic research related to the study of timing phenomena in a few organisms. Center investigators work on a restricted set of issues related to the central theme of exploiting timing mutants at molecular, cellular, and systems levels. This narrow focus is appropriate to basic research on complex scientific phenomena.

Center scientists, however, have begun to identify and pursue much broader areas in which their findings may have applications in such areas as using biological timing information to increase industrial worker safety and production by identifying individuals' cycles and possibly altering them. Timing information could possibly be used to increase agricultural production. Timing information is also important in the medical fields dealing with hormone and enzyme cycles.

The center has begun to work with heavy industry to explore the relationship between timing factors and accident rates. Center research may provide information which can lead to identifying ways to reprogram biological clocks or to identify the specific points in the cycle at which individuals are during their work shifts. This could lead to techniques to reduce accident rates.

At this stage, center scientists are hesitant to specify even possible applications of their basic research to specific areas. Timing factors may ultimately apply to rates at which plants produce seed, or cycles of hormone production in humans. For example, once the gene affecting obesity in rats was identified, it was a simple matter to identify the similar gene in humans. Likewise, if the gene affecting the hormone production cycle in rats is identified, it could possibly also be identified in humans. That information could then be used in medical applications.

Although there is clearly enthusiasm for these applications among the researchers at the center, they are not stated as part of the center goals. The team believes that the different meanings of "goals" as defined by scientists and by managers complicates communication of the center's value. Clearer articulation of these application goals may be of benefit in explaining the value of the center to persons outside the research community.

- **The management structure is simple but systemic, providing for effective day-to-day management, longer range program planning, and dissemination of technical information.**

The day-to-day management structure is characterized by a decision making process based on the stated mission and goals and involving informal, collegial interaction on a regular basis. The steering committee, composed of principal investigators from all three institutions, meets monthly to exchange information on scientific work. Assessment of this information is part of the decision making process that allects allocation of resources and member responsibilities such as outreach lectures.

Concepts of management cycles, including goal setting, review, and feedback are evident in the evolution of this center from a small group of principal investigators to a cohesive organization. The annual site visits and external advisory board meetings provide regular opportunities for input from outside sources. This input has been used to revise center goals and strategies in areas of research focus, budget, personnel, policies, outreach, and linkages to other sectors.

- Research focus has changed from investigator to center, with the Clock Genome Project as its focus. An effort has been made to establish a clear distinction between center and non-center research.

- The budget system has been revamped to reflect center goals. Funding is used as a catalyst to promote collegial interactions or to continue research efforts beyond initial publishable results. This provides a sense of continuity in the research effort.

- An assistant director and several principal investigators have been recruited from outside of the university, to broaden the center's base. Particular attention has been given to recruitment of women and minorities.

- Policies for participation in center activities, site reviews, outreach, and coordination have been developed to create a more cohesive community.

- Outreach has been extended to include other universities and disciplines, industry, and elementary and secondary school students.

- Principal investigators have strong ties to National Institutes of Health, but the center has just begun to develop other linkages to the government sector. In addition, projects with industry are being increased.

Center personnel and the external advisory board have assessed suggestions from the peer reviews and have implemented them at a practical rate as the center grows. Some suggestions have not yet been implemented because they are of lower priority, according to center personnel, or because they do not contribute to achieving center goals.

Important to the management of scientific research is regular dissemination of research results, and discussion of difficulties and alternative solutions. Weekly discussion groups at which lab participants present the results of their research, symposia, and conferences provide frequent opportunities for center members and others to exchange scientific information.

- **Center leadership is excellent, and facilitates the goal of coordinating research across disciplines and institutions.**

The center leadership has inspired enthusiasm among center members, and a growing sense of community. The NAPA team noted specifically the interest among the scientists in others' projects as evidenced in spontaneous discussion, and apparent concern and respect for others as individuals. As a result, the center has recruited a number of scientists from several departments within the university and from other universities, some of whom have relocated to the University of Virginia.

Appropriate to the center concept, the leadership has been able to bring to the center members of diverse departments and research facilities to enable cross-discipline collaboration. Center membership includes both plant and animal biology researchers, as well as persons from medical research labs, mathematicians, and engineers who would not normally collaborate in departmental research settings. Graduate students are able to write dissertations on center research with committee members from several departments. For example, biology students carry out research in medical labs.

Center activities have reduced duplication of research from formerly competitive labs. The center director indicated his eagerness to share information from his research with another researcher in the field whom he formerly might have considered a competitor. In one case at a professional meeting, a joint paper was presented by labs from Rockefeller University and Brandeis University between which there had been a long-standing unfriendly competition.

Center members with no financial support from center funding report that they spend considerable time involved in activities because of the benefits they receive from collegial interaction. Scientists characterized their membership in the center as enriching and adding to enjoyment of their research.

THE CENTER CONCEPT

The Zare Report advised that centers be formed in cases where the complexity of the research or the size and complexity of equipment required such cooperative arrangements. In addition, it recommended that care be taken not to detract from funding individual researchers, or from the center activities dominating the work and decisions made by individual researchers. The Center for Biological Timing infrastructure provided by NSF funding at the university facilitates individual researchers' work, and acts as a catalyst enabling such things as travel for cooperative work, outreach and educational programs.

- **Center research and management are predominantly in the hands of scientists individually capable of good quality scientific research.**

Principal investigators, including the center director, involved in the center are individually funded by such entities as NIH. None is dependent on center funding for maintaining his or her programs. The team believes that this is an indication of their superior abilities as individual scientists.

Although center management and outreach activities do detract from their research time, members indicate that the collegial interactions which improve their capabilities as scientists outweigh that loss. The center director indicated that he is aware of the frustration that can occur among scientists when administration or outreach activities impinge on their research efforts. For this reason, meetings are kept to a minimum and interactions take place at professional symposia or conferences. Outreach and other responsibilities are distributed across all members.

- **The center is a loose association of component parts involving Northwestern University, Rockefeller University, and Brandeis University as well as the University of Virginia.**

A significant share of center funding is given to these partners. However, they are not merely contractors. Principal investigators from these institutions are involved in the steering committee meetings and decisions through telephone conference calls.

Although center personnel admit that this technique is not as effective for them as it would be to have these scientists present, it does allow them some input into regular decision making.

Although work is done in separate labs, considerable collaboration takes place between the institutions. This has resulted in removing duplication of efforts, allowing results from one lab to be used to "leapfrog" research to another level, and publication of a significant number of jointly developed articles.

- **Center funding provides a catalyst that promotes research through enabling interactions among scientists and providing basic risk funding for emerging projects.**

Center funding represents about 10% of the total funding for member scientists. NSF's funding is leveraged considerably with funding for about 9.5 persons, while nearly 30 principal investigators and their staffs participate. Center funding enables educational programs for participating scientists including visiting expert lectures, technology demonstrations, travel to symposia and professional associations. It also provides a central location and forum for member scientists to convene and share research results or problems.

As one center member noted, funding and other resources for research are often difficult to obtain unless there is indication that the researcher is able to do the work designed. Center funding enables some initial research in areas considered "risky", because the reputation of the center is one of an established "track record" of successful projects. In one case, center status has enabled a project to be developed for which there is no other source of funding, but which provides a valuable database that can be used to apply research to industrial questions. In other cases, scientists and engineers have joined the center to help develop the technological resources to support the primary research efforts.

There is currently a firm plan to continue the center beyond the eleventh year. There is some concern that, as the funding declines, enthusiasm for center activities may be difficult to sustain as the most talented scientists turn to pursuit of additional funding for their individual labs. Recently, however, center members have begun to explore opportunities for continued center-funding.

UNIVERSITY, COMMUNITY, AND INDUSTRIAL RELATIONSHIPS

Centers must be campus-based and have intellectual support of industry. The Center for Biological Timing has strong ties with the University of Virginia where it is located, and both the local and related research communities. It has begun to develop effective relationships with industry.

- **The center is well grounded in the university as manifested in the university's continuing financial and professional support, and assignment of space.**

During the first three years of center operation, university support totalled nearly $1.5 million. However, in 1995, university support decreased to $150,000. In addition, the university supplies considerable support in terms of lab and administrative space and administrative support.

As noted above, there is sufficient support within the related university departments for the center to allow dissertation committees to include members from several departments. The director works to assure that center members get recognition within their respective departments for center projects. The center has recruited members from university departments such as pharmacology, neuroscience and medicine in addition to biology, highlighting its integration into the university.

According to center members, in return for its support, the university receives significant visibility in the field. Eleven new faculty members have been recruited to the university through the center. The university is seen by outsiders as hosting excellent symposia and conferences. Local schools have close ties through outreach programs designed, in part, to recruit students at all levels.

- **The outreach program is excellent, providing information to the research community, research opportunities to undergraduates, post-graduate fellows, and high school teachers.**

The outreach program includes training for center scientists in technologies and related science. Programs for students include post-doctoral opportunities as well as summer research opportunities for undergraduates. It also includes programs which enable secondary school teachers to participate in center lab activities.

Both undergraduate students and high school teachers who had participated in the summer research-opportunities demonstrated enthusiasm for the program. The undergraduate students applauded the opportunity for students to participate in specific research and to hear on-going discussion of research going on in other labs. Two teachers explained that being involved in actual research has increased their enthusiasm for biology and their ability to sustain interest in lab activities among their students. Among other activities, center investigators devised a simple kit to be used in high school labs to demonstrate the luciferase transfer method developed at the center.

In addition, the center maintains a video library reporting its research. Several labs with interest in the field subscribe to the service, which increases interest and participation in center efforts by others and aids in transfer of technology developed at the center.

- **Industrial contacts are minimal, but effective.**

Beyond industrial representatives' membership on the external advisory board, industrial contacts are just beginning in this center. The safety project mentioned above is

being carried out using the database of a heavy-industry corporation. Although the research being conducted has the potential of saving the industry large sums of money, the center scientists value their access to the data and are not requesting funding from the industry for their work at this time.

In addition, the center has a partnership with another firm to design, test, and produce a kit to be used in high school classrooms for teaching the basics of genetic engineering. The kit will soon be tested throughout the United States.

RELATIONSHIP WITH NSF

- **Relations with NSF appear to facilitate effective growth of the center.**

During annual visits, the technical coordinator and peer reviewers give recommendations which are considered by the steering and external advisory committees. In the past, recommendations have resulted in changes in programs and priorities. Center members had high praise for the work of the technical coordinator in facilitating their progress, and in her responsiveness.

CENTER FOR MOLECULAR BIOTECHNOLOGY

University of Washington
Site Visit Report
January 9-10, 1995

The Center for Molecular Biotechnology is located primarily at the University of Washington. Additional center research is done at the California Institute of Technology. It was funded as an NSF Science and Technology Center in the first round of funding in 1989. Center research includes interdisciplinary collaborations among scientists from the areas of biology, applied physics, chemistry, computer science, engineering and mathematics, and the medical school. The center is closely related to the new Department of Molecular Biotechnology at the University of Washington and has active programs to commercialize its technologies, as well as an extensive program of outreach to K-12 schools.

The center is committed to the principle that biological research drives the need for new technologies, and the development of those technologies further pushes the frontiers of research. Based on this principle, the center goals are to:

- Pursue leading edge research to develop and apply new strategies, technology and instrumentation for the investigation of complex biological systems and networks;
- Assemble a group of world-class scientists that represents the technologies required to succeed in a multidisciplinary research program and to contribute to the first objective;
- Foster an interdisciplinary environment in research and education;
- Rapidly disseminate new technology and instrumentation to industry for commercialization and to academia and industry to enhance research capabilities; and
- Continue a vigorous K-12 outreach education program that will bring the excitement and challenges of science to local elementary, middle, and high schools.

MANAGEMENT HISTORY

Although the center has been funded as an NSF STC only since 1989, many of its principal investigators have been part of interdisciplinary technology development efforts related to biological research which began in the early 1970s at Caltech. The center director presents the history of the center as beginning with his interest in developing technology to facilitate the study of science. NSF funding became available for technology development at the Cancer Center in 1980 and throughout the next decade it was involved in the development of numerous instruments and technologies, many of which have been successfully marketed.

When the competition for STC funding began in the late 1980s, some of these collaborating scientists saw the center concept as "made for us." In 1989, the group received NSF funding as an STC. They were aware that they fit the criteria of interdisciplinary and had close ties with industry. Under NSF STC funding, however, educational outreach was also a required activity of a center. The center director led the center in developing an outreach program for special summer-opportunities for local secondary students and teachers.

In 1992, the director lead the effort to move the center. After discussion with center members and an offer of considerable support from the University of Washington, discussions were begun with Caltech and NSF about moving the center. The director was offered a faculty position at the University of Washington, as were several other members. Caltech recognized Dr. Hood as a primary center-resource and agreed to the movement of the center. Many other center members also relocated to the University of Washington. Some funding and center activity has remained at Caltech.

Within the center, the director delegates responsibility for oversight of the various projects and activities, and is assisted in decision making by the executive committee, while he represents the center to the outside. He has developed close ties to several sources of funding, ranging from institutions, to wealthy individuals, to political entities. He is active in developing political opportunities for advancing the center's vision and has developed a vision for the future including research in areas related to cancer and AIDS. With the encouragement of the university administration, he has begun an endowment fund for the center based on royalties from technologies he has developed. He hopes to encourage other center members to do likewise. The provost of the University of Washington has made a commitment that the university will continue to support the center after NSF funding ceases.

In 1992, the center moved to the University of Washington, leaving a few principal investigators at Caltech, which is now considered the second node of the center. The purpose of the move was to broaden opportunities for interdisciplinary collaborations by both students and faculty. It is the center director's intention to seek funding to enable the center to continue beyond the end of the NSF STC grant in 2000. This can be done through competition in subsequent STC competitions, or through other federal, state, or private funding sources.

CENTER ACTIVITIES

Based on its goals, the Center for Molecular Biotechnology has research efforts in five major areas. These are aimed at development and application of technology for:

- Identification of components of complex biological systems at the protein and DNA level;
- Characterization of protein components at the primary-structure level, including secondary modifications;

- Investigation of the 3D structure, the function and functional interrelation of systems components;
- Investigation of the plasticity and variability of biological systems; and
- Computation for acquiring, storing, analyzing, modeling, and disseminating data accumulated in complex systems.

Many center technologies are transferred to the medical-research community. It is center personnel's conviction that the future course of medicine will be based on preventative therapies designed around the genetic characteristics whose study is made possible by center activities. Collaborations include research in the area of AIDS, cancer biology, signal transduction, autoimmunity, and sea urchin development.

Center technologies have also been transferred to industry through continuing interaction with companies that have spun off from collaborations both before and since STC funding. In addition, a number of instruments and computational tools have been commercialized by established companies.

The center's education and outreach programs reach from post-doctoral studies to K-12 schools. The University of Washington's new Department of Molecular Biotechnology has begun to accept interdisciplinary Ph.D. candidates as well as post-doctoral students from a wide variety of fields. The center has purchased kits for use in elementary schools and center researchers train teachers to use them. In addition, center personnel are involved in designing and facilitating research experiences and lectures for middle and high school students and teachers.

CENTER DESCRIPTION AND FUNDING

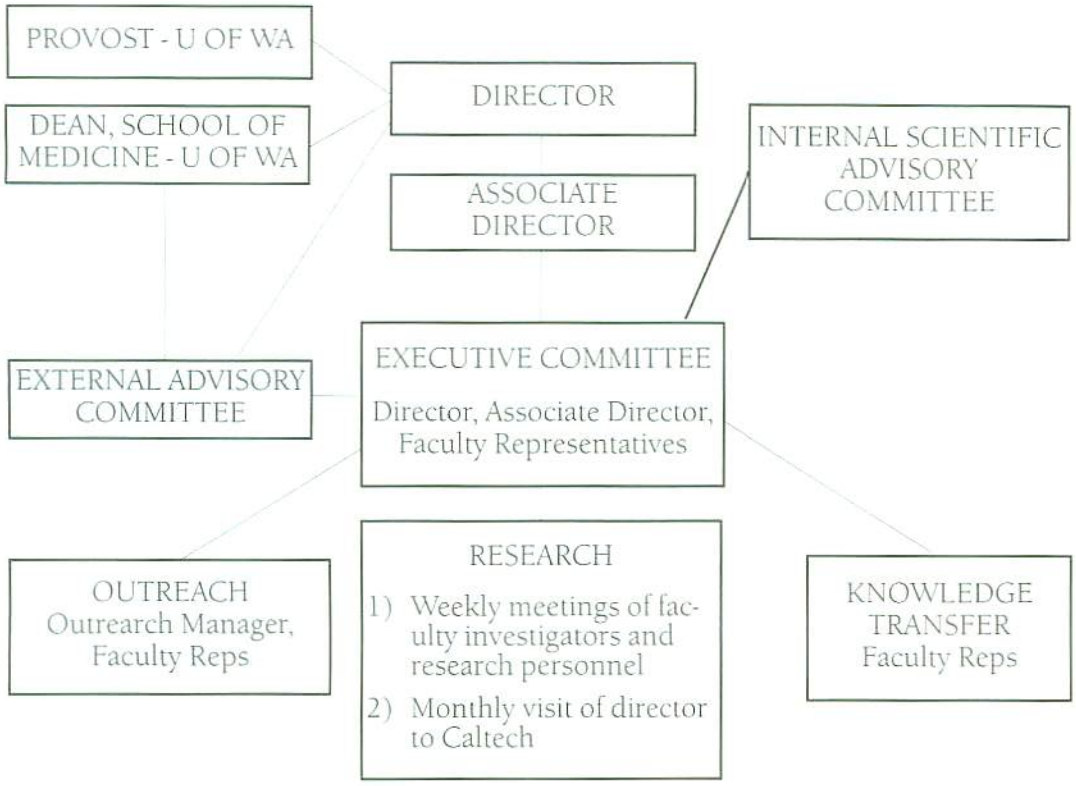
The center includes eight senior research-faculty, most of whom are funded at least in part by individual grants other than NSF's STC funding. Faculty are from the areas of biology, applied physics, chemistry, computer science, mathematics, and the medical school, and are located at both Caltech and the University of Washington, In addition, graduate and undergraduate students, and visiting faculty and industrial investigators contribute to center research efforts.

The center has administrative and technical space on both campuses. Rather than being disbursed throughout several departments, center members work in labs dedicated to center activities. Current space provided on the University of Washington campus was one of the inducements for the center's change of location. New space is being constructed at the University of Washington which will house the center, the Department of Molecular Biotechnology, and key members of the Departments of Medicine, Microbiology, and Structural Biology. The center owns a variety of costly equipment, including a mass spectrometer, purchased largely from university and private funds.

The center director and assistant director, along with four other center members who form the executive committee are largely responsible for both day to day center man-

agement and long term planning. They are assisted by the internal advisory committee composed of persons from several different departments at the University of Washington. An external advisory committee with members from academia and industry meets annually to give advice on center programs and goals, and to further acquaint center members with developments in the field which may affect their work. (See Exhibit F-3.)

EXHIBIT F-3: CENTER MANAGEMENT ORGANIZATION



SOURCE: Center for Molecular Biotechnology

NSF oversight involves annual site visits (every 18 months after the third year) by the technical coordinator from the Biological Sciences Directorate and peers, and full peer-reviews at the end of the center's third and sixth years. In addition to support in completing documents, developing budgets, and obtaining funding, the technical coordinator may annually suggest needed improvements. The peer-review process, as designed by OSTI, was based on program regulation standards for evaluation designed by center personnel that can be changed as developments at the center or in the field of biology lead to changes in projects and focus. The center presented written materials on its research efforts and results, as well as on funding, university support, and outreach programs to members of the peer-review team. After written comments on this presentation, the peer review teams visited the center and interviewed center members.

The focus of the peer review is the quality of the science practiced at the center, as well as knowledge transfer to industry, educational outreach, and management.

A special peer review was required at the time of the center's move from California to Washington. The report noted that the move would strengthen center management, and supported research in the areas of 2D gel electrophoresis, protein chemistry, and mass spectrometry areas. The promise of faculty positions at the University of Washington for senior researchers also met a concern of earlier reviews at Caltech that too many center researchers were not faculty members.

NSF funding is a small portion of the center funding. It is supplemented by funds from the university, additional government sources, and private sources. About $250,000 annual income from an endowment based on funds derived from the sale of center technologies also contributes to center funding. In addition, the university has supplied in-kind support in the form of space and faculty salaries. (See Exhibit F-4.) The University of Washington supplied $430,000 in one-time funding for the cost of moving the center.

NSF center funding is used to support the salaries of some of the research staff and of outreach and administrative staff. Specific outreach projects are funded by private sources, such as the Keck Foundation.

EXHIBIT F-4: CENTER INCOME AND EXPENDITURES

Annual Averages
(In Thousands of Dollars)

	1989-1991	1992-1994	1995-1997	1998-1999
Income				
NSF STC	10,050	10,457	10,786	5,372
NSF (other)		53	90	
University	450	25,431	2,582	1,388
Royalties	122	545	Unknown	Unknown
Other	8,644	23,065	2,545	445
Total	19,266	59,552	16,004	7,205
Expenditures				
Administrative	149	165	173	86
Research	9,836	10,192	10,200	5,079
Outreach	65	100	413	206
Total	10,050	10,458	10,787	5,372

SOURCE: Center for Molecular Biotechnology

CONCLUSIONS

The center is characterized by a dynamic and experienced leader with a simple but effective management structure. Scientists who are expert in specific areas have close collaborative relationships and are encouraged to seek expertise in a variety of other areas. While the center has ties to the institution in which it is based, it has demonstrated that it can be moved to another institution and maintain its identity. Center funding, although not a large portion of the scientists' expenditures, provides a catalyst by which interactions among researchers provide the opportunity to initiate new research, and to maintain a broad-based community outreach program.

Although it was not within the charge of the NAPA team to judge the quality of science practiced at the center, previous site visitors and other familiar with the field have judged that it is leading research and technology development in its field. In addition, by training post-doctoral students and by initiating an interdisciplinary Ph.D., the center is helping to promote a collaborative culture in scientific research.

MANAGEMENT AND LEADERSHIP

The management and leadership that have emerged at this center are appropriate for a long-standing effort at developing interdisciplinary relationships and fostering interdisciplinary technical expertise, as well as superior technical abilities in specific fields. They provide for systemic use of goals and dual feedback-loops on both program structure and scientific developments which affect program focus.

- **Research goals at the center are highly utilitarian, resulting in production of commercial technologies and graduates prepared for jobs in industry.**

As noted above, an important factor in center philosophy is the force of research to drive technology development and technology to push the frontiers of research, and the importance of supplying advanced techniques to the general research community. Center work is based on advances within the center and in the field of science in general, as well as on basic societal or national goals. Center advances can have important implications for medical research and practice. Genetic research has important implications in such areas as AIDS and cancer, and in possible future therapeutic medical practices.

Since 1990, the center has developed a number of technologies that have subsequently been transferred to industry. There include automated DNA sequencer reactions, hexagonal array pulse field electrophoreter, DNA sequence Gel Loader, Mass Spectrum Computer Data Analysis, software, and novel electrophoresis matrices. In addition, several other technologies in DNA mapping and sequencing are currently being developed.

In addition to developing new technologies and computational methods, the center embraces new technologies developed outside as part of its continuing progress. An example is the mass spectrometry technology. The center has recently added this tech-

nology to its program because of its far reaching effects on the ways in which genetic information can be studied.

The center director noted that, in a time when academic positions are difficult to obtain, all of the center students are able to find jobs. The utilitarian nature of the center research prepares students well for positions in industry.

- **The center revolves around one individual who drives and acts as a spokesperson for center goals and as a catalyst for center activities.**

The center director has more than twenty years' experience in promoting interdisciplinary development in the field of biology, largely relating to technology development. He creates the vision and is a major source of new ideas. As a major figure in his field, he is able to attract expertise and funding for a wide variety of projects which have current or near future applications.

Although center members are established scientists in their own field, the center has attracted a number of individuals who are interested in developing their abilities in areas other than their current areas of expertise. In several cases, such individuals interviewed by the NAPA team indicated that they were at the center because of the director.

The center director is seen as personally encouraging scientists to startup projects under the center umbrella until they are well developed and able to attract individual funding. In other cases, he is seen as having acquired, through center contacts, equipment or resources necessary to support promising center-related research in order to attract individuals with specific expertise to the center.

- **The management structure is simple but systemic, providing for effective day-to-day management, and research and program planning.**

Center management depends on feedback from several sources, including scientific community data on research needs, funding sources, and the various management entities within the center. This feedback provides a basis for changes in center goals and activities based on current needs and attitudes both within and outside of the center. Assessment of this information is part of the decision-making process that impacts allocation of resources and member responsibilities. The center has a long history of collegial interaction that enables an approach to review and revision which is largely informal except in NSF-mandated peer reviews.

The center director, assistant director, and two principal investigators comprise the executive committee which oversees the progress of research, sets center goals and priorities, and allocates resources. This structure has evolved, in part, because of the suggestion of the external advisory committee and NSF peer review to develop such a committee to assist the director. The position of assistant director was added as a response to the peer review required at the time when the center moved. Previously, the center director was the primary decision-maker in such important areas as the decision to change the center's location. He was viewed as "taking care of his people."

In some cases, most of the center's members are involved in program decisions. For example, center members were all involved in a brainstorming session used to design outreach programs in the Seattle area soon after the center moved there from California. After their program preferences were known, various center members took responsibility for designing and administering the various outreach program areas, with organization being provided by the outreach coordinator. As a result, outreach was extended to include middle and secondary schools.

In other cases, individual investigators or groups of investigators develop plans for new center research projects based on developments in the field or on the fact that current research is ready to be passed on to the commercial market. The external advisory board, which includes persons in related industries, provides input on program focus and available funding from the field. The internal advisory board, composed of persons from several university departments, also provides input on university resources and expertise related to specific projects. These data are used to assess project proposals.

Research results are disseminated to other center members through informal contacts. The center director is the liaison between the University of Washington and Caltech, commuting to the Caltech campus a few days per month.

- **Center management, especially the director, has begun to project a vision and seek support for the very long-term extension of center activities.**

Since the STC program is clearly designed to terminate funding to individual centers after the eleventh year, this six-year center has begun to look toward the future. The director noted the importance of reconstituting the center around new goals as progress is made toward current goals. He explained his vision of the future as including three possible applications of center programs:

1. Continued application of the Human Genome Project to revolutionize medicine to a more preventative approach;

2. Development of a new approach to studying the cancer of solid tumors; and

3. Application of techniques to study signal transduction and autoimmunity.

The director indicated concern for the long-term management of the center, indicating the need to continue to develop second-level leadership. In addition, he noted that a suitable source of funding would have to be developed. He has considered or is pursuing several sources of such funding such as: renewed NSF competition, university commitment to continue center funding, and endowments from private sources. At the suggestion of the university administration, he has contributed his royalties from commercialization to add to center funding and is encouraging other faculty members to contribute as well.

THE CENTER CONCEPT

The Zare Report advised that centers be formed in cases where the complexity of the research or the size and complexity of equipment required cooperative agreements. In addition, it recommended that care be taken not to detract from funding individual researchers, and that center activities should not dominate the work and decisions made by individual researchers. The Center for Molecular Biotechnology, however, was structured largely as an interdisciplinary effort based on the needs of developing technologies long before NSF STC funding was designed. In a presentation on the history of the center, the center director described technology development along interdisciplinary lines twenty years ago as the basis of center development.

- **Center research and management is in the hands of scientists each capable of good research in their specific areas of expertise, but who are regularly involved in building interdisciplinary connections.**

Most center scientists are recognized experts in their own fields and have significant individual funding, which the team believes is an indicator of their superior abilities as individual scientists.

A primary part of center philosophy, however, is building the capacity for interdisciplinary research and encouraging expert scientists to broaden their expertise beyond narrow disciplinary boundaries. Reflecting this philosophy, researchers are encouraged to develop projects and seek funding in interdisciplinary research and to expand their individual expertise beyond the boundaries of one discipline. Thus, the center management seeks to develop leadership in a paradigm of scientific research that includes both interdisciplinary as well as individual research.

A number of individuals have sought out participation in center activities either because they recognized their expertise to be too narrow to work on a specific problem they had identified, or simply because they were seeking a change. One of these individuals, on a sabbatical from another university, noted that his participation in work in another field could have negative effects on a long-term project on which he works at his home university. He was enthusiastic, however, about the overall positive effects of the interdisciplinary work on his development as a researcher. It is his intention to foster additional interdisciplinary work when he returns to his home institution. The center director has offered to help him initiate such work through contacts with his university administration.

Center members follow the leadership's example in devoting time to educational applications within the center, such as supporting graduate and post-doctoral researchers, and in outreach programs. A number of center members noted the personal satisfaction they received from these efforts as being worth the time they lost in their individual research projects. They do not feel that either extending their knowledge boundaries or spending time and resources on education and outreach projects impede their growth or productivity as scientists.

- **Center collaboration is the result of long-term commitment to interdisciplinary research and technology development, and continuing recruitment of scientific expertise needed to respond to new needs in the field.**

Central to the center philosophy is the belief that research drives the development of new technologies, which in turn drives more advanced research. Technology development, even though it is geared to biological research, requires expertise in a wide variety of fields including applied physics, chemistry, computer science, mathematics, and engineering. Although some of the work is done in labs within these other departments, center laboratory facilities encourage close collaborations among researchers from these fields.

- **The association between the center at the University of Washington and Caltech is based on individual investigators' relationships.**

At the time that the center moved from Caltech, the technical coordinator, based on the peer review, commented:

> The continuation of activities at the California Institute of Technology until 1994 is logical with respect to the scientific activities of the center and will minimize disruptive effects of the move on the scientific programs. The management arrangements include adequate provision for direction and coordination of staff at the two institutions....Some of the staff remaining at the California Institute of Technology may elect to move. During the interval appropriate replacements for those who do not move may be recruited. (April 16, 1992)

Subsequently, research projects located at the California location have been continued, with periodic visits from the director, who participates in the sea-urchin project. Caltech is now funded as a subcontract of the University of Washington STC funding.

- **Center funding provides a catalyst that promotes research through enabling interactions among scientists based on shared instruments and facilities, providing basic risk funding for emerging projects, and enabling educational and outreach programs.**

NSF's funding is substantially leveraged by center scientists' individual funding, and funding to the center from other sources. As reported by center staff, NSF funding represented less than half of total center funding from 1989-1994. In addition, center members have significantly more individual funding for specific research projects.

Center funding facilitates the purchase of a large variety of equipment shared in common center laboratory facilities. It also provides time for center members to develop and participate in education and outreach programs. Center staff note, however, outreach materials, participant stipends, and other costs of outreach programs are covered by additional grants.

Some center funding provides "seed" money or "venture capital" for investigators to initiate projects. Scientists are expected to develop the projects rapidly until private or government funding is available. This is seen as a particularly valuable asset for younger

researchers in building a record of scientific achievement. It is also valuable in a scientific environment in which funding for interdisciplinary projects is limited.

UNIVERSITY, COMMUNITY, AND INDUSTRIAL RELATIONSHIPS

Centers must be campus-based and have intellectual support of industry. The Center for Molecular Biotechnology is an individual entity located largely within the University of Washington, with strong ties to the university through the related Department of Molecular Biotechnology. It also has strong ties to industry, largely through companies marketing spin-off technologies, and to the community through its extensive outreach programs.

- **The University of Washington provided facilities and other support to encourage the center to move to its campus, and continues to expand such support, grounding the center more heavily in Washington than it was in California.**

Caltech supplies space in the Beckman Center and an annual amount to cover the cost of administration and a fellowship. When the center was at Caltech, center researchers were not part of the regular academic faculty and interdisciplinary majors were not available to students.

At the time of the move from California, the University of Washington paid moving expenses of $430,000, and supplied 16,000 square feet of laboratory and administrative space. In addition, new facilities are under construction that are expected to cost the university over $9 million. On a continuing basis, the university will provide $500,000 per year and four faculty salaries to the center. Center researchers are faculty members and can seek tenure.

In addition, the University has established the Department of Molecular Biotechnology with the center director as chair. In process is the establishment of an interdisciplinary Ph.D. program. Elements of this program include:

- A core course in molecular biotechnology integrating the principles of genomics, protein chemistry, and computation and instrumentation;
- Laboratory rotations to work with faculty representing diverse research interests;
- Individualized programs of course work to assure interdisciplinary formal training; and
- Dual mentorship of graduate students involving department faculty and faculty from a different department with expertise in the area of thesis research.

In return, the University of Washington has recruited top scientists in several fields and has received considerable recognition for the program. In addition, the University

receives funds as a result of the center's income from other sources. The center has been instrumental in building community relationships. The center director plans to use his community contacts to bring attention to the danger that recent state budget initiatives imperil funding to higher education institutions.

The NAPA team noted, however, that the center is an entity of itself. Although current integration within the institution is an important center characteristic, NSF did not oppose the center's relocation to Washington from California. Allegiance to the University of Washington is high, but if another university were to offer the center significantly greater support there is a remote possibility that center members could again choose to move.

- **The outreach program is excellent, providing information to the research community, research opportunities to high school, undergraduate, graduate, and post graduate students, and high school teachers, and support in teaching science for K-12.**

The center director noted that it is the duty of scientists to make their research and technologies available to others, thus transferring and expanding knowledge in the research community. Center members publish frequently and often join in collaborations. Such collaborations outside of the center are carried on in the areas of microbiology,urology, genetics, immunology, structural biology, chemistry, bioengineering,biochemistry, and computer science in the Seattle area. In addition, the center sponsors workshops such as the one in November 1994 entitled "Biotechnology for Scientists and Engineers" for non-biologists interested in or working on biotechnology.

The center fosters outreach programs for K-12 in both the Los Angeles and Seattle areas. In Los Angeles, the center sponsors one week-summer institutes for teachers and kits which can be used in their classrooms. In Seattle, the outreach programs spanning elementary, middle and high schools include:

- Elementary: Provides commercially produced, hands-on kits for teachers and parents and workshops on using them; and presents a pre-service course for teachers including hands-on experiments. The center is also participating in obtaining an NSF grant for a local initiative to train and provide equipment and support to K-5 science teachers.

- Middle: Provides a nine-day summer-institute for teacher/scientist collaborations; and participates in design, construction, and testing of interdisciplinary science modules and classroom tool kits.

- High: Designed and is implementing a pilot program to involve high school students in a project-mapping, and sequencing the human genome.

One high school student involved in a summer program has started a science club at his school that involves a large number of students who will be designing and delivering science workshops to elementary students with the help of center scientists.

- **The center has close contacts with industry and has spun off a number of center developed technologies into commercial ventures.**

The director has continuing collaborations with many of the nine biotechnology companies for which he has facilitated start-up. These companies focus on instrumentation, biological computation, genetic engineering, immunology, stem cells, and genomic/combinatorial chemistry. In addition, the center has a wide variety of collaborations with companies who use center technology or supply instruments to it. Many of these are world leaders, contributing to U. S. international competitiveness and to employment.

Industrial members of the external advisory board value the center's contributions. Membership enables them to influence to some extent research in the field and to benefit early from new discoveries.

RELATIONSHIP WITH NSF

Relations with NSF appear to have facilitated the growth of the center. Although center members collaborated prior to the 1989 NSF funding, they note that the outreach program is a direct result of the STC program requirement for outreach activities.

Annual visits of the technical coordinator and the suggestions of peer review teams, and the external advisory board required in the STC program have contributed to center structure and research focus.

Center members noted that NSF took a neutral stance in discussions about the center's move from California to Washington. However, after the decision to move was made, NSF reported that it was supportive of the move because of expected management and research focus improvements which were to result from the new environment.

CENTER FOR RESEARCH ON PARALLEL COMPUTATION

Rice University
Houston, Texas
Site Visit Report
January 12-13, 1995

The Center for Research on Parallel Computation links researchers at six institutions: Rice University, California Institute of Technology, The University of Tennessee, Syracuse University, Argonne National Laboratory, and Los Alamos National Laboratory. It was funded as part of the first round of National Science Foundation Science and Technology Centers in 1989. Researchers from the areas of computer science, applied mathematics, and a variety of science and engineering fields participate. The center's purpose is to develop a knowledge base and technology to make parallel computing truly useable.

Center research focuses on development in five areas: programming, integration, complex linear equations, optimization problems, and algorithms for physical simulations. Research results are disseminated to industry through a variety of public mechanisms, with software remaining in the public domain. The center has diverse outreach and education programs including curriculum development and faculty training for other institutions, undergraduate and graduate interdisciplinary courses, research opportunities for students, awareness and computing workshops for K-12 teachers, and curriculum development in Rice's K-8 school.

MANAGEMENT HISTORY

Although the center is distributed over several institutions, the director, with the help of the external advisory board has, established a unified approach to research, and strong central management.

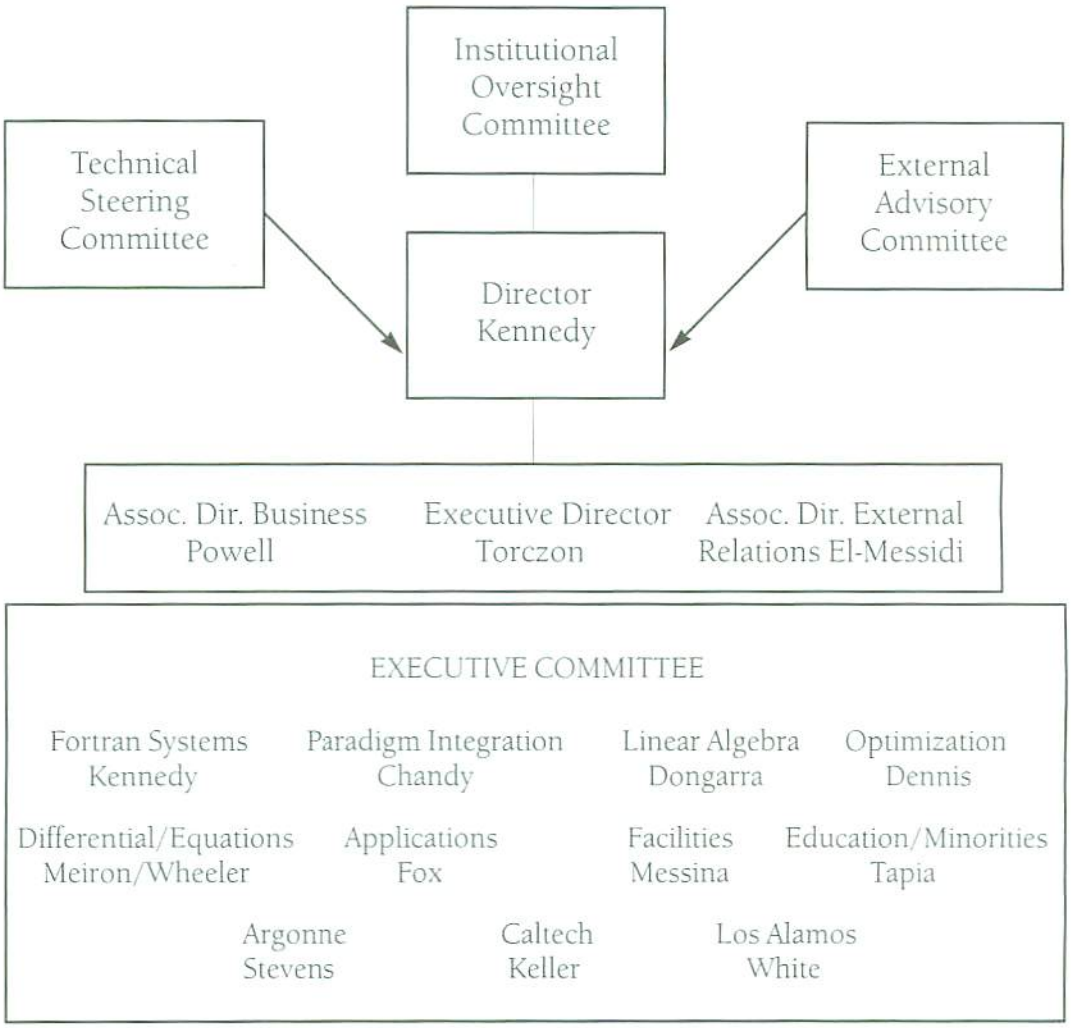
Originally, similar grants were proposed by Rice and Caltech. NSF encouraged those institutions to combine their proposal, and funded the project to the two universities and the national labs. During the first year, management was by the institutional oversight committee representing those four entities. The committee included provosts from the universities. Inconsistencies and inefficiencies in governance made management difficult for the center director.

Change came as the result of disputes that arose when one key center member moved to the University of Tennessee. The center director, recognizing this member's key role, decided to move some of the center funding with him to Tennessee. Members of the institutional oversight committee, however, feeling that the funding was by institution rather than by research issues, refused to allow the transfer.

The external advisory board addressed the question and advised the institutional oversight committee to allow the center director to strengthen his role, and to approach the center as issue-based, rather than as institution-based. After considerable debate, the committee agreed. Some of the funding was transferred to Tennessee, although all of the

original institutions remained participants. Later, a similar move of a faculty member to Syracuse was dealt with in the same manner. (See Exhibit F-5.)

EXHIBIT F-5: CENTER MANAGEMENT ORGANIZATION



SOURCE: CRPC

Although the institutional oversight committee still has a presence and represents the interests of the various institutions, the center director now takes the lead in management issues. He works with center members as colleagues and communicates with members at different locations through e-mail, teleconferences, and video conferences, but maintains a leadership position in decisions about center issues such as research funding, outreach activities,and equipment purchase. (See Exhibit F-5.)

CENTER ACTIVITIES

Center activities are designed to meet needs identified as barriers to the acceptance of parallel computing in science and engineering fields. Specific current projects include:

- The Parallel Programming Group is developing language extensions, compilers, and programming tools which can be used to write parallel code more easily at the Fortran level.
- The Parallel Paradigm Integration Group is developing language extensions, methods, and theories and implementing tools to integrate distributed computing with parallel scientific computing.
- The Linear Algebra Group has developed an extensive library of routines to solve several major problems in linear algebra on hardware, and is continuing development of templates for iterative solution methods which can be incorporated into numerical simulation models.
- The Parallel Optimization and Automatic Differentiation Group is developing parallel algorithms for a broad range of numerical optimization problems.
- The Parallel Algorithms for Physical Simulation Group is developing algorithms and software to facilitate the efficient parallel simulation of physical systems.

The center's outreach and education programs range from post-doctoral research projects to kindergarten. Center personnel are active in designing curriculum and training faculty for minority colleges in the Southwest. Center members have developed interdisciplinary courses at their institutions, and provide summer research opportunities to undergraduate students. Teachers from local K-12 schools attend seminars on opportunities for students in computer science and mathematics as well as graduate work in applied mathematics. The program concentrates on feeder patterns of schools, assuring reaching teachers of all levels in a given area. Center personnel feel they reach the maximum number of students through their teachers. Center members have been active in designing curriculum for Rice's experimental school for K-8. All outreach programs give special emphasis to involving minorities and women in mathematics and science.

The center is active in helping industry gain the advantages of parallel computation. Industrial affiliates are active in designing center goals and have the benefit of early information on new developments. A large variety of public domain software has been developed and some items have been commercialized by businesses which have added enhancements and support systems. The center participates directly in Texas geoscience research and grand challenge applications. Symposia and seminars are delivered to scientists, mathematicians, and engineers from industry on recent developments and barriers to parallel computation encountered in industrial practice.

CENTER DESCRIPTION AND FUNDING

The center includes 27 research faculty from the areas of computer science, mathematics, science and engineering. Based on proposals from Rice and Caltech, which the National Science Foundation recommended be combined, the center began representing four institutions: Rice, Caltech, Argonne, and Los Alamos National Laboratories. When principal researchers moved to Syracuse and University of Tennessee, those institutions were added. Subsequently, outreach and education programs were also expanded to those institutions. Recently, the University of Maryland and the University of Illinois have been added as affiliate institutions because of their special interest and expertise in specific areas of center research.

All member institutions provide space and equipment to center activities. The center has administrative and technical space at Rice University as its principal home. A large space is being constructed to house the center and the Department of Computer Science. Its design takes into account the need for interdisciplinary space and areas in which to provide industrial and community outreach programs. Critical to center operations is the use of a variety of computers available at member institutions and labs and at Oak Ridge National Laboratory in Tennessee. Computer time is also available on equipment belonging to industrial affiliates.

The center director is assisted by an executive director, associate director for business and associate director for external relations in providing day to day operations management. (See Exhibit F-6.) In long-term planning an executive committee helps the director identify some problems and allocate resources to solve some of the problems which the computer world faces. The institutional oversight committee represents the interests of the center's principal institutions in defining these problems. An additional perspective is given by the industrial advisory board. Specific projects to address the problems are designed by individual researchers and presented to the committees for consideration. The facilities committee plays an important prioritizing and scheduling role because of the distribution of computers at several locations.

NSF oversight has played an important role in the nature of the CRPC since the time of the competition. After the original proposals were combined and awarded, the center was managed by consensus of the institutional oversight committee which had one person representing each of the member institutions: Rice, Caltech, Argonne and Los Alamos. As a result of the review at the end of the first year by NSF and the industrial advisory board, final decision making authority was concentrated in the hands of the center director.

Regular NSF oversight has involved annual visits by the technical coordinator from the Computer Information Science and Engineering Directorate and scientists (every 18 months after the third year), and in-depth peer reviews in 1991 and 1994. The technical coordinator provides information on budgets and NSF documents and other federal programs which may be related to CRPC's research. For the full peer-reviews, the center presented written materials on its research efforts and results, as well as on funding, university support, knowledge transfer to industry and outreach programs. After written

comments on this presentation, the peer-review team visited the center and interviewed center members. The result of both peer reviews was recommendation to the National Science Board for continued funding.

NSF STC funding represents only about one fourth of center cash receipts. (See Exhibit F-7.) In addition to reported cash receipts, university and industry supply significant in-kind support in terms of salaries, facilities, and computer time.

EXHIBIT F-7:

Total CRPC Income for Years 4-6/ Expenses for Year 7

(In thousands of dollars)

Income*

NSF STC	14,000
NSF (Other)	3,319
Federal	20,296
State	6,888
University & Labs	7,237
Industry	2,378
Total	**54,118**

**Total center-related income*

Projected Expenses for Year 7 Only (2/95-1/96)

Expenses**

Research	2,880
Administration	630
Outreach	420
Equip.	500
Facilities Support	500
Total	**4,930**

***Expenditures of NSF STC funding only*

SOURCE: CRPC

NSF funding supports initial work on new projects, outreach, and center administration. Considerable funding is involved in travel to meetings and symposia and other activities, partially because of the center's active participation with industry and in national standard setting bodies. Center members also have individual research grants to support work considered part of center activity.

CONCLUSIONS

The distributed nature of the center and its purpose of making parallel computing truly useable define its management and relationship to its various communities. The key asset of the center is the intellectual capacity of its members, combined with their ability and willingness to transfer their knowledge to the surrounding communities. Because of its distributed nature, the center's management and leadership are important to defining its direction and distributing its resources.

MANAGEMENT AND LEADERSHIP

Evidence of management feedback-cycles is found in this center in the strategic goals-set, changes made based on NSF and advisory board suggestions, a committee structure, long term planning, and use of performance indicators. On the other hand, a great deal of the direction and energy of the center are the result of the dynamic vision of the director.

- **Center goals, classified as "strategic", are appropriate for the field of computer science.**

Strategic goals are aimed at overcoming specific problems. According to NSF standards, strategic goals are basic because they produce new methods that can be used in a variety of ways to solve research problems. The center's goal of making parallel computing truly useable is closely related to national information superhighway goals. In particular, parallel computation is an area in which the center's contribution can make U. S. companies globally competitive. In addition, knowledge transfer and outreach programs will contribute to excellence to the next generation of computer applications designers and users.

- **The center director is a leader who inspires a high degree of trust.**

A number of center members worked together before the center was formed. The center director, beginning with this core, established opportunities for collegial interactions among them to provide input into decision making. These interactions are formalized in the meetings of the executive, institutional and facilities committees. Final decisions, however, are made by the director, who manages the center in a classic business-model.

The center director has frequent interactions with the industrial advisory committee. Many of the members of the committee have a long history of interaction with the director and appreciate his vision and leadership ability. Since a principal activity of center leadership is to identify barriers to parallel computing, input from industrial users of parallel computing techniques is crucial to the director's decision-making process.

- **The management structure is slightly more elaborate than other centers' management, but still with collegial collaboration rather than command-and-control.**

The distribution of center members across several institutions who may be working on the same project may necessitate formal interaction. As a result of reorganization after the first year, final decision-making became the function of the center director rather than the institutional committee. The executive, institutional, and facilities committees insure input from all institutions, even though the director and administrative offices are at Rice. The center takes advantage of electronic communications such as e-mail, telephone conferencing, and video conferencing to facilitate frequent interactions.

In addition to the committee structure and changes in management after the first year, there is evidence of a formal management-feedback system in the system which is part of the center's self-evaluation program. The evaluation criteria outlined by the center are similar to those currently used in some federal government agencies.

- **Center personnel believe the center should persist beyond the end of the current funding period and have begun to take action to find alternative funding.**

One of the challenges in the field is the rapid change in technologies. It is possible that in three to five years all of the obstacles to use of parallel computing outlined in the center proposal will be overcome. It is difficult in such a rapidly changing field to tell what additional research may be needed. Constant interchange with its industrial advisors and membership in standard setting organizations help to keep center members in touch with the needs of the field.

Center members have identified support for real applications including leadership in standardization, libraries, building new templates, and efforts to address impediments to performance in applications, capture and dissemination of software and knowledge, integration of research to attack problems with multiple themes, and coping with changing computer architecture as continuing challenges.

If NSF has an additional round of STC funding, the center is likely to submit a proposal based on the needs of the computing world at that time. If not, university and industry sources will be called upon to increase their already substantial support if the center is to persist. Individual researchers, of course, will be able to continue to get grants if STC funding ceases.

CENTER CONCEPT

In the case of the CRPC, the center mode of funding has allowed scientists to build a critical mass of expertise and to share critical equipment. The complexity of the research and the equipment required would make it difficult to accomplish this research individually. The time spent on center activities is compensated by gains in exposure to other scientists and to industry.

- **Center research and management are in the hands of scientists capable of good-quality scientific research.**

CRPC's director, executive director, and members are well respected in their scientific fields and in industry for their participation in the field of parallel computation. Top researchers are on the executive committee. The list of publications and software developed by center leaders and other members is extensive.

The center management is aware of the difficulties of keeping a research schedule when meetings and other center functions interfere. Management has arranged for as little disruption as possible to researchers' schedules by using electronic means of communication such as e-mail and video conferencing. Members' participation in standard setting bodies, however, is considered central to the purpose of the center even though it may interfere at time with research.

One particular example of balancing research with center activities was in the outreach program. One center member who is a world-recognized researcher is highly involved in outreach programs. In talking to him the NAPA team noted his commitment to outreach, while maintaining his research schedule.

- **Interactions in this distributed center are more between individuals than institutions.**

Although the center started as a collaboration among four institutions, two (Syracuse and the University of Tennessee) were added directly as a result of research faculty moving to them. In the case of Syracuse, an interdisciplinary course has been added to the curriculum, and the State of New York has been active in center support. However, it is not obvious that center support is institutionalized. The recent institutional affiliates have been added because of interested individuals at those institutions.

Unlike the close proximity that has been helpful to building a sense of community in some centers, shared computer facilities and electronic communications are the critical factors for this center. Institutional ownership of the facilities is their link. However, institutional power was severely curtailed after the first year when the institutional oversight committee was changed from a decision-making body to an advisory body.

- **NSF funding allows control over discretionary resources critical to the success of this highly complex project, and leverages substantial additional resources.**

Not including in-kind support from industry, the universities, and the labs, and individual researcher grants for center members, NSF STC funding represented only about 27% of total center funding for the years 1992-1994. Industrial, state and institutional funding is growing, so the NSF share is likely to be smaller for the next funding period.

Center personnel note the center funding allows a critical mass of researchers to work on programs including outreach and knowledge transfer that could not be handled with individual grants. This critical mass also aids in gaining visibility and bringing the CRPC's research into the mainstream. Work across a spectrum of disciplines has also contributed to acceptance of the center's work.

Critical to the success of the center in an area where technology changes very rapidly is the flexibility of the STC grant. Funds can be allotted to new projects without re-competing the contract; this allows rapid movement into critical fields. In one case, several active projects released funds to begin a new one. As a result, research was started in a timely fashion and eventually this new project was individually funded.

UNIVERSITY, COMMUNITY, AND INDUSTRY RELATIONSHIPS

Since the purpose of the center is to make parallel computing truly useable, exposure of the communities in which it operates to its research is important. The center is important in both community outreach and knowledge transfer to industry. Although it is an example of an intellectual community rather than a consortium of universities, the center enjoys support from its institutions.

- **The center is an example of a distributed center, consisting of a group of individuals from multiple sites so that the center is managing intellectual capacity. However, the institutions involved have invested in the center concept.**

Rice treats the center like an asset, building on its strengths. Although there was some concern in the Computer Science Department, of which the center director was head, that center funding would detract from individual or department funding, problems seem to have been worked out as the center prospered. The university is constructing a new facility, which will be totally debt free when complete, for the use of the center and the Department of Computer Science. Rice also provides substantial in-kind and cash support, partially in exchange for the visibility the school receives from center activities. Interdisciplinary courses are being offered to Rice students.

Caltech, which along with Rice represents 60% of the budget, also donates significant in-kind and cash to center activities. Syracuse University has developed an interdisciplinary computer science course, while the State of New York has supplied research and outreach funds.

The CRPC is an example of a distributed center, in which individuals stay constant so that the center is managing intellectual capacity. However, when one individual left Los Alamos to go to a university, the program was maintained at the lab by other individuals. In addition, computer equipment is key to its success. This equipment is housed at and often owned by the various institutions, securing their link with the center.

- **The center has demonstrated an investment in outreach with positive results in the community.**

Community outreach is a natural offshoot of the center's purpose to make parallel computing truly useable. The center has taken special care in its outreach programs to include minorities and women. Several students cited the personal mentorship of world class scientists as critical to their progress in the field.

Rice has made a commitment to helping to improve education in K-12 schools in the Houston area. Originally it offered summer research-opportunities for high school students. Center personnel decided they could reach many more students by training their teachers and began a dual approach: awareness workshops aimed at helping teachers understand opportunities and barriers in the field for students including minorities and women; and workshops in mathematics and computer skills. One local teacher described the benefits of faculty members' increased enthusiasm and skills.

In addition, Rice has been active in curriculum planning in the Rice demonstration school for K-8. In addition to improving the school's curriculum, one center member indicated an increased appreciation for and understanding of K-8 curriculum.

The center has also worked with minority colleges to improve mathematics, computer science, and science curricula. Citing the sensitive nature of the issues involved at minority colleges, center personnel noted the importance of training faculty from those institutions in recent developments in the field and helping in curriculum design.

In several locations, undergraduates have the opportunity of summer research institutes with center members. In Syracuse and Los Angeles, center members have led outreach to local minority students.

Outreach efforts account for expenditure of only about 10% of NSF funding expenditures and perhaps 20% of total funding expenditures. Additional outreach funding is also obtained from individual program resources.

- **The center facilitates effective knowledge transfer to and from industry.**

Industry knowledge-transfer is also a key to the center's purpose of making parallel computing useable, and is related to the goal of maintaining American competitiveness in the global market. To be able to solve current barriers to these goals, the center must be able to absorb information from industry as well as pass on results of their research. Key to this communication is the system of industrial affiliates in which companies pay $15,000 annually to receive early publication of research results and to participate in the annual conference presentations and contribute to research planning.

Research results are passed to industry by a variety of symposia, conferences, workshops, newsletters, publications, and on-line help. Recipients of this knowledge transfer are applied mathematicians, physicists, software and hardware engineers, and scientists from various fields.

In addition, the center produces a vast array of public-domain software. Rice's policy is for all software to be in the public domain, with licensing requirements being only that Rice will be held harmless in its use. It is common policy in the industry for software from academia to be without cost, while industry provides enhancements and support. Based on center developments, commercial enterprises have announced at least ten high-performance Fortran products recently.

As practical demonstrations of their research, center members are involved in several industrial projects. One such project is a simulation exercise mapping Galveston Bay with Texas Geosciences. Another is work with Boeing. Center members are involved in the Grand Challenges program in which participants seek solutions for a number of difficult problems such as optimization of airline scheduling.

THE CENTER FOR QUANTIZED ELECTRONIC STRUCTURES

University of California
Santa Barbara, California
Site Visit Report
February 6-7, 1995

Traditional methods for storage and retrieval of computerized data have aimed at development of smaller, denser devices, which may be reaching their size limits. Quantum structures, which can contain as few as ten to as many as 100 atoms, may provide the small structures necessary for the next step in data storage and transmission. Quantum structures, however, do not follow the traditional laws of physics. The Center for Quantized Electronic Structures (QUEST) involves researchers from the areas of physics, chemistry, and electrical and computer engineering at the University of California at Santa Barbara and at Notre Dame University in developing a science of quantum structures. The center was funded as part of the first round of National Science Foundation Science and Technology Centers in 1989. This center is the only place in the United States in which quantum structures are being studied in this way, while Japan has funded a large effort in this direction within its universities.

The center includes a number of well-known scientists developed collegial relationships and a culture of sharing unique equipment and instruments while working in the areas of fabricating quantum structures and studying their properties. Although research results may not be developed enough to be commercialized within the next five years, the center maintains collegial relationships with industry. The center also fosters a number of outreach and education programs including research opportunities for graduate, undergraduate, and high school students, and for high school teachers. Center staff have developed devices and helped teachers plan curricula for study of electronic circuitry for elementary, middle, and high school students.

MANAGEMENT HISTORY

In the summer of 1994, the center director at the Center for Quantized Electronic Structures at the University of California at Santa Barbara retired and a new center director was appointed with the full support of the executive committee and other center members. Although the management styles of the old and new directors are somewhat different, the transition has been a harmonious one. Since the vision and direction of the center director are important to molding center characteristics, this time of transition is particularly important.

NSF funding for QUEST as an STC began in 1989, but it has a long history of earlier collaborative efforts. The spirit of the center actually began two decades ago when UCSB began expanding its faculty with the addition of several researchers from Bell Labs. A group of faculty developed, whose vision was to go beyond current technologies in communication. As a result of that vision and his industrial experience, the first director recognized the importance of interdisciplinary, collaborative research. His management skills mirrored his experience at Bell Labs, with a high degree of collaboration, but final decisions made by the leader.

Santa Barbara was a particularly good home for interdisciplinary projects. The university has a good reputation, but is fairly young and mid-sized. The administration supports innovation, including collaborative efforts. The university is also home to an NSF Materials Research Lab, which shares labs and technologies with QUEST.

The first director, as remembered by QUEST members, had a particular ability to keep abreast of what was going on in all of the labs and to anticipate when collaborations would be needed. He was known for being able to analyze situations within the labs and understand the investments–financial, personal, and scientific–in the various projects. Members report that he had the ability to anticipate or pinpoint the cause of critical pressures and devise solutions which they were willing to accept. For example, he facilitated the introduction of summer research-positions for high school students by making special equipment available for the labs in which they were to work.

When the first center director decided to retire, the choice of the new center director was nominally shared by center members, the University and NSF. In reality, the current director was chosen with the unanimous agreement of center members from their ranks. The new director has a long history of both outstanding scientific research and administrative ability both at Bell Labs and at QUEST. She is responsible for long-term planning, representing the center to the university, NSF, and the public, and general administration. The assistant director handles day-to-day center operations.

The new director, who has solid support from center members, has a collegial management method better fitting a university department than that of an industrial enterprise. She finds it more comfortable to speak to the university or other entities representing the views of the entire center rather than simply speaking for herself. She finds that when solutions are needed concerning allocation of resources, for example, the executive board or center members as a whole often come up with creative ideas. However, center members note that when necessary, the new director makes hard-line decisions.

CENTER ACTIVITIES

QUEST is organized into five research areas, two of which involve the fabrication or assembly of quantum structures, and three of which seek to explore their properties:

- Growth of Self-Assembling Quantum Structures Project includes investigation of two growth methods for quantum wires, dots, and wells, with emphasis on understanding conditions leading to self-assembly.

- Processed Quantum Structures and Patterned Growth Project includes investigation of patterning, etching, and regrowth techniques, including ex-situ high resolution patterning processes and passivation techniques.

- Quantum Transport Project includes investigation of behavior patterns of nanostructures under free electron laser excitation, infra-red magneto-optical spectroscopy, ballistic electron emission, electron coherence and waveguide

phenomena. Edge states and condensation and non-linear properties are studied in this project.

- Quantum Optics Project includes investigation of microcavity effects and single photon generation, and high speed dynamics and limiting processes, including understanding of high resolution in both time and space.

- Superconductivity and Magnetism in Quantum Structures is a new project investigating the superconductor/semiconductor interface, including study of the magnetic properties of some quantum structures.

The center's outreach and education programs range from post-doctoral research projects to early elementary education. Center personnel are active in working with elementary, middle, and secondary teachers in developing curriculum and a network for study of electronics and related science activities. One important activity is the manufacture and use of "Questboards" which are used to study electrical circuitry in local schools with teacher and student training by QUEST personnel and graduate students. Summer research projects are available for teachers and high school students in QUEST labs, in addition to teacher curriculum planning workshops which are aimed at systemic change in science education throughout the county surrounding UCSB. Graduate students may have advisors from various departments and may work in research areas other than the areas of their dissertations, and undergraduates also work in QUEST labs. Both graduate and undergraduate students work as mentors to high school students who work in the labs in the summer programs. In addition, graduate students are required to present their research at a series of brown bag lunches designed to disseminate information about center research.

QUEST personnel and industrial representatives feel QUEST research is important since the Japanese government has launched an ambitious program of research in quantum physics within Japanese educational institutions, and there are few projects of this kind in the US. Although commercial products based on the program may not be developed within the life of the current center, industry has shown considerable interest in the science and exchanges have taken place between industry and academic labs. Some QUEST students have graduated and formed their own companies closely related to the semi-conductor industry. Other center students have been hired by collaborating industries in areas of research not related to quantum structures, but central to industrial research and development efforts in related areas.

CENTER DESCRIPTION AND FUNDING

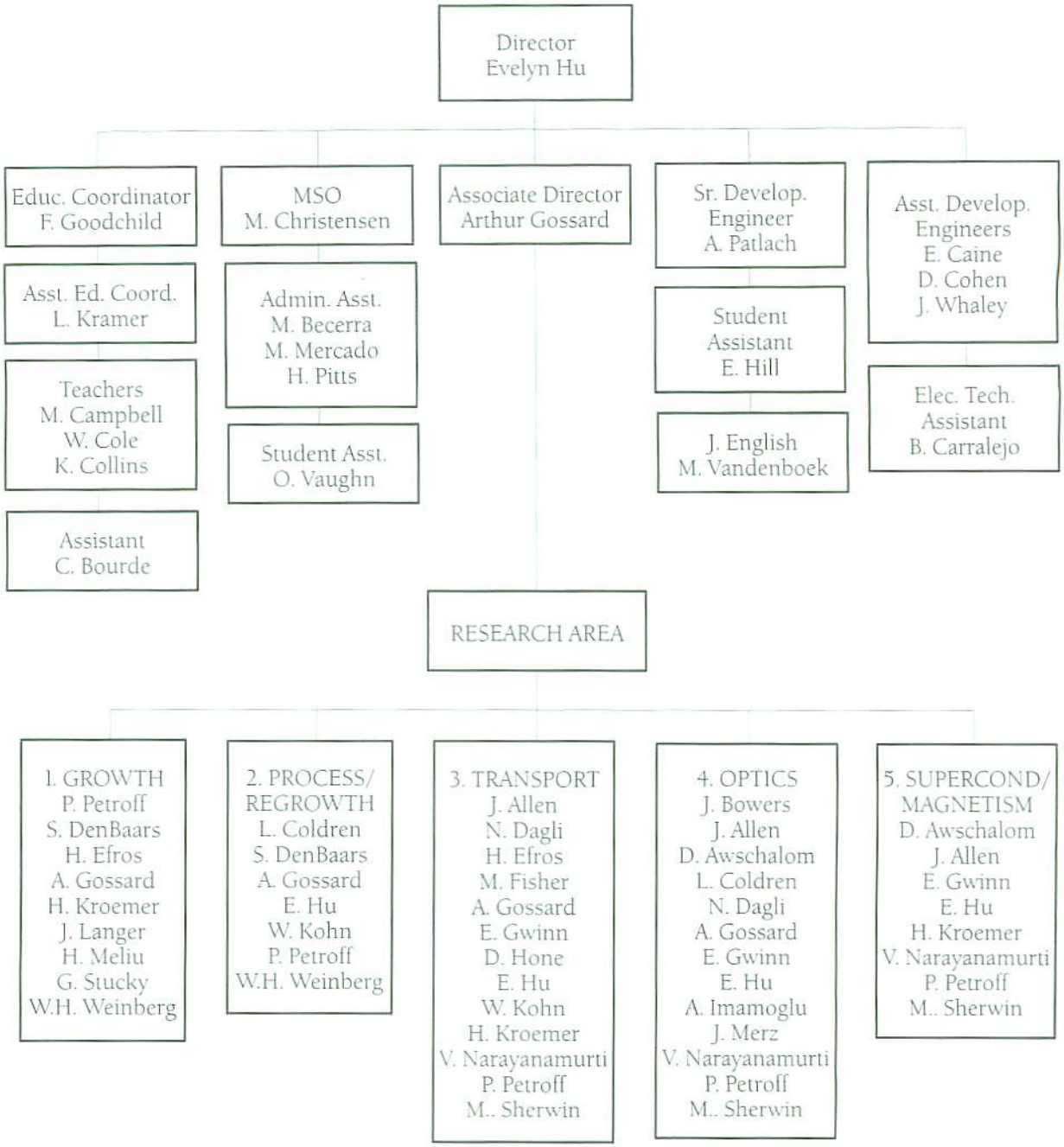
QUEST includes 19 research faculty from the areas of chemistry, physics, and electrical and computer engineering. Although the program is primarily based at the University of California at Santa Barbara, the move of the original center director has brought Notre Dame University into the center's collaboration. Less formal collaborations take place between QUEST and several national laboratories and US universities as well as with European and Japanese universities. These collaborations are largely through shared research results and personnel exchanges.

The University of California at Santa Barbara provides technical and administrative space for the center. Critical to center research is a large amount of unique equipment which has been purchased using center funding, or has been donated by the university or industry.

Collaboration of scientists in this area at UCSB began several years ago with a core of faculty from the areas of electrical engineering, chemistry and physics. As the core group grew, UCSB attracted a number of well-known scientists from AT&T Bell Laboratories and academic institutions and national laboratories. After building a critical mass of expertise, these scientists decided to concentrate on the areas of quantum physics now the focus of QUEST. NSF funding helped further build the personnel base, equipment inventory, and the outreach program. When the center director moved to Notre Dame in July of 1994, the current center director and assistant director took over leadership.

Center administration is highly collaborative, with principal investigators, as well as the outreach coordinator and director and assistant director, composing an executive committee which meets regularly to discuss and make decisions on research programs and budget issues. (See Exhibit F-8.) The center director concentrates on long term planning and external relations, while the assistant director concentrates on day to day administration and budgetary matters. The external advisory committee is composed of members of the industrial and research communities. It meets annually and offer advice on the center's planned research, outreach, and industrial contacts.

EXHIBIT F-8: CENTER MANAGEMENT AND ORGANIZATION



SOURCE: QUEST

Under NSF guidelines, the center is reviewed thoroughly. Annual site visits by the technical coordinator from the Mathematics and Physical Sciences Directorate and scientists, along with those of the external advisory committee represent a considerable expenditure of effort on the part of center members. In addition, peer reviews on which further funding is based are carried out every three years. In each of these reviews, center members must prepare written information on the quality of science practiced, research goals and accomplishments, center management, knowledge transfer to industry and educational programs. In addition to the written presentations, each review requires a one or two-day site visit. The focus of these reviews is the quality of the science practiced at the center.

NSF leadership has helped develop within the center specific concepts of management style and program requirements. Although center members were accustomed to collaborative work before NSF STC funding, NSF oversight has played an important role in building the outreach program. After the center's first year of operation, reviewers encouraged an active outreach program which has resulted in considerable work by center members with the local community as noted above. As a result of NSF oversight of another center, the first director of QUEST was once asked to aid that center in setting up a management system. His style of developing consensus among center scientists was regarded as a particularly effective management method by NSF personnel.

NSF funding represents about one-half of the center receipts (See Exhibit F-9). Additional funds are supplied by the university, industry, and other federal programs. The largest outside funding is from the Office of Navy Research. The university supplies some faculty salaries, administrative support, and both technical and administrative space.

EXHIBIT F-9

QUEST Focused Funding Expenditures Years 4-6
(In thousands of dollars)

Income:

NSF STC	$7,350
NSF (Other)	270
Federal	3,957
National Laboratories	96
Industry	487
Other	42
UCSB Matching	1,103
Total	**13,305**

NSF funding supports some faculty and administrative salaries, as well as funding for work on new projects and outreach. Considerable funding is involved in the purchase of the complex equipment involved in research with quantum structures. Center members also have individual grants to support work related to center activity.

CONCLUSIONS

The nature of the research and the interaction of the center scientists define its management and relationship to the various communities in which it resides. Key center assets are intellectual expertise and equipment. The ability of the center to provide a new technology which is not available elsewhere in the United States and may have important implications for data storage and transmission makes its activities important. NSF funding provides the flexibility to react to current developments in the field and to respond to community needs through educational outreach programs.

MANAGEMENT AND LEADERSHIP

Although center members relate in a collegial fashion there is evidence of management feedback-cycles in setting project and outreach goals. The center is at a turning point as the director whose vision was the formation of the center is replaced by a new director who must continue to facilitate cooperation and collegiality among the center's scientists, plan for the future, and continue the evolution of center goals and activities.

- **The center goals are appropriate to the development of a new basic technology.**

Since the development of quantum structures requires the study of entirely new materials which behave according to the laws of quantum physics, appropriate goals are to develop consistent ways to manufacture the structures and then to study their characteristics and behaviors. As the research develops, one goal of the program is to remain flexible enough to add or change research focus. For example, within the past year study of the magnetic properties of quantum structures was added to the program as researchers indicated a need for this study focus.

- **The center is in a critical transition from leadership by the original director to a new director who facilitates the interactions and research of other members.**

The critical mass of scientists at the center originated in a core of personnel from Bell Labs, with a leader whose vision was an interdisciplinary center. The university encouraged the interdisciplinary nature of their work, hiring some faculty on dual appointments. The leader was a consensus builder, who was able to convince a number of talented scientists to collaborate.

The transition to the new director has been effective, and she has the support of the center members. She considers herself a facilitator, and endeavors to help researchers find the resources they need and compromise or come to consensus. She has frequent meetings with the center executive committee, and is aided by the assistant director in matters of budget and daily administration.

- **The center is a loose confederation of researchers more consistent with university departmental organization than with industrial management.**

The director acts in close collaboration with the executive committee in planning research and other activities. Once the budget is decided, however, each researcher manages his or her own funding. The preferred method for budget management is to make periodic reports about expenditures on various projects so that project managers can evaluate their own progress on the budget cycle. When funds are transferred or projects are terminated, it is generally because the researchers involved found the work unproductive and moved on to another focus.

The center director and other members confer annually with the external advisory board, which is composed of persons from the academic and industrial research communities. The board advises the center on developments in the field and possible applications of the research findings. The board also interacts with the center members on a collegial basis. Center members meet annually to review long term plans and progress, and incorporate board suggestions and comments, as well as to prepare for board presentations and NSF reviews.

- **The center has yet to develop a clear vision of its future beyond NSF STC funding.**

The center has plans for future research activities and industrial outreach. These include adding a biological component and offering use of the laboratories as a resource for community businesses. In addition, the center director envisions having a role along with university, community, and industrial entities in creating an incubator for small community businesses in the future.

The principal assets built up in the center for this future activity are the intellectual capacity of the scientists, their ability to collaborate, and a large amount of costly and complex equipment and laboratory space. Center members express the hope that they will be able to compete for future NSF STC grants. So far, it appears that no specific plans have been made to finance activities from industrial or commercial income after such grants are no longer available, nor have specific plans been made to terminate the center.

CENTER CONCEPT

The center mode of funding has allowed UCSB to build a critical mass of talented individual scientists, and to encourage collegial interactions that can facilitate research in this basic technology. The complexity of the research and equipment would make it nearly impossible for significant advances to be made without collaboration. The center concept may have significant implications for future US economic competitiveness in this area.

- **Center management is by competent scientists whose principal concern is scientific research.**

The center director is respected in her field as a scientist and has considerable funding from sources other than the STC grant. The assistant director and other center members

are also well known scientists in their fields, most with funding from other sources. Although the center has yet to produce a large number of patents, the list of publications by its members is extensive.

Aware of the difficulties of maintaining a research and teaching schedule while burdened with management meetings, the center director limits management meetings. Members do participate frequently in informal seminars given by graduate students, and often discuss center "business" informally.

Although the director spends considerable time on such administrative activities as reviews, development of brochures, and paperwork, she finds that such time is tempered by the excitement and freedom of developing new and innovative programs. She notes, "The role of the administrator is made easier when working with a dedicated core of excellent scientists who operate with a common vision and enthusiasm, and gladly contribute their time and energies."[1]

- **Although QUEST has interactions with foreign and US institutions, it is housed completely at UCSB.**

The center has collaborative efforts with several European universities and is developing another with Japan. It also has some contract research done at the University of Utah, and the former center director continues to collaborate with QUEST researchers. All of these interactions are with specific individuals within these institutions rather that collaborations among the institutions.

For the most part, shared labs and equipment bind the members of this center. These elements are almost entirely at UCSB. Membership in a developing national consortium for fabrication of nanostructures may broaden collaborations at UCSB in the future.

- **NSF funding allows concentration on new long-term projects, flexibility to distribute funds among the related projects in QUEST, to provide seed money to new projects, and to leverage considerable additional funding for individual members' research.**

The ability to provide long-term funding for QUEST as a whole while allowing the flexibility to redistribute funds among projects or to new efforts is particularly important to research at this stage of maturity. QUEST represents study in a new area of science almost unique in the United States, while research in quantum structures is heavily funded in Japan. Flexibility, collaboration, and the ability to make long-term plans which are encouraged by the center concept can be a key to rapid development of science in this area. This may have important implications for American economic competitiveness in the future.

NSF STC funding, however, accounts for less than half of the total research funding received by its members. Funding from other government areas such as the military and national laboratories is growing, and further developments may encourage further participation by industry. In this case, STC funding will be leveraged significantly.

UNIVERSITY, COMMUNITY, AND INDUSTRY RELATIONSHIPS

QUEST has established close ties with community educational institutions through its educational programs and with the university. Industry relationships are limited, largely due to the maturity of the discipline.

- **QUEST is a "beachhead" within the university, offering an example of interdisciplinary work which is used as an example by university officials to encourage similar efforts.**

UCSB has encouraged the development of QUEST's interdisciplinary efforts. The university has encouraged the recruitment of personnel to QUEST, offering several dual appointments between departments, supporting faculty salaries, and providing funding, space and equipment.

The centers administrative office is housed in relatively new space which the external advisory board encouraged the university to supply. Tremendous resources in terms of lab space are shared with university departments and the Materials Research Laboratory.

University officials are encouraging other areas to develop interdisciplinary research efforts, using Quest as an example. As a young, medium-sized university, the administration sees such collaborative efforts as a way to build expertise and an international reputation in exceptional research. Students are encouraged to work across traditional departmental boundaries and to have faculty members from several departments on their dissertation committees. In addition, university officials are encouraging collaboration with the social science departments to offer quantum-science courses to their students as part of a program aimed at education of future politicians and citizens.

- **QUEST has made an investment in K-12 education, hiring an outreach coordinator who is a professional science educator.**

The outreach coordinator and others involved in the program are professional K-12 educators who have developed extensive ties to the community. The programs they have developed include curriculum development and research training for middle and high school teachers throughout the area, outreach to minority students from the District of Columbia through contacts with Howard University, and summer research institutes and summer school for high school students.

QUEST also designs, manufactures, and maintains Questboards, which allow students manipulative experiences with electrical circuitry. A QUEST representative is available to work with teachers planning lessons to use with the items, and work sheets and other written information are furnished when the boards are loaned to area teachers.

Although they were once skeptical about taking time from research and university teaching for these programs, many QUEST researchers are now enthusiastic about working with students and teachers in their labs. In addition, QUEST graduate students and even

undergraduate researchers often work with the outreach programs, mentoring and advising the younger students with whom they work.

- **Although the center's industrial contacts are limited, they do provide valuable contacts for graduates and information for industry on developments in this important field.**

QUEST maintains good relationships with national laboratories and corporations involved in data storage and transfer. This enables graduates to be introduced into these areas as well as into the academic research areas of quantum physics. QUEST students are well respected and sought out by industry. This method of technology transfer will become more important as the center's research comes nearer the main stream.

There is some difficulty in collaboration with industry because of the lessening industrial investment in basic research. This may be further complicated by the University of California's intellectual-property regulations. However, as the technology develops these barriers to collaboration with industry may lessen.

Quantum structures may provide an answer to more efficient data storage and transfer. As the world becomes increasingly more computerized, QUEST's contribution may be critical to use of this technology. It also may be a key to maintaining U. S. competitiveness in this area in which Japanese institutions are investing heavily.

CENTER FOR ANALYSIS AND PREDICTION OF STORMS

University of Oklahoma
Norman, Oklahoma
Site Visit Report
February 9-10, 1995

The Center for Analysis and Prediction of Storms (CAPS) is the only NSF Science and Technology Center associated with a single institution. It was funded in the first round of STC funding. Center assets include the special expertise of its members in meteorology, the unique weather conditions in Oklahoma, its role as a constituent in the Norman Weather Center, and proximity to the Oklahoma Mesonet, a unique and extensive source of weather data. The center's mission is to demonstrate the practicality of numerical weather prediction with an emphasis on deep convective storms, and to develop, test, and help implement a prototype regional forecast system appropriate for operational, commercial, and research applications.

Center research focuses on developing a mathematical model for predicting severe thunderstorms in a timely manner, obtaining and integrating the available data into the system, and performing operational evaluation of the model. The center is part of a network of weather research facilities located in Norman and funded by state and federal government and private sources. The new director of the center is developing plans for implementing new outreach efforts and for building contacts in the industry for future center products.

CENTER ACTIVITIES

The center's research plan includes development of a storm prediction model from basic science to operational use. Specific projects include:

- Development and operational testing of a new prediction model for thunderstorms.
- Development of techniques for assimilating data, primarily from single Doppler radars, into the models.
- Simulation studies and sensitivity of mathematical models to errors studies to provide better understanding of thunderstorm predictability.
- Development of an Oklahoma-area local analysis and Prediction System with National Oceanic and Atmospheric Administration.
- Operational evaluation of CAPS components with the Experimental Forecasting Facility.

To increase active, coordinated educational outreach efforts, the center director hired a half time outreach coordinator in March 1995. Outreach to date has included a short series of radio programs and funding weather discovery kits through a local museum for

use in public schools. In addition, CAPS has participated in several research opportunities and summer institutes. Individual center members have also participated in local educational functions.

Although the center has had few ties with industry until recently, it has had a research program funded by Federal Aviation Administration, and it interacts with the network of weather research facilities in the area. The unique data collection of the Oklahoma Mesonet and the frequency of severe thunderstorms in the area make it an ideal location for the study of storm systems. Recently, the center's weather prediction model has come closer to completion and has had numerous inquiries from industry and foreign countries with possibilities for further support.

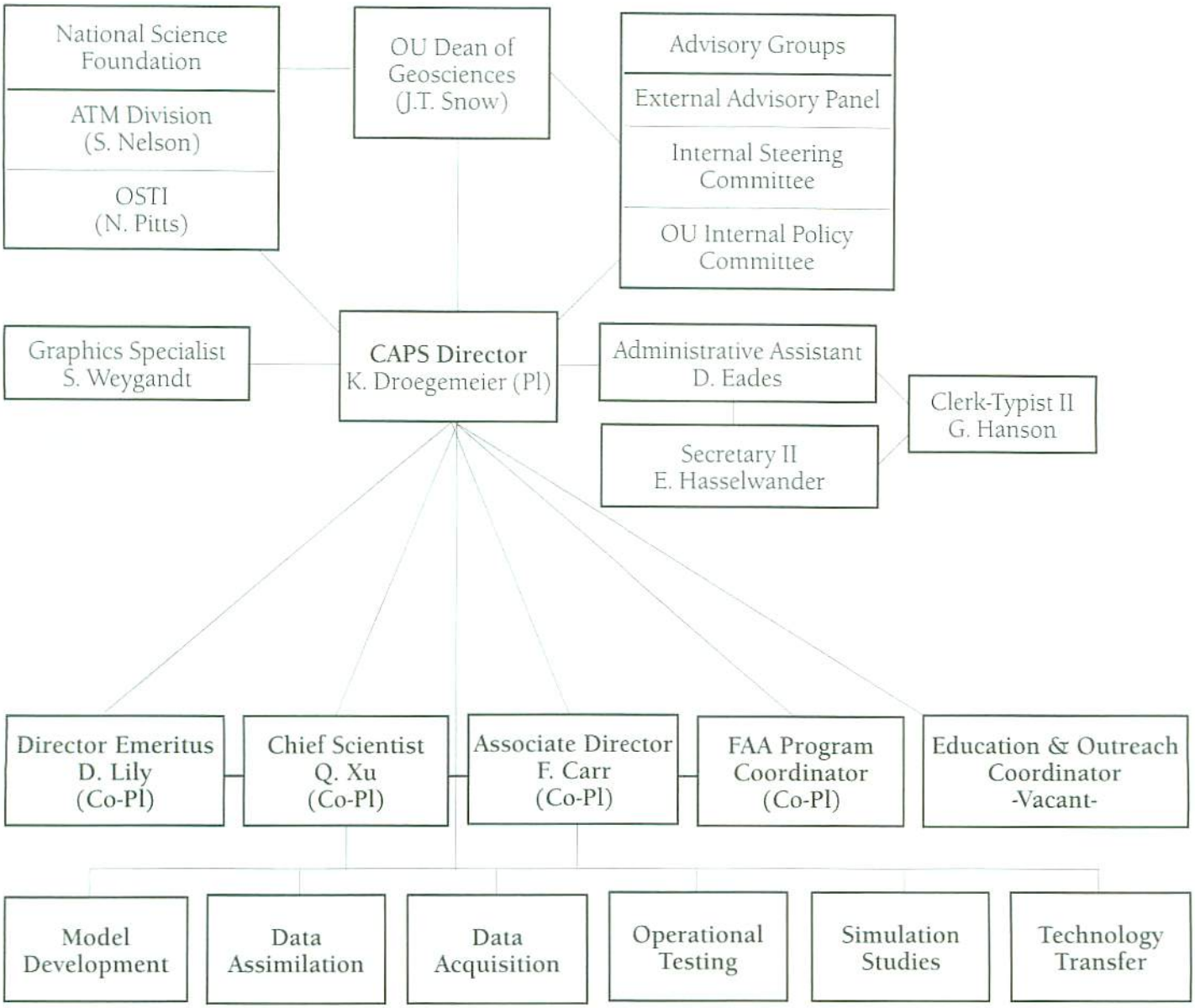
CENTER DESCRIPTION AND FUNDING

Although the center's membership originally included some applied mathematicians, center members are now primarily meteorologists, some of whom have extensive skills in mathematical modeling and computer software design. Five of the ten center members are University of Oklahoma faculty, while the others are strictly researchers. Some graduate students have worked at the center, but as the research moves away from model development to more applied areas of data accumulation and integration, the center director plans to rely increasingly on other researchers. Center members also collaborate with mathematicians and computer scientists at other institutions.

The center is housed at the University of Oklahoma and has use of extensive networks for gathering weather data in the area. Center members are from the School of Meteorology of the College of Geosciences. Considerable collaboration has taken place with the computational service developed as part of the College of Geosciences.

The original center director developed the scientific thrust of the center. He has been succeeded by a new center director who has established a more focused management system. The center director is involved in all aspects of decision making and in coordination and planning efforts with other programs in the Norman Weather Center. The associate director works in personnel and facilities planning, on linkages with NOAA, and on reporting. They are aided by a chief scientist who has oversight over the research activities and a steering committee of the principal investigators which meets regularly. In addition, there is a program manager for the FAA research project. (See Exhibit F-10)

EXHIBIT F-10: CENTER MANAGEMENT ORGANIZATION



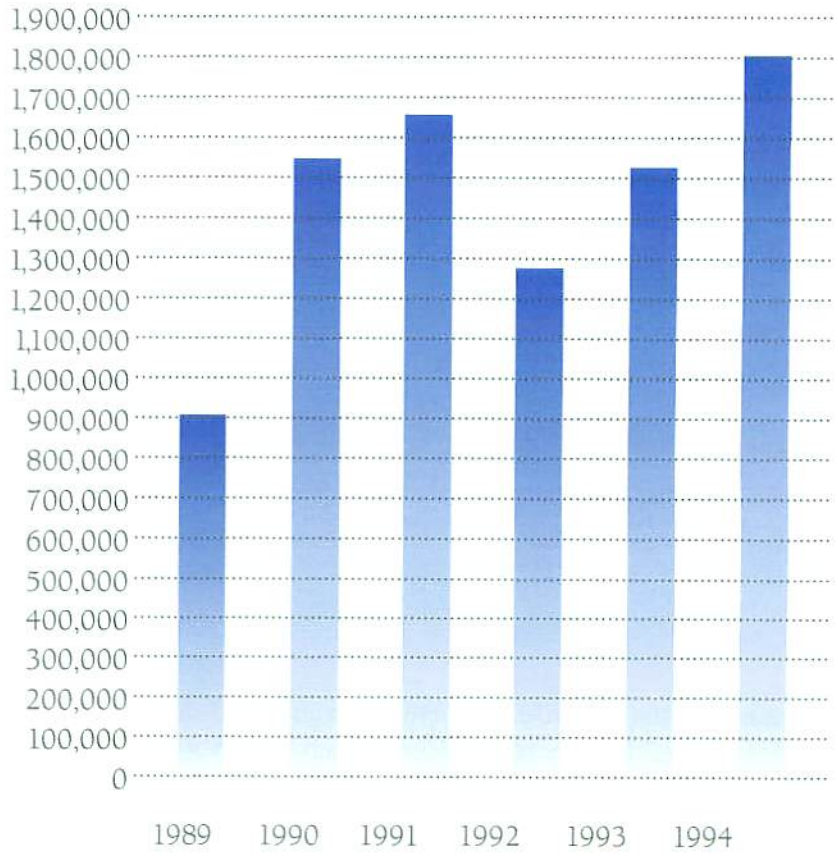
SOURCE: CAPS

The external advisory panel advises the center director on developments in the field. It meets annually and provides a written report which is delivered to the center director approximately three months after the meeting. Board membership includes researchers from NOAA, National Center for Atmospheric Research, one academic institution and one private research group. Members serve four year terms with one or two rotated each year.

The center enjoys a good relationship with its NSF technical coordinator. In annual site visits (every 18 months after three years), the technical coordinator and peer reviewers assess the center's research and outreach and knowledge transfer programs. In addition, the technical coordinator provides aid in preparation of NSF budgets and paperwork. The technical coordinator has aided center personnel in gaining additional funding and in dealing with NSF requirements for center activities. NSF requires in-depth peer reviews of the centers after the third and sixth years and renewal funding is dependent on the results of those peer reviews. For each of the past peer reviews, center personnel prepared written materials for the reviewers which were evaluated in writing before the site visits. After site visits, peer reviewers prepared reports which were submitted to NSF. NSF has strongly encouraged the center to strengthen its outreach program and the director recently hired an outreach coordinator.

Except for an FAA grant, CAPS researchers are largely supported by the NSF grant of approximately $1.5 million. In addition, the university supplies faculty-salary support. See Exhibit F-11 for the center's income.

EXHIBIT F-11: YEARLY BUDGET SINCE START OF THE CENTER



SOURCE: CAPS

Total Funding (1989-1994)=$8,721,886

MANAGEMENT HISTORY

According to NSF personnel, at the time that the centers were established CAPS was a special case in several ways:

- It is the only single academic-institution STC center.
- Its location and ties to the Norman weather research community offer special opportunities to work with research facilities which are not university based.
- Although the original director is well known in the field of science, NSF recognized the importance of the assistant directors in the area of management.

At the outset, the center had a significant number of young scientists. The center director had the unusual ability to recognize and nurture young talent and drive toward significant scientific progress. However, some concerns about center management arose in the first year, largely because of the lack of a unified approach to forming and implementing a plan. After the grant was received, there was no center retreat or other mechanism for further refining the center's mission. According to center members, the results included:

- Some early accomplishments were positive and significant and the degree of intellectual freedom they required was appropriate, but they did not strengthen the center as a whole nor contribute to a unified goal.
- As at other centers, most members focused on research rather than on outreach. educational programs, however, reached a large number of students and community members and to give exposure to the center, but they were expensive and did not involve the particular expertise of the center members.
- Controversy erupted over hiring programmers to work with center members to develop the software for their models. A number of members wanted to hire experts in the parallel computation area. Others, after corresponding with people in the field, including Dr. Kennedy of the Center for Research in Parallel Computation, the STC at Rice University, determined that such a process would be detrimental to the research. Ultimately, dependence on the outside programmers resulted in delays, causing some distress to student researchers. Due to this situation, some center members felt control was taken out of their hands. Contracting the programmers proved to be a costly experience, both financially and in damaging relationships within the center.

The lack of a coordinated plan which allowed these events resulted in financial difficulties. The original grant of $900,000 annually seemed large, but was rapidly used, and after a short time, the center was $200,000 in debt. The external advisory panel recognized the excellent quality of the science and assisted the center to define its visions and mission, develop milestones to monitor its progress and set up an organizational structure.

Armed with the newly developed vision, mission, milestones, and organizational structure, center members began to take a more unified approach to their research. They were strongly supported by NSF's technical coordinator on the basis of the science being practiced. Center performance, however, was hampered by further administrative difficulties:

- Administrative and funding support were no longer available for the radio programs and members of the external advisory panel and steering committee were not eager to support new outreach attempts.

- There was constant turnover in administrative staff. A rotating system of deputy directors brought instability to the leadership, and the administrative secretary left. The secretary's replacement was part time and was expected to do both secretarial tasks and coordinate outreach.

- Dissention arose with NSF personnel over paperwork for NSF's database and for the STC budget, which resulted in funding delays.

The current center director sees 1992 as the year the center began to turn around and form a cohesive unit. The center began to focus on building a model and aiming toward operational testing. Members with individual interdisciplinary backgrounds (meteorology and computer science) convinced the others that the expertise existed within the center to complete the necessary programming with collaboration with other centers such as CRPC. After the hired programmers were dismissed, center members began to take more ownership and control of the research. Research progress began to be rapid as new center members found their niche in the common mission.

The next step was to develop a more structured, stable management capability. The original center director, who was nearing retirement age participated in the choice of one of the younger scientists who had been an assistant administrator as the new center director. NSF strongly supports this young director. Specific responsibilities for management and implementation of daily activities are carried out by a center administrator, a new outreach coordinator, a chief scientist, and a permanent associate director, in addition to the center director.

The center mission was slightly altered to reflect both the change in management style and the change in research from development of the basic mathematical model to movement toward operational testing of that model and a long term plan was created. Center plans include progress toward operational use of their model as well as toward increased knowledge transfer, and industrial and educational outreach. Center members worked on a system of milestones for each aspect of their center at a retreat and further refined it in meetings following the retreat. (See Exhibit F-12.)

EXHIBIT F-12: CENTER FOR ANALYSIS AND PREDICTION OF STORMS 1994–2000

Target Year	Model Development	Assimilation Development	Simulation/ Prediction Studies	Data Acquisition & Archival	Operational Testing	Technology Transfer	Storm Prediction Center
1994	• ARPS 4 released • Further testing and shakedown • Improve code performance on MPP's	• Bakeoff complete • First-generation forward scheme • Begin hand-coded adjoint	• ADIFOR & 1-D Model • Begin VORTEX case studies • Begin QPF study • Continue ensemble experiments	• OLAPS I and T-OLAPS operational • R/T WSR-88D ingest testing	• CRAFT/ VORTEX • Begin daily ARPS runs on IBM Cluster	• Establish joint venture with UNISYS • Seek additional STTR/ SBIR contracts • Full marketing plan in place	• P. Bothwell and G. Grice arrive • Begin discussion on collaboration • Begin winter testing
1995	• Enhance time and space discretization • Improve physics • Add cumulus parameterization scheme	• ARPS 4 dry adjoint • Further testing of all schemes • First-generation multi-param microphysics retrieval scheme (MPMR)	• Begin winter case study • Apply ADIFOR to ARPS 4 • Continue storm dynamics studies • Continue ensemble experiments and begin MOS work • Begin convective initiation study	• OLAPS II (includes WSR-88D data) • Improve OBAN	• CRAFT/ VORTEX	• Establish formal relationship with metr. consulting firm	• Start construction of new building • CRAFT/ VORTEX collaboration
1996	• ARPS 5 released • Full production on MPP's and workstation clusters	• Second-generation forward scheme • ARPS 4 full adjoint	• VORTEX case studies	• Add resampled WSR-88D data (?) on Level II data	• 2-part CRAFT (EFF, airlines)	• $600 K revenue base	• Plan for ARPS testing in SPC • Initial support staff arrives; Partial ops.
1997	• Shakedown and testing	• Testing/ comparison with real data • Second-gen. MPMR	• Case studies • Sensitivity studies	• Local data archive • R/T 88D data available regionally	• 1-part CRAFT (EFF), local television	• $800 K revenue base	• All 38 staff on station; Full ops. begin
1998	• Testing and improvement	• Testing/ comparison with real data • ARPS 5 full adjoint	• Case studies • Sensitivity studies	• Evaluation	• Daily R/T model runs	• Establish formal agreement for joint operations with NOAA/NSF	• SPC fully operational
1999	• ARPS 6 released • Final testing and documentation	• Final operational scheme • Testing of scheme at SPC	• Final MOS and ensemble strategy • Testing of MOS/ ensemble at SPC	• Evaluation • Final version tested at SPC	• Daily R/T support of SPC via ARPS 6	• Continue consulting work • $800 K revenue base	• ARPS 6 R/T testing
2000	Formal STC designation ends. Various strategies are put in place for continuing CAPS operations. (Such strategies are considered 1995-2000.)						

The sixth-year renewal-review resulted in increased NSF funding. The director's focus is to continue to lead the center in giving increased attention to NSF goals for the STC program. Along with center members and the external advisory panel, he has outlined a program to increase technology transfer and outreach which is beginning to show results. In addition to the efforts taken to hire personnel in the outreach and scientific areas, the center director notes several areas of recent significant progress:

- In the area of technology transfer, the center is moving toward software that can be used on equipment available to many businesses, rather than that useable only on massive parallel computers. The model is being tested in cooperation with several different agencies. As a result, the model will be useful to many private concerns in areas such as aviation and agriculture. This represents a movement toward the STC program goal of technology transfer between the centers and businesses.

- The center is beginning to seek market for its support products. Recently, it has begun working with the Air Force in developing a $4 million contract. Income from these areas will replace that lost from the completion of the FAA contract. This represents movement in the direction of NSF goals for leveraging NSF funds.

- In addition to use of the model in France, interest has been indicated by the Korean government in working with CAPS in developing their model for use throughout Korea, which helps to increase U.S. influence in the international marketplace.

- Although CAPS has stopped using Oklahoma University's mathematics partners, they have developed partnerships with other mathematics and computer science research centers in the U.S. and abroad. One such collaboration is with the Syracuse member of CRPC. This work toward interdisciplinary collaboration is an important aspect of the STC program.

- Plans are being made to increase outreach using center members' particular expertise along the lines of former programs such as one for high school competitions in the area of meteorology. The center director is actively soliciting ideas for outreach with the object of involving many center members rather than just "buying" outreach.

- CAPS has begun to take specific steps to continue to pursue its goals in the future. It is the goal of center personnel to be included in NOAA research efforts. They have begun actively pursuing movement in this direction. The under secretary of Commerce for Oceans and Atmosphere visited the center in March 1995 to begin developing plans for building a CAPS/NOAA relationship.

CONCLUSIONS

CAPS is passing through a critical period of transition in both the management and technical areas. Technically, the initial development of the model for storm prediction is nearly complete and the project is entering a new phase of data integration and testing. In the management area, the new center director is strengthening strategic planning, reporting, and outreach and ties with the community.

MANAGEMENT AND LEADERSHIP

Center leadership is evolving to a more structured management paradigm. The goals include development of a model and plans to attempt to use the model to become a NOAA research center after NSF funding expires.

- **Center goals are appropriate to its purpose and to the conduct of basic research.**

Center goals are tied to the development and testing of a mathematical model for prediction of small scale storms in a timely manner. Goals are revised annually to reflect developments in Center projects. As the center matures, the annual goals move more toward developmental testing of the model and away from theoretical research. Center plans include waymarks for the entire life of the project, including goals for obtaining and processing data, and for operational testing of the model. These plans reflect the maturity of the research in being able to more accurately predict the nature of developments in the next few years than is possible in the early stages of basic research.

- **The center director is developing a more structured management system than was used by the previous director and the center is passing a critical transition period.**

Previously, the center's relationship with NSF was marked by failure to turn in reports and budgets on time, and by confusion in the budgeting process. The new director has developed a structured management system, including specific benchmarks for development of the science, technology transfer, and outreach programs. Although the steering committee assists in planning research and the associate director is involved in some administrative activities, the center director carries out most of the decision making functions in the center. Center members seem comfortable with the arrangement, preferring to maintain their research focus and avoid administrative or other center activities.

Critical to the center is its use of management feedback-loops and data, including obtaining the proper feedback. The center external advisory panel has a rotating membership. Since the board has actively opposed some NSF center requirements, such as outreach and industrial knowledge transfer in the past, the center director's relationship with the new members will be important and his careful use of feedback from them critical. In the new, more structured management scheme the director should be able to balance the areas of external advisory considerations with those of NSF and the center's executive committee.

- **Center personnel believe that the center should not be dependent upon NSF funding after the 11-year program.**

The nature of the research is such that it is designed to develop a complete operational model at the end of the grant period. The purpose of the center is to develop and test a technology and make it available to others. The center director believes in the sunset provision of the NSF program. However, center researchers hope to make their center part of NOAA's R & D program at the end of NSF funding.

CENTER CONCEPT

The center concept allows flexible control of funding and interactions with other research facilities, which enhances the research by center members. Center management, however, is by credible scientists, allowing for the special characteristics necessary in the management of research.

- **Center research and management is in the hands of scientists capable of good quality scientific research.**

One of the critical assets of the center is the expertise of the former director. Other scientists involved are also well-known in their fields and have published extensively. The new director is a credible scientist as are the other center members. Some center scientists have been reluctant to divert time from their research to outreach activities and other center functions. The center director carries most of the burden of administration but still maintains some of his research functions and his familiarity with the field.

- **The center mode of funding allows for a system and resources which enable the center to interact with a network of meteorological research groups based in the Norman, Oklahoma area.**

Although it has no formal collaborating universities, the center enjoys proximity to sources of a large variety of meteorological data based on the information from the Oklahoma Mesonet, which supplies radar information, and a large nearby community of researchers. These unique assets, along with Oklahoma's weather conditions and the public safety aspects of meteorological research make collaboration with researchers in the field an important aspect of center activities. Center members also collaborate with a number of university faculty outside of the Oklahoma area.

- **NSF funding allows control over discretionary resources critical to the success of the project.**

NSF funding allows the flexibility for the center members and director to develop new areas of application as appropriate to the research. This is particularly important to development of the integrated data-base and the model as it will eventually apply to other areas of the country with different geographic and demographic conditions. As research progresses and greater use of parallel computing technologies and interactions are needed, additional uses of flexible funding are important to CAPS progress.

UNIVERSITY, COMMUNITY, AND INDUSTRY RELATIONSHIPS

CAPS has been valued as an important addition to the university and weather research communities since its inception. As the mathematical model is being tested, the center is beginning to build relationships through community outreach and industrial knowledge transfer.

- **The center is an important addition to the University of Oklahoma's research efforts, and as such is given good support by the university.**

The center was developed at a time when the university was seeking to expand its research base. The center represents a source of prestige for the University and is used as a model for other centers within the university. It is "nested" within the university and its relationship with it is mutually beneficial. The university provides space, some matching funds, faculty salaries and administrative support. The new university president is perceived by center members as willing to raise additional funds for center activities. Currently, the university is making an effort to restructure the intellectual property regulations to make transfer more attractive.

The center does not contribute to an interdisciplinary graduate degree, although center graduate students do work in several fields for their projects. Many of the researchers are not on the faculty and do not teach. As they complete their work, graduate students doing dissertations in center research efforts are being replaced by shorter-term research efforts. This is largely because the center is now moving from model development to testing and applications, which are not appropriate areas for dissertation research.

- **Although the center's outreach program has dwindled in the last two years, the new center director has plans to increase outreach activities.**

In the past, the center has funded community outreach in the areas of public radio and a children's museum, research opportunities and summer institutes. The radio program was a short educational-spot on public radio that aired for about six months. Although the center applied for an NSF grant to continue the program, it was unable to obtain funding and the program was canceled. The center also funded the development of weather discovery kits by a local museum. The kits are loaned to elementary school teachers for use in their classrooms.

In developing an outreach program, the center director has faced the opposition of several center members and some of the external advisory board. Some center members and the director have begun small, personal efforts at outreach, such as corresponding by e-mail with elementary children on topics in their areas of expertise.

A half-time outreach coordinator was hired for the center in March 1995. The center director has allotted funding for the new coordinator to develop and test ideas for outreach. It is hoped that additional funding would be obtained for such programs.

- **Center contacts outside of the university research community are primarily at government-funded research laboratories, where there is mutual benefit from knowledge transfer.**

The nature of the center's activities are such that they pertain most directly to the government function of "assuring public safety", rather than to industrial concerns. Thus, the center has contacts with several government agencies, and hopes to develop greater contact with NOAA as a research arm as the research develops.

Center research is a natural progression along the path of research history in this area. The object of this area of meteorological research has been to be able to predict thunderstorms with greater accuracy and speed. The Oklahoma Mesonet and related data are directly applicable to this effort. The knowledge obtained by the data researchers and CAPS research are mutually beneficial and transferable.

In addition, CAPS shares valuable data and information with the parallel-computing research community. The CAPS model is dependent on rapidly developing parallel-computing technologies. CAPS personnel participate in development of algorithms for parallel computers in meteorological applications.

- **The center has developed some ties with industry and has begun an effort to increase those ties as the research develops.**

Center members feel strongly that they need a fuller proof of concept before their research can be marketed in the industrial community, although they do have two ongoing projects involving industry. One such project is funded by the FAA, and deals with weather effects on airline safety. The other deals with fog conditions developing in the manufacturing plant.

The center has developed a relationship with a marketing representative which is expected to expand as the research develops a product more marketable. Eventually, the center's products, such as software and data, could be marketable to airline, agricultural, and recreation industries.

Software from the first phase of the model development project has been marketed to a French company for use in weather prediction research there. Since weather is important globally, the center hopes eventually to develop the technology to make its model applicable globally.

NSF MANAGEMENT OF THE CENTER

NSF characterizes CAPS as practicing outstanding research with a unique source of data and expertise in the area, even though it does not fully follow the model of the Zare Report. The recommendations of the Zare Report suggested that STCs should have members from multiple institutions and multiple disciplines. CAPS has the opportunity to have numerous informal collaborations with scientists and mathematicians world-

wide. CAPS is actively promoting the additional outreach to industry and the educational community suggested in the Zare Report as the mathematical model is being tested.

CAPS' technical coordinator is a strong advocate of the center, recognizing the superior quality of the science. Problems with NSF paperwork which darkened CAPS[1] horizons in its early years seem to have been resolved. The center was recommended for renewal at both the third-year and sixth-year reviews.

ENDNOTE

1 Evelyn L. Hu. [Personal communication to NAPA]. April 24, 1995

APPENDIX G

NSF RESEARCH CENTERS PROGRAM

What is an NSF research center? Simply put, it is a campus-based research unit typically involving from 10 to 50 or more investigators, their students and postdoctoral fellows, and major shared use of scientific equipment. According to the FY 1995 budget request to Congress, all NSF research centers share three distinguishing features:

- "Some scientific questions and research problems can best be addressed through the multidisciplinary, long-term, coordinated research efforts of a number of scientists working in unison on many facets of a complex problem;
- "A strong educational component to aid the training of this nation's next generation of scientists and engineers and to encourage the participation in science and engineering of students of all ages, and;
- "A well-defined coordination with industry to ensure that research is relevant to national needs and that knowledge quickly migrates into the private sector."

These features combine to make research centers quite different from the traditional NSF approach to funding science and engineering research. First, NSF funding for a center goes to a group of investigators, rather than to an individual investigator. Second, centers are typically funded via cooperative agreements and not the traditional grant. And third, center researchers work quite closely with industry representatives, whereas NSF grantees have traditionally worked less so. For these reasons, all NSF research centers programs can be considered to be experimental forms of sponsorship to one degree or another.

NSF currently supports 163 research centers spread among 10 different centers programs. These numbers rise to 167 centers and 11 centers programs if we include supercomputer centers, which are technically listed as "facilities" for NSF budget purposes. For purposes of the NAPA study, references to supercomputers include the Cornell Theory Center, the National Center for Supercomputing Applications, the Pittsburgh Supercomputer Center, and the San Diego Supercomputer Center, but they exclude the National Center for Atmospheric Research managed by the GEO Directorate.

Despite similarities, however, there are important differences among the ERC, STC, I/UCRC, and SCC programs. These and other contrasts make it difficult to think of the centers programs as interchangeable or to generalize conclusions across all four types of centers. They differ in important ways, and they must be treated separately for purposes of assessment. Figures G-1 and G-2 show, for example, that the four programs vary on:

- The number of centers funded (from 4 SCCs to 55 I/UCRCs);
- The total annual NSF funding (from $4.5 million for I/UCRC to $68.1 million for SCC);
- The average NSF funding per center (from $80,000 per I/UCRC to $17 million per SCC);
- The average number of industry partners per center (from eight partners per STC to 33 partners per ERC);
- The average percentage of a center's total funding which comes from NSF (from 9% for I/UCRC to 60% for SCC);
- The number of years each program has funded centers (from five years for STC to 15 years for I/UCRC); and
- The number of years a center is guaranteed funding (from one year for an I/UCRC to five years for the other three types of centers).

Exhibit G-3 shows that these four research centers programs also differ on:

- Their research goals, ranging from the relatively open-ended I/UCRC goal of stimulating collaborative research to the more specific ERC goal of working closely with industry in certain ways.
- Whether each is a "franchise" program with relatively high uniformity of structure and operations from site to site (ERC, I/UCRC, SCC) or a "portfolio" program with considerable variations from site to site (STC).
- NSF's program management, ranging from three programs centralized in one directorate (ERC, I/UCRC, SCC) to one program which is decentralized to five separate directorates (STC).
- Their distinguishing operational characteristics, including ERC's importance of strategic planning, STC's flexibility, I/UCRC's leveraging of small amounts of funding, and SCC's strong emphasis on facility access.

NSF'S ASSESSMENTS OF PROGRAM PERFORMANCE

Historically, NSF has established rigorous review-systems for selection and renewal of funding of individual awards as part of its grant award and administration process. Of most interest here are the post-award merit-review activities that apply to individual centers, such as:

- Each center submits annually to NSF a written report according to a prescribed format. Some parts of this format address the performance of the center in various areas.

- Each center submits annually to NSF a set of data for the program database. These data follow a prescribed format which NSF revises as new information needs arise. The SCC database, for example, includes data on the number of users, reported in normalized CPU hours to allow comparisons among different types of supercomputers, and the number of projects supported.

- Each center is visited annually and assessed according to specified performance review factors.

- The STC program requires each center to provide as part of its application proposal a list of the "evaluation criteria" to which the center should be held. These criteria are then used during site visits to assess the center's performance.

- The I/UCRC program attends twice-yearly industrial advisory board meetings for each center and communicates regularly with each center's on-site evaluator.

In addition, NSF has also assessed the performance of higher levels of aggregation than individual centers, i.e., centers programs:

- In 1989 NSF asked the National Academy of Engineering (NAE) to assess the program's impact and future directions, resulting in the report *Assessment of the National Science Foundation's Engineering Research Centers Program*. NSF has also asked the National Research Council (the operating arm of the NAE and its sister organizations the National Academy of Sciences and IOM) to conduct other ERC program evaluations: *Assessment of the Engineering Research Centers Selection Process* (1988) and *The Engineering Research centers and Their Evaluation* (1988).

- The ERC program is currently contracting for two separate studies of its performance. The first study is assessing the types of impacts on industry of interactions with ERCs, and the second is assessing the impact of ERC involvement on graduates' effectiveness in industry. Before contracting for the second study, the ERC program commissioned a now-completed pilot study *Industry Perceptions of ERC Graduates*.

- The STC program is current soliciting proposals for a two-year evaluation of its effectiveness and impact. The second task of this evaluation calls for the contractor to "design and propose performance indicators that reflect the degree to which and ways in which the centers have achieved the program's original goals and additional goals that emerged subsequent to initiation of NSF support."

- The I/UCRC program has contracted with an evaluation expert, Denis Gray of North Carolina State University, to maintain the national database on all I/UCRC centers and to produce useful analyses and reports at the I/UCRC program level. In addition, the I/UCRC program will convene a group of 10 representative stakeholders in September 1995 to discuss evaluation criteria and renewal policies for the centers.

- The SCC program has drafted specific and measurable goals in the area of high performance computing as part of its report *1994 Overview of the Management of the NSF High Performance Computing and Communications Program*, recently submitted to the Senate Committee on Appropriations.

More recently, NSF has begun to assess performance across centers' programs :

- In January 1992, NSF's program evaluation staff convened a two-day workshop on "Methods for Evaluating Programs of Research Centers". This workshop brought together over 30 professional evaluators from outside NSF and divided them into separate working groups on research, education, knowledge/technology transfer, and institutional/organizational impacts. The present study will build on the work accomplished during and immediately after the 1992 workshop.

Most recently of all, NSF has begun to assess performance across NSF:

- In its FY 1995 budget request to Congress, NSF highlighted eight initiatives as critical activities in support of research and education in the national interest. In a July 1, 1994 supplemental submission, NSF provided detailed goals, objectives, and milestones for each of these eight strategic initiatives.

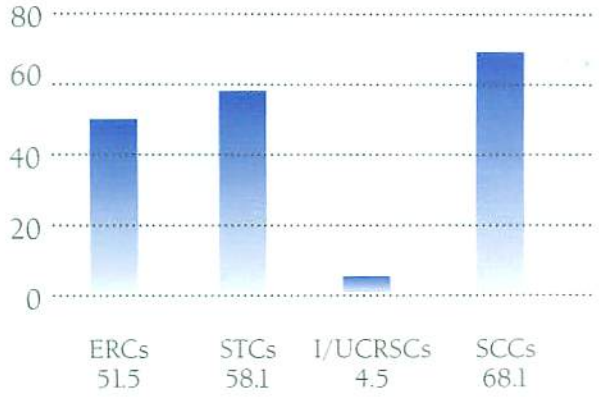
- NSF nominated four programs to participate as GPRA pilot projects for FY 1994 and, as a result, has developed performance plans for each program. (Two of these GPRA pilot projects - Science and Technology Centers, and High Performance Computing and Communication Initiative - overlap with two of the four center programs in the first phase of the NAPA study - STCs and SCCs.)

These beginning efforts by NSF are important and should be recognized, yet both Congress and NSF realize that more work is needed in this area. The Senate Appropriations Committee noted in a September 1993 report that "The Committee has been concerned that the many NSF-supported centers, which have grown in large numbers over the last decade, have not sufficiently identified and developed their goals, objectives, and annual milestones."

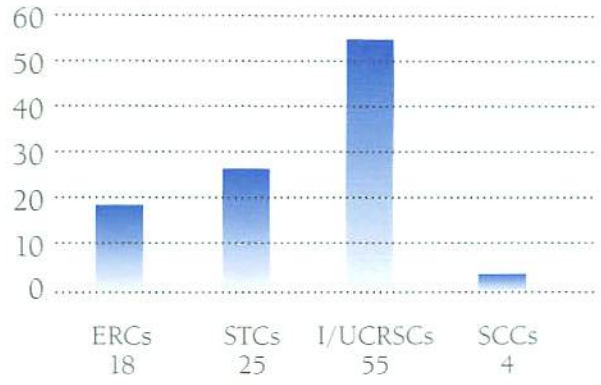
In addition, NSF staff report that these 1992 words are still true: "Little work...has been done on evaluating one or more entire NSF programs of centers...." While the issue of performance assessment is critical in any time period, the current era of the Chief Financial Officers Act of 1991, the Government Performance and Results Act of 1993, the introduction of total quality management into federal agencies, Vice-President Gore's reinventing government initiative, and the National Science and Technology Council make the issue even more compelling in late 1994.

FIGURE G-1: DIFFERENCES AMONG NSF RESEARCH CENTER'S PROGRAMS

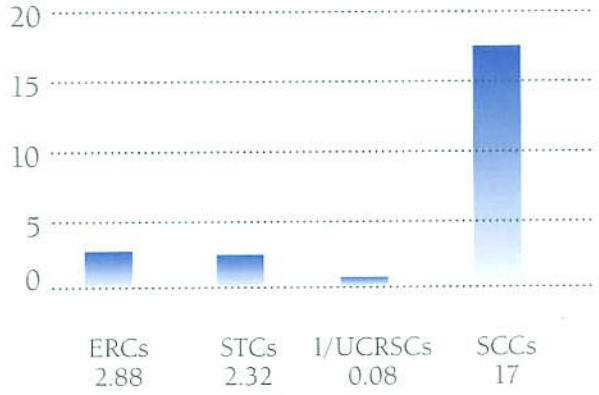
Total NSF Funding



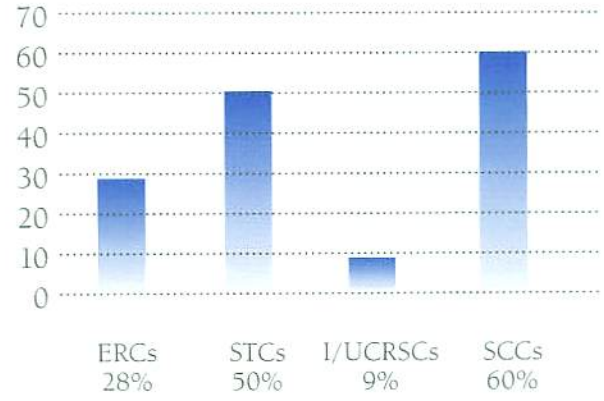
Number of Centers Funded



Average NSF Funding per Center



Average NSF Share of Total Center Budget

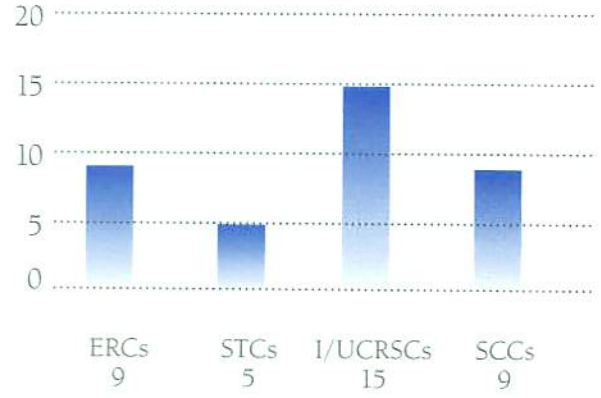


FY 1994 data

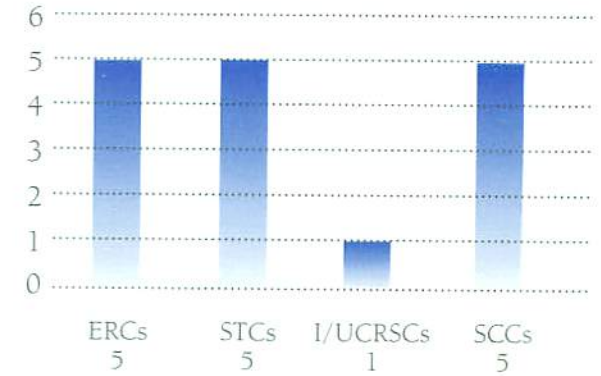
FIGURE G-2: MORE DIFFERENCES AMONG NSF RESEARCH CENTER'S PROGRAMS

Average Number of Industry Partners per Center

Years of Experience Funding Centers



Years A Center is Guaranteed Funding



FY 1994 data

EXHIBIT G-3: DIFFERENCES AMONG NSF RESEARCH CENTERS PROGRAMS

TRAIT	ERC	STC	I/UCRC	SCC
Research Goals of the Program	To conduct fundamenl (next-generation) research that takes a systems (cross-disciplinary) approach to problems of interest to industry and that extends to the test-bed stage.	To exploit opportunities in science and engineering where the complexity of the research problems or the resources needed to solve them require the advantages of scale, duration, facilities, or collaborative relationships that can best be provided by campus-based research centers.	To stimulate high quality industrially relevant fundamental research.	To conduct research in computational mathematics, software, and algorithms, and research and development of new supercomputers to researchers in academia, industry, government, and underrepresented groups which will promote collaboration and partnership formation.
Type of Program?	Franchise	Portfolio	Franchise	Franchise
Program Management Within NSF	Centralized within the Directorate for Engineering	Central STC Coordinating Office, but budget authority decentralized among five different Directorates	Centralized within the Directorate for Engineering	Centralized within the Directorate for Computer and Information Science and Engineering
Distinguishing Operational Characteristics	Each ERA must have a highly developed strategic plan that articulates a clear and coherent vision, that integrates research and educational activities, and that focuses research and education activities on achievement of advances that would not occur with separate individual research grants.	An STC's unifying research focus can involve any field of research supported by NSF. No single type of center fits the needs of every field. Rather, the size, structure, and operations of each STC are determined by its proposed research.	NSF funding is small; primary funding comes from industry partners, and federal and state agencies and universities. A percentage of NSF funding is set aside for evaluation. Some I/UCRCs have multiple university affiliations, since applicants pursuing a field similar to an existing I/UCRC are encouraged to join forces with an existing I/UCRC.	Changing use of federal funds: from 1984-1987 NSF purchased supercomputer access, from 1985-1989 NSF purchased hardware, and from 1990-1995 NSF is keeping the hardware state of the art, increasing collaboration among the centers, improving access, and promoting basic and applied research.

APPENDIX H

PERSONS INTERVIEWED DURING PHASE I

Congress

Kevin Kelly
Staff Director
VA, HUD, and Independent Agencies Subcommittee
Senate Appropriations Committee

Chris Gabriel
Fellow
VA, HUD, and Independent Agencies Subcommittee
Senate Appropriations Committee

Genevieve Knezo
Specialist in Science and Technology Policy
Congressional Research Service

National Science Foundation

Rolf Piekarz
Senior Staff Associate
Office of Policy Support

John Perhonis
Policy Analyst
Office of Policy Support

Mary Clutter
Acting Deputy Director
Office of the Director

Karl Erb
Senior Science Advisor
Office of the Director

Sonja Sperlich
Associate Director
Office of Science and Technology Infrastructure

Judith Sunley
Assistant to the Director for Science Policy and Planning
Office of the Director

James McCullough
Senior Policy Analyst
National Science Board

Joel Widder
Director
Legislative Affairs Division

Edward Blansitt
Director
Budget Division

Madeline Hymowitz
Chief, Program Analysis
Budget Division

Robert Abel
Chief, Budget Operations and Systems
Budget Division

Vernon Roff
Computer Specialist
Budget Division

Lynn Preston
Deputy Director
Engineering Education and Centers Division

Linda Parker
Program Analyst
Engineering Education and Centers Division

Fred Betz
Program Officer
Engineering Education and Centers Division

Tapan Mukherjee
Program Officer
Engineering Education and Centers Division

Joseph Mathias
Program Officer
Engineering Education and Centers Division

Persons Interviewed During Phase I

David Schindel
Senior Advisor
Office of Science and Technology Infrastructure

Alex Schwarzkopf
Program Officer
Engineering Education and Centers Division

John Hurt
Program Officer
Engineering Education and Centers Division

Robert Borchers
Director
Advanced Scientific Computing Division

Richard Hirsh
Deputy Director
Advanced Scientific Computing Division

Larry Brandt
Associate Program Director for
Centers Program
Advanced Scientific Computing Division

Irene Lombardo
Staff Associate
Advanced Scientific Computing Division

James Hays
Director
Division of Earth Sciences

Research Centers

Nino Masnari
Director
ERC - NC State University

Gary Rubloff
Associate Director
ERC - NC State University

Penny LeBourgeois
Assistant Director
ERC - NC State University

Jeff Coriale
Industrial Liaison Coordinator
ERC - NC State University

Charles Moreland
Vice Chancellor for Research
ERC - NC State University

Four thrust area leaders
ERC - NC State University

Five students
ERC - NC State University

Dave Bohling
Industrial Advisory Board
ERC - NC State University

Kenneth Swartzel
Former Director
I/UCRC - NC State University

Denis Gray
Coordinator for I/UCRC Outcome
Evaluation Project
I/UCRC - NC State University

Student
I/UCRC - NC State University

Daniel Wang
Director
ERC - M.I.T.

Noubar Afeyan
Industrial Advisory Board
ERC - M.I.T.

Robert Brown
Head, Chemical Engineering
ERC - M.I.T.

Two thrust-area leaders
ERC - M.I.T.

Students
ERC - M.I.T.

Audrey Jones
Administrative Officer
ERC - M.I.T.

Others

Timothy Webb
Deputy Director
Critical Technologies Institute

James Bonomo
Senior Policy Analyst
Critical Technologies Institute

Susan Cozzens
Associate Professor
Department of Science and Technology Studies
Rensselaer Polytechnic Institute

APPENDIX I

PERSONS INTERVIEWED DURING PHASE II

Congress

Stephen Kohashi
Staff Director
VA, HUD, and Independent Agencies Subcommittee
Senate Appropriations Committee

Kevin Kelly
Former Staff Director
VA, HUD, and Independent Agencies Subcommittee
Senate Appropriations Committee

Chris Gabriel
Fellow
VA, HUD, and Independent Agencies Subcommittee
Senate Appropriations Committee

National Science Foundation

Bruce Barnes
Technical Coordinator,
Center for Research on Parallel Computation

William C. Harris
Assistant Director
Mathematical and Physical Science

Laverne Hess
Technical Coordinator,
Center for Quantized Electronic Structures

Neil Lane
Director

Steven Nelson
Technical Coordinator,
Center for Analysis and Prediction of Storms

Kathie Olson
Technical Coordinator,
Center for Biological Timing

John Perhonis
Policy Analyst
Office of Policy Support

Rolf Piekarz
Senior Staff Associate
Office of Policy Support

David Schindel
Science and Technology Program

Gerald Selzer
Technical Coordinator,
Center for Molecular Biotechnology

Sonja Sperlich
Associate Director
Office of Science and Technology Infrastructure

University of Virginia
Center for Biological Timing

Eugene Block
Director

Richard Day
Principal Investigator
Technology Development

Otto Friesen
Undergraduate Summer Research Program

Dave Hudson
Administrator

Steven Kay
Principal Investigator
Clock Genome Project

Peter Low
Vice President/Provost

Persons Interviewed During Phase II

Emilie Rissman
High School Teacher

Margaret Shupnik
Principal Investigator
Frequency Modulation Project

Rae Silver
Chair
External Advisory Board

Martin Straume
Industrial Outreach

Michael Terry
External Advisory Board

Michael Thorner
Chair
Steering Committee

2 Students

Center for Molecular Biotechnology

Ruedi Aebersold
Assistant Director

David Baker
Principal Investigator

Roger Bumgarner
Principal Investigator

Tekla Haasl
Administrator

Leroy Hood
Director

Lee Huntsman
Asoc. Dean of Scientific Affairs

Timothy Hunkapiller
Principal Investigator

Larry Loeb
Visiting Scientist

Valerie Logan
Outreach Coordinator

David Miller
Visiting Scientist

Deborah Nickerson
Principal Investigator

Buddy Ratner
Visiting Scientist

David Thorud
Provost

John Yates
Principal Investigator

5 Graduate Students

1 High School Student

Center for Research on Parallel Computation

David Auston
Provost, *Rice University*

Michael Carrol
Dean of Engineering

Paul Jennings
Provost
California Institute of Technology

Ken Kennedy
Director

Danny Powell
Business Manager

Kathy El-Messidi
External Relations

Richard Tapia
Principal Investigator

Linda Torczon
Assistant Director

3 Graduate Students

Center for Quantized Electronic Structures

James Allen
Principal Investigator
Quantum Transport

David Awschalom
Principal Investigator
Superconductivity & Magnetism

John Bowers
Principal Investigator, *Quantum Optics*

Lynn Cavazos
Outreach Staff

Marquita Christensen
Administrator

Larry Coldren
Principal Investigator
Processing and Patterned Growth

Joe Gonzales
Student Summer Researcher

Fiona Goodchild
Outreach Coordinator

Arthur Gossard
Assistant Director

Archie Holmes
Graduate Student

Evelyn Hu
Director

Liu-Yen Kramer
Outreach Staff

Pierre Petroff
Principal Investigator, *Materials Growth*

Karen Pruett
Undergraduate Researcher

David Sanchez
External Advisory Board

Edward D. Wolf
External Advisory Baord

Henry Yang
Chancellor

Center for Analysis and Prediction of Storms

F. Carr
Associate Director

Kelvin Droegemeir
Director

Deanna Eades
Administrative Assistant

Nancy Merglerl
Interim Sr. Vice President and Provost

J. T. Lee
FAA Program Manager

D. Lilly
Director Emeritus

John McGinley
External Advisory Board

Renee McPherson
Oklahoma Climetological Survey

K. Nixon
Center for Computational Geosciences

Alan Shapiro
Research Scientist

John T. Snow
Dean, College of Geosciences

J. Straka
Assistant Professor of Meteorology

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Item 12: ERC Indicators Database
Item 13: Background Material on NSF Center Programs
Item 15: Material Research Laboratories Reviewer Letter
Item 16: Material Research Laboratories

Item 17: Background Material on NSF Center Programs
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