AN EVALUATION OF THE

NSF SCIENCE AND TECHNOLOGY CENTERS (STC) PROGRAM

VOLUME I: SUMMARY

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ABSTRACT

The Program. The National Science Foundation (NSF) launched the Science and Technology Centers (STC) program in 1989. In all, 25 university-based research centers were selected to participate for a period of up to 11 years. The centers were established in order to accomplish three goals. First, the new program would promote *the performance of cutting-edge, fundamental research* in all areas of science. Second, these new centers would also initiate efforts to *improve the quality of our science and mathematics education*. Third, the centers would combine the scientific and engineering resources at our universities with those of the Nation's Federal laboratories and of private industry in order to *enhance the transfer of knowledge* among these different groups. The 25 centers selected by NSF as STC sites represented a broad spectrum of biological, computer and information, geological, mathematical, and physical sciences; a typical center embodied a number of disciplines. These centers also represented a complement to the more traditional individual investigator grant as a means of supporting university-based fundamental research. A key question concerns how well this type of research center fills a niche in the research ecology of the scientific and engineering fields that NSF supports.

The Evaluation. This evaluation, conducted in 1995-96, had three objectives: 1) to provide relevant and timely information to NSF decisionmakers considering whether or not to continue support of the STC program as presently constituted; 2) to document whether or not the STC program's research centers were, in the aggregate, accomplishing their research, education, and knowledge transfer objectives consistent with the original rationale for the STC program; and 3) to provide inputs to a pilot evaluation process under the Government Performance and Results Act (GPRA). The evaluation approach was built around the three basic dimensions of STC activity: research, education, and knowledge transfer. For each of these dimensions of activity, five aspects are documented for all centers: *goals, achievements*, *impacts*, *responsiveness to changing opportunities*; and *institutional change.* In each case, the study sought to identify aspects uniquely attributable to the center mechanism of operation. Four separate but related data gathering strategies were employed in this study: historical review; analysis of secondary data; bibliometric and patent analyses; and surveys of a variety of populations associated with the centers.

STC Financial Resources. Funding of the Science and Technology Centers through 1995 by NSF totaled $330 million, and by other, government and private sponsors totaled $487 million for a grand total of **$817 million**. NSF has achieved a significant leverage on its own investments in the STC program, attracting roughly $1.50 in investments by others for every dollar of NSF funding.

Organization, Human Resources and Infrastructure. The typical center involved three to four universities, more than 7 private sector firms, and 2 Federal laboratories, although there were varying degrees of involvement in these partnerships and considerable variation from center to center. In 1995, there was a total of 762 faculty members at the 25 STCs -- or an average of 30 faculty members per center. In 1995, the 25 STCs had over 500 postdoctoral fellows and close to 1,000 graduate students, or an average of 21 postdocs and 40 graduate students per center. The centers were generally

below national norms in reaching members underrepresented groups among their graduate students, but attracted more foreign born graduate students than the norm. Many centers provided state-of-the-art instrumentation that would be beyond the range of any single investigator or small group. All centers operated state-of-the-art computational resources.

Research Accomplishments. A key finding of this study is that as a group, the centers have breathed life into the term "Science and Technology Center". The STC program as a whole behaves as an infrastructure program in the most profound sense. The breadth, depth and degree of integration of the centers' research activities mean that the program is much more than simply an instrumentation program. First, the centers develop research tools in the broadest sense, including not only new instruments but also new research methods, new modes of data analysis, and new approaches to organizing complex experimental programs to achieve results not obtainable previously. Second, and even more important, the centers' tool development activities are deeply imbedded in productive research programs which both require the new tools and make possible their continued development. These fundamental characteristics of the program are valid across the full spectrum from basic to applied research, so that many different types of center can - and do - operate successfully under the STC framework. Thus, with the general program orientation of integrated infrastructure development as a foundation, the individual centers have taken a variety of approaches and developed distinctive identities. The center mode of operation opens the possibility of more elaborate forms of organization and coordination of research than would be possible in an individual investigator's lab or in informal collaboration among small groups of individual investigators. We find that the STC program has in fact realized that promise in large measure, encompassing a variety of organizational types reflecting the varied research missions of the centers.

Bibliometric Assessment. The STC program as a whole has compiled a creditable publication record. STC articles were cited 1.69 times as often as the average U.S. academic paper for the same journals for the same years. Analyzed by field of publication, STC papers achieved especially high relative citation rates in Physics, Biomedical Research, and Engineering and Technology, with the average citation rates of center papers exceeding the norms in these fields by factors of almost 1.8. Analysis of the centers' 1989-1995 papers revealed that as a group the centers are publishing in journals with a somewhat higher influence level than average. Averages for most of the individual centers are concentrated in a band of relative influence values between 1.0 (average) and 1.5; three centers have values somewhat below average, while four have values substantially greater than average. STC papers tend to be published in journals oriented more toward basic than applied research. STC papers in Mathematics and in Chemistry have unusually high representation of industrial organizations in their authorship, and STC papers overall have relatively high industrial representation among citing organizations. There is no evidence that STC research is tilted toward the applied end of the spectrum compared to the average papers in the Centers' respective fields. STC publications in four fields stand out as having relatively high outside subfield-to-inside subfield citation ratios - Mathematics, Biology, Engineering & Technology, and Chemistry.

Education. The individual centers have developed a broad range of educational components and are achieving the objectives established under this program. They build directly upon their specific research missions in establishing educational programs, whose *goals* include reaching K-12 teachers and students, undergraduate and graduate students, and the general public, as well as women and underrepresented minorities. In some cases, mid-career and faculty enhancement education is also a focus. According to PIs, the center context is an especially effective one from which to develop and operate educational initiatives. Key factors contributing to this include the subject matter orientation of the individual centers, interdisciplinary orientation of the research, the ability to hire staff to specialize in these efforts, the availability of staff and students in support of these programs, and the longer term funding context within which these programs may be operated. A special survey of STC graduates documents that STC graduates are well prepared for their subsequent careers, whether they be in academia, industry or research laboratory. STC graduates score highly on both self-ratings and supervisors' ratings of job performance compared to peers, across all sectors of employment and all dimensions of performance.

Knowledge Transfer. Knowledge transfer activities are seen by the centers as stimulants to the development, use and dissemination of new center research. In general, centers with the *goal* of a stronger focus on applications and tools also have more vigorous interactions with industry than do others. Centers have structured their knowledge transfer instruments to facilitate a bi-directional flow of information. Center *achievements* include successfully collaborating with participating organizations, establishing effective channels of communications, obtaining patents and licenses, and disseminating and maintaining electronic data. The impacts cited most often were instances of transfer of center research results or their application in industry, or development of commercial products whose origins lay within center research. To date, relatively few patents - 76 - have been issued to the STCs as a group, and around half of these are credited to a single center. STC patents have a relatively short technology cycle time, are relatively heavily linked to science, and STC research papers are consistently cited by the universe of U.S. patents at a rate 2-4 times higher than the average academic paper, suggesting that they are making superior contributions to technology based upon their research activities.

STC Management Issues. PIs complimented OSTI's sponsorship of periodic conferences for center staffs that allow for exchange of ideas on problems and issues. Favorable comments were made concerning both proactive technical support, and reactive responses to requests for guidance. However, there are problems with how the STC program is administered; a number of PIs expressed concern that there is inadequate coordination between OSTI and the NSF directorates with which the centers are affiliated. There are important inconsistencies both among the directorates (in how they supervise operations of the various centers) and over time (with changes in policies governing any given center). PIs expressed concern over the dissolution of the STC advisory committee which could make judgements and answer questions about the overall program. OSTI and the directorates fail to adequately coordinate the STC site review process. The site visits are not well coordinated between OSTI and the directorates, with conflicting messages being given by the review teams from different directorates in any given review cycle, or within a directorate over time. Finally, there are problems with the volume and frequency of OSTI data requirements and other requests for information from the centers; at the same time, there are problems with the usability of the OSTI database and the reliability of some of the data it contains.

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Mary Look, Michael Hetu and George Nozicka reviewed the OSTI and NSF databases and OSTI hard copy files on the 25 STCs in order to provide the historical data on funding, staff and students presented in Chapter 3, Volume II, and in the individual center profiles contained in Volume III.

John Perko and Fran Narin of CHI Research Inc., Haddon Heights, New Jersey, performed the data gathering and analysis for the bibliometric and patent analyses that appear in Chapters 5 and 9 of Volume II, in the center profiles in Volume III, and in the Volume IV technical appendix C.

We would like to thank Erich Bloch, former director of the National Science Foundation, and William Harris, James McCullough, Lynn Preston and the many other NSF staff who helped us in the process of preparing the historical review of the STC program which appears in Chapter 2, Volume II.

Throughout the life of the project, we have received valuable and timely support from Dr. David Schindel, our Technical Officer on this project, and Senior Advisor, Office of Science and Technology Infrastructure. We also express our appreciation to Drs. Nathaniel Pitts and Sonja Sperlich of OSTI, and to the other OSTI staff who helped us in many ways over the life of the project.

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PREFACE

The present evaluation represents an exciting opportunity in science program evaluation in at least two respects. First, the Science and Technology Centers (STC) program itself constitutes an innovative approach to *the support of fundamental science at university-based research centers* by the National Science Foundation (NSF). NSF has traditionally funded individual investigators as the principal means for performance of such research. The STC program constitutes a new and hopefully productive means both for addressing new classes of fundamental research problems, and for promoting improvements in science education and in communication among academia, industry and Federal laboratories.

Second, the STC program offers an exciting opportunity from the program evaluation perspective as well. As a program, it is an extremely complex undertaking and therefore requires *an innovative and comprehensive approach to evaluation itself*. In fact, NSF convened a special working group several years ago just to consider the critical dimensions for such an evaluation of an NSF research centers program. We have made use of historical analyses, secondary data analyses, surveys, and bibliometric and patent analyses in the present study, and sought to provide an integrated assessment of program performance.

However, the innovative nature of the program and the diverse approaches required for its evaluation warrant a cautionary note. Originally, it had been the hope to perform case studies of several of the centers in order to understand the operational dynamics behind the survey findings. This proved not to be possible, and thus some questions remain open regarding why certain programs operated in the manner they did, and achieved what they did.

Moreover, the STC program was designated as a pilot project under the provisions of the Government Performance and Results Act. However, the question of how best to measure the success of a fundamental research program is still open. In preparing the study design for the present evaluation, we outlined a rationale for incorporating a series of qualitative dimensions of performance in the evaluation of a fundamental research program, and for the use of an expert panel to assess the quality of the program's research and other accomplishments on the basis of structured, qualitative data. However, such a panel was not included in the study. This limitation may be overcome in some measure through review of the evaluation data by a special panel of the National Research Council which is operating in parallel with the evaluation.

Finally, despite an impressive history of accomplishments by many individual centers, the Science and Technology Program has been in operation for less than a decade. Fourteen of the 25 centers funded have been in operation for only five years. It will likely be a number of years yet before the full fruits of the program are realized; the definitive story of the STC Program is yet to be written.

Several reports have been prepared from this evaluation study, including:

Volume I: Summary Overview of the study objectives, context, findings, conclusions and recommendations;

Volume II: Technical Evaluation Report for use of NSF program staff, a National Research Council special STC Program Review Panel, individual center staff, and other interested technical readers;

Volume III: Series of 25 individual Program Profiles that describe the research, education, and knowledge transfer activities, achievements and impacts of each of the individual research centers;

Volume IV: Technical Appendix which includes copies of the survey questionnaires used in the study, and sets of tables from the surveys, and bibliometric and patent analyses.

The present Volume I Summary highlights the key findings and recommendations of the study, but does not provide the documentation and greater detail found in the Technical Report.

The Volume II Technical Report is designed to provide a complete record and documentation for the entire study. It provides extensive background information, details on the study design, and a complete review of all data and analyses. This report is accompanied by an STC database (available in FileMaker Pro) containing a wide range of secondary and primary data that may be obtained through NSF technical staff; this data base is maintained by the Office of Science and Technology Infrastructure (OSTI), Office of the Director.

In Volume III, the reader will find a set of 25 individual STC program profiles, organized by affiliated NSF directorate. For each center, we provide a basic overview of their research, education and knowledge transfer missions, organizational resources, senior staff, and organizational affiliations. More detailed information follows concerning their goals, activities, achievements, impacts, and institutional characteristics with respect to their key components.

Finally, in Volume IV, four appendices are provided with this report: Appendix A provides copies of the individual questionnaires used in our surveys, while Appendix B provides selected tables referred to in the text to this report based upon the surveys of STC alumni and their supervisors. Appendices C and D provide supporting data from the bibliometric and patent Analyses. A series of separate databases also accompany this report and are available from the OSTI program staff.

1.0 INTRODUCTION

1.1 CONTEXT AND OBJECTIVES OF STUDY

Traditionally, the National Science Foundation has used the individual investigator grant as the principal mechanism for supporting fundamental research by scientists and engineers located at institutions of higher education throughout the United States. More recently, NSF has provided funding in support of research centers that consist of a number of scientists working together to solve fundamental research problems. In the process of developing various research center programs considerable controversy has arisen with individual investigators expressing concern over both competition for funds, and the quality of research supported in such centers. A key question here concerns how well one type of research center fills a niche in the research ecology of the scientific and engineering fields that NSF supports.

The Science and Technology Centers program was given an auspicious introduction in 1987 by then President Reagan who announced, as a part of his State of the Union address, that the National Science Foundation would establish a number of these science and technology centers at research universities located throughout the country. These centers were being established in order to accomplish three goals. First, the new program would promote *the performance of cutting-edge, fundamental research* in all areas of science. Second, these new centers would also initiate efforts to *improve the quality of our science and mathematics education*. Third, the centers would combine the scientific and engineering resources at our universities with those of the Nation's Federal laboratories and in private industry in order to *enhance the transfer of knowledge* among these different groups.

NSF launched the Science and Technology Centers (STCs) program in 1989 when it initially funded the first cohort of 11 centers; an additional cohort of 14 more centers were subsequently established in 1991. Initially, the STC program was operated by the Office of Science and Technology Centers Development, later to become the Office of Science and Technology Infrastructure -- a part of the NSF directorship. Subsequently, individual NSF scientific directorates took over technical supervision of those individual centers with affiliation being based upon corresponding research expertise. Today, management responsibility is shared between OSTI and the sponsoring NSF directorates. A list of the 25 STCs appears in Table 1.

It is now eight years since the program got underway, and the time has come to examine what has been accomplished by these centers. In 1995, Abt Associates Inc. was commissioned by the National Science Foundation (NSF) to conduct an evaluation of the Science and Technology Centers (STC) program. The evaluation was initiated in order to accomplish three principal objectives:

To provide relevant and timely information to NSF decisionmakers who will be considering whether or not to continue support of the STC program as presently constituted; in addition, if the decision is favorable, to suggest such modifications in the management, organization, and support of research centers as may warrant consideration.

TABLE 1 NSF SCIENCE AND TECHNOLOGY CENTERS AND UNIVERSITY SPONSORS, BY SCIENTIFIC DIRECTORATE

Biological Sciences (BIO)

Center for Biological Timing, *University of Virginia*
Center for Engineering Plants for Pathogen Resistance, *University of California, Davis*
Center for Molecular Biotechnology, *University of Washington*
Center for Magnetic Resonance Technology and Basic Biological Research, *University of Illinois, Urbana-Champaign*
Center for Light Microscope Imaging and Biotechnology, *Carnegie Mellon University*
Center for Microbial Ecology, *Michigan State University*

Computer/Information Science and Engineering (CISE)

Center for Discrete Mathematics and Theoretical Computer Science, *Rutgers University*

Center for Computer Graphics and Scientific Visualization, *University of Utah*
Center for Research on Parallel Computation, *Rice University*

Geosciences (GEO)

Southern California Earthquake Center, *University of Southern California*

Center for Clouds, Chemistry, and Climate, *University of Chicago*
Center for Analysis and Prediction of Storms, *University of Oklahoma*
Center for High-Pressure Research, *SUNY Stony Brook*

Mathematical and Physical Sciences (MPS)

Center for Advanced Liquid Crystalline Optical Materials, *Kent State University*

Center for Superconductivity, *University of Illinois, Urbana-Champaign*
Center for Computation and Visualization of Geometric Structures, *University of Minnesota*
Center for High-Performance Polymeric Adhesives and Composites, *Virginia Polytechnic Institute & State University*
Center for Quantized Electronic Structures, *University of California, Santa Barbara*
Center for Ultrafast Optical Science, *University of Michigan*
Center for Particle Astrophysics, *University of California, Berkeley*
Center for Advanced Cement-Based Materials, *Northwestern University*
Center for Synthesis, Growth, Analysis of Electronic Materials, *University of Texas*
Center for Photoinduced Charge Transfer, *University of Rochester*

Office of Polar Programs (OPP)

Center for Astrophysical Research in Antarctica, *University of Chicago*

Social, Behavioral and Economic Sciences (SBE, co-funded with CISE)

Center for Research in Cognitive Science, *University of Pennsylvania*

- To document whether or not the STC program was accomplishing its research, education, and knowledge transfer objectives consistent with the original rationale for the STC program; here the focus is specifically directed toward the question of whether the mechanism of the research centers fulfills a unique niche in the ecology of the research community.

- Finally, consistent with instructions from the Congress in the Government Performance and Results Act (GPRA) of 1993, this study would help to test various approaches for applying GPRA to a government program that supports fundamental research.

1.2 DESIGN AND IMPLEMENTATION OF STUDY

It is important to recognize that the purpose of the Science and Technology Centers program evaluation is to evaluate the program as a whole, but *not* to evaluate the individual centers *per se* -- a task carried out regularly via NSF's existing review mechanism. Nevertheless, since the centers are the vehicle by which program-level goals are to be achieved, some assessment of the performance of the individual centers is essential to understanding what the program as a whole has achieved relative to its goals.

Prior to developing our assessment approach, Abt Associates carried out several preparatory steps including a review of documents regarding the startup of the program and site visits performed by review committees, and the conduct of interviews with NSF staff and others who were very familiar with the program and the centers. We then travelled to five of the centers to meet with center leadership, scientific and educational staff, and students in order to obtain center perspectives on the STC program evaluation, to gain a clearer understanding of how the component activities of an STC combine to form an integrated whole, and to explore the implications of this phenomenon for performance assessment.

Our preliminary investigations led us to four observations:

- The STC program reflects NSF's commitment to nurture the continuing vitality of the nation's science and technology efforts.

- The STC Program solicitations provided only general guidelines as to the types of activities which would be considered suitable for NSF support under the program.

- The fundamental basis for evaluating the performance of the STC program is qualitative and subjective.

- The qualitative and subjective basis for program assessment can provide the most effective means of meeting the requirement of accountability to the public through the vehicle of Congressional review and oversight.

Our approach to the assessment, which is guided in general terms by the principles described above, is built around the three basic dimensions of STC activity: research, education and training, and knowledge transfer. For each of these dimensions of activity, we wish to understand five aspects, two of which primarily concern the center in and of itself and three of which address the interaction between the center and the surrounding world:

1) the *goals* of each center - because the specific goals of each center are not specified centrally by NSF, but rather determined independently on the initiative of the center itself, identification of the centers' goals provides a necessary framework for the assessment of center activity;

2) the *achievements* of each center - these are the primary "results" of the centers' activities, and as such occupy a central place in any assessment of the success of the centers and the program;

3) the *impact* or *influence* of center achievements - a key consideration in the creation of the program was the goal of enhancing the linkage of university-based research to activities in other sectors in order to enhance the benefits of NSF-sponsored research for society (there is no presumption, however, that a center should be exclusively or primarily judged in this respect by its *short-term* impacts);

4) the extent and ways in which the center demonstrates *responsiveness to changing opportunities* - another aspect of effective linkage is the extent to which center activities are informed and guided by outside developments so as to maximize center achievements and positive impacts (this is, however, a matter of proper balance - there is no presumption that the best center is one which is hypersensitive to constantly changing demands from competing constituencies); and

5) the extent and ways in which the center has served as a catalyst for *institutional change* - this includes the extent to which the presence of the center elicited those adaptations in the administrative practices of the sponsoring university which are required for the center to pursue its mission effectively, and the extent to which aspects of the center approach which are successful have also proven to be of value as models either within the same institution or elsewhere.

In each case, we also seek to understand what aspects are especially or uniquely attributable to the center mechanism of operation. Exhibit 1 presents the basic questions which follow from this conceptual framework.

EXHIBIT 1 STC STUDY PARADIGM

	goal	achievement	impact/influence	responsiveness	institutional change
research	What are the key research goals of the center? Which important scientific problems are targeted? How are the goals distinctive as a consequence of the center mechanism?	What are the most important research achievements of the center? How, if at all, were they dependent upon the center mechanism?	What are the most important impacts of center research? How, if at all, were they made possible or enhanced by the center mechanism?	How does the center's record demonstrate responsiveness to changing scientific opportunities? How, if at all, was this made possible or enhanced by the center mechanism?	What are the most important changes, if any, which your university has made in order to accommodate the center's goals and approaches in *research*? What impact, if any, has the center's approach had on the work of peers in the research community?
education and training	What are the education and training goals of the center? Which populations are targeted? How are the goals distinctive as a consequence of the center mechanism?	What are the most important education and training achievements of the center? How, if at all, were they dependent upon the center mechanism?	What are the most important impacts of center education/training? How, if at all, were they made possible or enhanced by the center mechanism?	How does the center's record demonstrate responsiveness to the education and training needs of academic science, of industry, and/or of society more generally? How, if at all, was this made possible or enhanced by the center mechanism?	What are the most important changes, if any, which your university has made in order to accommodate the center's goals and approaches in *education*? What impact, if any, has the center's approach had on the work of peers in the academic science community, on educators in university or secondary education, or on others?
knowledge transfer	What are the knowledge transfer goals of the center? Which knowledge transfer partners are targeted? How are the goals distinctive as a consequence of the center mechanism?	What are the most important knowledge transfer achievements of the center? How, if at all, were they dependent upon the center mechanism?	What are the most important impacts of center knowledge transfer? How, if at all, were they made possible or enhanced by the center mechanism?	How does the center's record demonstrate responsiveness to opportunities for knowledge transfer which will impact the activities of research and industrial organizations and maximize the value of center research to society? How, if at all, was this made possible by the center mechanism?	What are the most important changes, if any, which your university has made in order to accommodate the center's goals and approaches in *knowledge transfer*? What impact, if any, has the center's approach had on the work of peers in the academic science community, on researchers in industry, or on others?

Four separate but related data gathering strategies were employed in this study: a historical review; the use of secondary data; bibliometric and patent analyses; and the use of eight questionnaires for purposes of gathering information on various relevant STC population groups. In addition, a systematic panel review of all of these data was proposed in order to develop conclusions regarding the performance of the program; NSF elected to delegate responsibility for this component of the evaluation to a special panel of the National Research Council.

Historical Review. Among the first data gathering efforts undertaken was the development of a history of the STC program. The purpose of the history was to chronicle the development of and changes in the basic components of the STC program, including the program's goals, eligibility, guidelines, criteria for review, review procedures, and management policies and practices. While the program began with a specific set of goals stipulated by NSF, the history also identified additional goals that emerged as being of importance for the Centers and/or the Program as they developed.

Secondary Data Analysis. OSTI gathers information from all 25 STCs on an annual basis; the available data concern the characteristics and operations of these programs. In addition, site visit teams periodically visit the STCs, conduct on-site interviews and observations, and report to NSF on their findings. Moveover, periodic renewal applications provide additional information. Finally, various NSF databases contain additional information regarding funding, staffing, students and the like. This relevant information was available to the evaluation effort and there was no need to regather the data. Various hard copy and electronic data sources were reviewed early in the project, including award applications, annual reports, site visit reports, STC databases maintained by OSTI, and other NSF databases. These data, in turn, provided a basis for describing many aspects of STC operations, including amount and sources of funding, staff, students, facilities and equipment.

Bibliometric and Patent Analyses. Publications of scientists working with the STCs were identified in order to document:

a. The *number of publications and quality of journals* in which they appeared as compared with other papers in the same subfields and years;

b. *Institutional and cross sectional authorship* -- that is, whether the papers show wide institutional and corporate linkage. For example, if the papers have higher institutional coauthorship and especially if they are highly coauthored with scientists in private sector firms compared to other papers in the same subfields and years, that would be an indication of the intersectoral impact of the centers;

c. *Citation frequency*;

d. *Cross-sectoral and interdisciplinary citation* -- whether the papers are cited by authors from different sectors and in journals from different sub-fields;

e. *Journal Influence* -- or whether the centers are publishing in high impact journals, which is a useful surrogate for expected long term citation frequency for papers which are too new to have established citation records of their own;

f. *Research Level* -- Journals can be classified on a scale from 1 to 4, with 1 representing the most applied focus and 4 the most basic. The average level of the journals in which center papers were published was compared with norms for the respective subfields.

Patent analyses were also employed. We began by examining various indicators of the likely impact of the patents on a center-by-center basis. For the older patents associated with the Centers, that is, patents issued in 1992 or before, we looked at whether they are cited in subsequent patents, a direct measure of their impact. We also generated indirect indicators described below. For the newer patents, which were not likely to have yet received many citations, we looked only at more indirect indicators, specifically,

a. *Technology Cycle Time* - whether the patents reference very recent patents, an indicator that they are in fast moving technologies.

b. *Science Linkage* - whether the patents cite to the scientific literature, an indication that they are leading edge.

c. *Linkage to highly cited earlier patents* - whether the patents themselves reference to earlier highly cited patents, which would be indications that they are in hot clusters.

Surveys. In order to gather primary data of the type called for in the evaluation paradigm, a total of eight surveys were performed -- each reaching a specific population affected by the STCs. Open-ended questionnaires were first developed for the following five population groups:

Principal Investigators
Advisory Board Chairmen
University Deans or Provosts
Industry/Federal Laboratory Representatives
Educational Outreach Collaborators

Items in these open-ended questionnaires concerned the goals of the centers, their achievements and impacts, and other relevant matters as appropriate for the particular respondent group.

In addition to the above five open-ended questionnaires, a sixth questionnaire, an activities inventory using closed-ended items, was addressed to

Center Administrators

in order to obtain information from the STCs regarding the specific types of education and knowledge-transfer activities they provided.

Finally, in order to learn more about the nature of the educational experience of graduates, and their subsequent job performance, two additional populations were surveyed:

STC Graduate School Alumni

Alumni Job Supervisors

The graduate students were asked to report upon their educational, research, and knowledge transfer experiences while participating in the STC, how they found their job, what their present job responsibilities entail, how they would rate themselves in comparison with their peers on the job, and what aspects of the STC experience were most or least valuable for their present job requirements. Supervisors, in turn, were asked to comment upon the job responsibilities and the performance of the STC graduates relative to their peers on the job.

For many of the questionnaires, the entire population was surveyed (e.g., PIs, Advisory Board Chairs, Deans, graduates and their supervisors), and no sampling methods were required. For the industrial and educational outreach partners, centers were asked to identify three individuals who had worked with the Centers in each of the respective capacities.

The surveys were conducted during the period of September 15, 1995 through March 1, 1996. Individual, open-ended questionnaires for each of the recipient groups were returned as follows:

QUESTIONNAIRE	N MAILED[1]	N RETURNED	RESPONSE RATE
Principal Investigator	25	25	100%
Activities Inventory	25	25	100%
Advisory Board Chair	25	21	84%
Dean/Provost	25	21	84%
Educational Partners	84	55	65%
Industrial Partners	75	47	63%

The response rates to these questionnaires were sufficient to provide the data needed to prepare a series of individual center profiles (see Volume III), and for the performance of cross-center assessments (which appear in the Technical Volume II) that are summarized in this Volume.

For the graduate/supervisor surveys, a total of 518 names of STC graduates were initially available for contact. Of these, 412 were located, determined to be presently employed, and mailed a survey. Over half of these (217, or 53%) returned completed questionnaires. We also requested permission from all graduates to contact their supervisors, and we ended up contacting 275 supervisors for the survey. Responses were obtained from 257 of these supervisors (93%). Supervisor interviews were available for most of the graduates who responded, and for 90 of the non-respondents. We compared supervisor ratings for the non-respondents with those for respondents, and found no significant difference, suggesting that at least in job performance the data from responding graduates are reasonably representative of the entire STC graduate population.

2.0 SIGNIFICANT HISTORICAL FACTORS SHAPING THE STC PROGRAM

ÊÊÊÊ[1] A few centers provided more or fewer than three names for one or both of the partner categories.

Before providing information on the operations of the program, and various achievements and impacts, we first provide a brief overview of the historical context to this program that was documented as a part of this study.

> ***The emergence of large-scale, integrative and multidisciplinary research centers is a logical development in science in light of two factors.***

First, recent decades have witnessed the pervasive influence of concepts of computation and simulation across the broad spectrum of science, driven by the spread of affordable, high-powered computers. Second, new instrumentation technologies have offered increasingly powerful experimental tools with practical applications in many fields. Indeed, there were already many examples of *applied* research centers and national labs supported by the various mission agencies of the Federal government such as the DOE, NIH and USDA. At the time of the STC program's inception, NSF itself already sponsored *fundamental* research at the National Center for Atmospheric Research, such university- based programs as the Materials Research Laboratories and the Engineering Research Centers, and a variety of other university-based, basic research facilities.

> ***When the Science and Technology Center concept was first proposed, it was viewed in academia with mixed emotions.***

In general, interdisciplinary research remained the object of considerable skepticism and suspicion in an academic world whose departments, research mechanisms, standards of judgment, and traditional funding sources were built within the framework of disciplinary boundaries. Indeed, the long-term tendency of successful interdisciplinary research initiatives appeared to be an evolution toward institutionalization as new disciplines in their own right.
Many individual investigators saw this program as further competition for scarce resources. Concern was expressed over the lack of peer-review of the research that would be performed in these centers, once given initial funding approval.

> ***In one way or another, the President and Congressional leaders hoped that the dual emphasis on science and technology, combined with an emphasis on basic research firmly anchored to education and knowledge transfer, would increase the likelihood that Federal science investments would, over time, contribute to U.S. global competitiveness.***

The capture by Japanese manufacturers of substantial shares of the American markets for such highly visible consumer durables as automobiles and television sets, with products competitive in performance, superior in manufacturing quality and lower in cost than their American counterparts, was a shock to Americans who had grown accustomed to the technological and economic superiority enjoyed by the nation during the postwar years. The government was seen to have a logical role in stimulating economic progress via the creation of new fundamental knowledge and the training of technical talent which could apply that knowledge. The Reagan administration increased support to basic research, and sought to emphasize *basic science of particular importance to industrial competitiveness*.

> ***Industry representatives too believed that university-based science would be of value to their***

long-term competitiveness

The importance of stimulating university-based research relevant to industry was further underlined by a clear trend for major industrial companies, under intense international competitive pressure, to rationalize operations and cut costs by consolidating in-house research programs and redirecting them toward more applied, shorter-term targets. Under these conditions, industry's long standing support for government funding of more fundamental research in universities was, not surprisingly, renewed and strengthened.

There was an emerging consensus on the need to better prepare the Nation's future technical workforce.

Four separate manpower issues were prominent in the rhetoric of the time: the *quantity* of technical talent in aggregate, the *quality* of the available technical talent, the *distribution* of technical talent among the different fields, and the *composition* of the technical workforce. NSF itself was emerging as a leader in addressing issues relating to science education. It was recognized that efforts to improve the quality of technical education would have to begin with basic skills, and thus was born a number of major initiatives in K-12 education (to improve both the teaching and the content of science, and the means of teaching it to students), and the emphasis on reaching out to groups underrepresented in the sciences.

NSF already had initiated a program for the engineering disciplines that served, in certain respects, as a model for the planned STC program.

The Engineering Research Centers program provided an example of a program model already in operation that influenced thinking about the STC program. In particular, it brought innovative approaches to academic research and education, and forged vital links to industry. It, too, constituted a three-way partnership between government, university, and industry. However, it differed in one very important respect. Academic science had not the long tradition of working on industrial and government problems, and training a workforce for industry, agriculture and commerce that had typified the engineering disciplines.

The 1986 Packard-Bromley Report laid the conceptual groundwork for a Federal S&T initiative.

The Packard-Bromley Report emphasized the need to use the existing strengths of both university and industry to address problems of long-range national scope. The report asserted that it was now time to take the multi-disciplinary, problem-oriented engineering centers approach and adopt it within the broader view of the science and technology centers. The report asserted that "much of the most exciting research to be undertaken in the future will not fall within the traditional natural science disciplines. As the questions relating to science and technology become more complex, and demand teams of researchers with a board range of expertise, it will be to the Nation's advantage to provide multidisciplinary centers for their solution. ...As presently constituted, the universities cannot comfortably accommodate interdisciplinary research. It will be important for the Federal government to provide funding to enhance these interdisciplinary activities within the universities." The report further emphasized that "emerging technologies are the foundation of industrial competitiveness, and depend heavily on future developments in basic research.[2]

NSF Director Erich Bloch, an NSF task group, and an NAS panel all helped to shape the conceptual basis and initiation of the STC program

Within NSF, then-Director Erich Bloch stressed the need for a multidisciplinary center approach, for a new form of social organization for research performance in the university and elsewhere, for improved education programs to train scientists, and for cooperation and knowledge transfer between academia and industry. The NSF Task Group on Strategic Planning for Centers and Groups emphasized a series of unique contributions that such centers might make, including interdisciplinarity, improved infrastructure, better undergraduate and graduate education, university-industry collaboration, and greater technology awareness and usefulness stemming from fundamental research activity.

The NAS Zare Panel Report was less sympathetic to the strategically-managed research program idea in general. It expressed opposition to forms of intervention required to influence subject matter, organization, or mode of operation of research. It also rejected interdisciplinarity as a defining feature of an STC's research program (although it did not reject this form of science, where warranted) and it rejected the idea of identifying "the most promising areas of science". It also downplayed the "technology" element of the STC concept, and the idea that industrial support be a prerequisite for approval. The Zare panel, instead, emphasized that the STCs should exploit opportunities in science where the complexity of the research problems or the research needed to solve these problems "require the advantages of scale, duration, or facilities that can be provided only by the center mode of research."[3]

The program was initiated by the Office of Science and Technology Centers Development (later the Office of Science and Technology Infrastructure) while the individual NSF science directorates with the appropriate subject matter specialization took over substantive supervision of the respective centers.

The Office of Science and Technology Centers Development was formed by Erich Bloch to take leadership in the program's initiation and development, with an emphasis on playing a coordinating role. The individual directorates with the substantive expertise took on the role of technical coordination of the individual centers. A NSF advisory board was appointed to provide oversight and professional consultations for NSF staff, but this was terminated as a result of an executive order limiting the number of federal advisory committees.

ÊÊÊÊ[2] *Report of the White House Science Council Panel on the Health of U.S. Colleges and Universities*, Executive Office of the President, Office of Science and Technology Policy, February 1986, p. 16.

ÊÊÊÊ[3] See Volume 1, Chapter 2, Appendix 2.1 of this report for the Zare panel's summary of its full set of recommendations.

3.0 Financial, Organizational and Human Resources of Centers

3.1 Financial Resources

3.1.1 Overview

The Science and Technology Centers program constitutes a significant investment over the past decade both by the National Science Foundation and by other sponsors.

Direct or core funding from NSF by means of cooperative agreements with the 25 centers implemented during the period 1989 through 1995 amounted to **$330 million**.

An additional **$487 million** in support directly to the centers was received from other sources, as follows:

State, foundation, and industry grants and awards	$147 million
Donations of equipment, other contributions, and fees	$185 million
Host university funds (salaries, stipends, facilities, etc.)	$155 million
Total Other STC Support	***$487 million***

Thus, a total of **$817 million** was awarded directly to the individual centers over this seven year period.

3.1.2 Support by Other Sources

Total non-Federal support of $487 million to individual investigators affiliated with the STCs also exceeded core funding provided by NSF

Contributions directly to the centers by states, businesses, foundations, and host universities exceeded those from all sources other than NSF itself. These consisted of various grants and awards, donations, and university funds for faculty salaries, buildings and renovations, and student stipends.

Non-Federal grants and awards A total of $147 million went largely to BIO, MPS and CISE affiliated centers.

Donations A total of $185 million, consisting largely of equipment and other contributions, went disproportionately to CISE centers (3 times the average amount) and centers affiliated with BIO.

Host University Funds A total of $155 million, including $87 million for faculty salaries, $44 million for buildings and renovations, and $24 million for student stipends went disproportionately to CISE, BIO, and MPS centers.

CISE-affiliated centers seem to have been far and away the most successful in obtaining funds from such non-Federal sources, followed by BIO- and MPS-affiliated centers.

3.1.3 LEVERAGE OF NSF FUNDS

NSF has achieved a significant leverage on its own investments in the STC program, attracting roughly $1.50 in investments by others for every dollar of NSF funding.

The most conservative estimate of the leverage obtained under the STC program would be as follows:

NSF core funds to STCs	$330 million
Other direct awards to STCs	$487 million
Total Direct STC Awards	***$817 million***

NSF leverage for the seven year period was approximately l.5:1; for every dollar invested by NSF, $1.48 was invested by others.

3.1.4 FUNDING OF THE INDIVIDUAL CENTERS

While the above overview of total STC funding provides a good sense of the *scale of the total STC program*, and the diverse sources of support that have been associated with the program, there were in fact important *differences among the individual centers* in terms of support received.

Not all STCs received equal NSF core funding support.

STC core funding between 1989 and 1995 amounted to $330 million, or an average of $13 million per center over the lifetime of the STC program. However, there were significant differences in the funding levels received as a function of funding cohort as well as affiliated directorate. Briefly summarized:

Cohort and funding period (Dollars=millions)	***Total Funds***	***Avg. Per Center***	***Per Ctr Per Year***
Cohort 1 centers (11 centers, funded 1989-1995)	$201	$18.3	$2.6
Cohort 2 centers (14 centers, funded 1991-1995)	$129	$ 9.23	$1.9
All 25 centers	***$330***	***$13.2***	***$2.2***

Cohort 1 centers have operated two years longer than Cohort 2 centers, received on average of almost twice as much in cumulative STC core funding, and have always been funded at significantly higher annual levels. The Cohort 2 centers have never caught up with Cohort l centers in average annual funding. In terms of average core funding provided to the centers by the different directorates, the most generous per center support has been provided by CISE. Next came MPS and SBE, BIO, GEO, and finally OPP.

Some STCs did much better than others in terms of total funding as well.

Total funding between 1989 and 1995 amounted to $1.5 billion, or an average of $60 million per center over the lifetime of the STC program. As with core funding, there were significant differences in the total funding levels received as a function of funding cohort as well as affiliated directorate. Briefly summarized:

Cohort and funding period (Dollars=millions)	***Total Funds***	***Avg. Per Center***	***Per Ctr Per Year***
Cohort 1 centers (11 centers, funded 1989-1995)	$529	$48.1	$6.87
Cohort 2 centers (14 centers, funded 1991-1995)	$288	$20.6	$4.12
All 25 centers	*$817*	*$32.7*	*$5.45*

As with Core Funding, Cohort 1 received on average of more than twice as much in cumulative funding, and have always been funded at significantly higher annual levels.

3.1.5 CENTER INDIRECT COST EXPENDITURES

NSF has not gathered annual data in a systematic fashion on the overall disbursement of funds by specific categories of STC activity (e.g., funds used principally for research, education, or knowledge transfer). However, it provides an overview of the expenditures as proposed by the individual STCs in their most recent renewal grant application package. The most recent round of 25 STC cooperative agreements (covering a 3-year period) resulted in awards totaling $89 million (or slightly under $30 million per annum). Expenditure proposals by category were provided for $62 million of these awards. In terms of principal expenditure categories,

- 22% of funds were allocated to subcontractors (typically involving partnerships with other universities);

- 21% was allocated to cover indirect costs assigned by the host university (which cover a variety of staff, student, and facilities costs);

- 8% was assigned to postdoctoral salaries;

- 7% was allocated to cover equipment and instrumentation;

- 5% to 6% was allocated respectively to cover the costs of senior researchers, other professionals, graduate students, fringe benefits, and other materials.

3.2 ORGANIZATIONAL RESOURCES

NSF envisioned that a variety of organizational arrangements would be possible under the STC program. These included:

- cooperative arrangements among universities for the development of a critical mass of significant research capabilities;

- exploitation of center resources in support of diverse science education programs designed to serve various populations (e.g., K-12 students, university undergraduates and graduate students, the general public, and underrepresented groups);

- outreach to the private sector, Federal laboratories, state government and others in order to assure two-way transfer of knowledge from the university to various partners and vice versa.

The typical STC has an array of organizational arrangements that involve other universities, private sector firms, and Federal laboratories.

The present study determined that the typical center involved 3 to 4 universities, more than 7 private sector firms, and 2 Federal laboratories. Having described the typical center, however, we must note that in fact there were few "typical" centers. Various degrees of involvement with other organizations were apparent:

- Several centers involved relationships between five or more universities, while several centers involved only one to three universities[4]. Moreover, in some cases, multiple universities participated in the formal relationship which constituted the center, while in other cases the extent of the partnerships was more limited. Some centers involved regional linkages, while others involved academic institutions and research centers with similar scientific interests distributed across a broad geographic area.

- Several centers had relationships with from 10 to more than 20 private firms, while others had relations with few private firms. Some of these relationships were quite complex, while in other cases the firms had only limited involvement. Certain large firms show up as partners with a number of centers (e.g., AT&T Bell Labs, Allied Signal, DEC, Eastman Kodak, Ford Motor Company, General Electric, General Motors, Hewlett Packard, Hoechst-Celanese, IBM, Motorola, Silicon Graphics, Sun Corporation, and Texas Instruments). Some other major corporations are working with only one STC. Finally, there are a number of instances of much smaller firms (some of them start-ups) having relations with individual centers.

- Finally, several centers involved four or more Federal laboratories, while several other centers had no arrangements with any Federal labs. Again, in some cases, the laboratories were actual members of the center, while in others the laboratory had a limited role. Some Federal labs participate in more than one center, including Argonne National Laboratory, Jet Propulsion Laboratory, Lawrence Berkeley Laboratory, Los Alamos National Laboratory, and Sandia National Laboratory. Some national laboratories have relationships with only one STC (e.g., MIT's Lincoln Laboratory, Naval Research Laboratory, National Center for Atmospheric Research, Smithsonian Astrophysical Observatory, U.S. Army Supercomputer Laboratory).

ÊÊÊÊ[4] With respect to educational arrangements, we concentrate here on relationships with universities. In our educational chapter we also discuss partnerships with local school districts and other public education institutions -- aquariums, museums, planetariums, and zoos -- which tend to be highly idiosyncratic and localized.

Other forms of organizational relationship were also identified. A number of centers have established relationships with state and local government agencies and research entities, while some of the centers have developed working arrangements with international corporations or foreign laboratories. On the whole, there exists a set of diverse organizational arrangements consistent with NSF's original objectives for the program.

Reviews of individual centers provided many illustrations of the nature and diversity of these relationships. These may be characterized along two dimensions: the nature of the organizations (e.g., academic, private sector, and Federal laboratory) and the objective(s) of the partnership (e.g., research, education, knowledge transfer, employment, business startups).

> ***The partnership of multiple universities in individual centers serves above all to facilitate research collaboration and sharing of experimental facilities.***

There are numerous examples of university collaboration across the STC program involving both domestic and foreign universities, and focusing on a spectrum of theoretical, experimental and simulation research of common interest.

> ***Educational partnerships often involve pre-college education, and outreach programs to serve women and underrepresented minorities.***

Many centers coordinate educational partnerships which focus on high school and minority students through outreach programs that enable them or their teachers to interact with center personnel. For instance, the Center for Computation and Visualization of Geometric Structures has collaborated with the Minnesota Educational Computing Corporation and the Anoka-Hennepin School district to create an electronic network to link rural teachers in Minnesota. Some centers also have collaborations with educational agencies such as museums, aquariums and planetariums. A cooperative venture between the Center for High Pressure Research and the Museum of Long Island Natural Sciences, for example, provides outreach to primary and secondary schools and the general public under the "Journey to the Center of the Earth" program.

> ***Partnership with industry was universal, involving both small and large firms, and serves research, education and knowledge transfer objectives.***

Relationships with industry facilitate knowledge transfer through collaborative research. Companies also help set the research agenda at many centers through their involvement in external advisory committees. Visitor programs allow industrial fellows to reside at centers, and center personnel to conduct research at company sites. For instance, the Center for Photoinduced Charge Transfer is characterized by a three-way collaboration between the University of Rochester, Eastman Kodak Co., and the Xerox Corporation. These three partners collaborate on pre-competitive research projects, share instrumentation, participate in project review and advisory functions, and provide opportunities for interaction by staff and students of the university with the industrial participants.

Many centers have evolved rich, complex networks of universities, national labs, and industrial organizations to address many facets of their chosen focus areas. For example, the Center for Particle Astrophysics involves some 20 institutions in the US, including other campuses of the University of California, San Francisco State University, Stanford University, Brown University and Temple University, two national labs (Lawrence Berkeley and Lawrence Livermore), and close to ten foreign groups in Russia, France, the UK, Australia and Venezuela.

3.3 HUMAN RESOURCES

3.3.1 FACULTY SIZE

Faculty size rose rapidly from a total of 245 for the 11 STCs in Cohort 1 in 1989, to 762 at the 25 STCs in both Cohorts by 1995. This translates into an average of 30 faculty members per center. At present, faculty size varies from a high of over 60 at two centers to a low of 15 at two centers. Overall differences among centers affiliated with different NSF directorates were not pronounced.

3.3.2 POSTDOCTORAL FELLOWS AND GRADUATE STUDENT BODY SIZE

In 1989, the eleven Cohort 1 centers reported a total of 50 postdoctoral fellows and 89 graduate students; by 1995, these numbers had expanded to the point where the 25 STCs had over 500 postdoctoral fellows and close to 1,000 graduate students. Postdoctorates made up an important component of the centers' human resource base, with 521 postdoctoral fellows affiliated with STCs in 1995, or an average of 21 per center. Most centers had postdoctorates, with the number ranging from over 45 in three centers to as few as 3 or less at three centers.

The graduate student population reached a high of 1,008 in 1994 and decreased slightly to 994 in 1995 (with an average of 40 graduate students per center for both of these years). Five centers reported more than 60 graduate students in 1995, while 7 centers reported 10 or fewer graduate students. In general, SBE-, MPS- and CISE-affiliated centers had the largest numbers of graduate students in 1995, while BIO- and GEO-affiliated centers had the fewest.

3.3.3 FACULTY AND GRADUATE STUDENT GENDER

Centers provided data to NSF on both faculty and graduate student gender. Among faculty members, men outnumbered women by almost 10 to 1. This changed little over time. Males outnumbered females across all centers, irrespective of the directorate affiliation of a center. Proportionately more women were reported by the one social sciences center.

Higher proportions of females were uniformly found among the graduate students than among faculty at these centers; by 1995, around 20 percent of the graduate students were women. There are proportionately more women at those centers in the biological, geological and social sciences, and proportionately fewer in the computer, mathematical and physical sciences. The number of STC female graduate students is below the national average of 43 percent of all graduate students.

3.3.4 GRADUATE STUDENT RACE, ETHNICITY AND CITIZENSHIP STATUS

The graduate student populations of these centers over the period through 1995 were 60% white, 30% Asian, and under 10% of Hispanic or African American origins. Native Americans and Pacific Islanders constituted less than one percent of the population. Whites were found disproportionately in the computer and social sciences, and Asians in the mathematical and physical sciences. Blacks were proportionately most likely to be found in biological and mathematical and physical sciences, while Hispanics were found disproportionately in the computer sciences. When compared with national averages for S&E graduate students, the number of Blacks and Hispanics participating in the STC programs generally fell below the norms; only in biological sciences did the participation rates for Blacks exceed national averages.

Roughly 4 in 10 graduate students held foreign citizenship. Graduate students with foreign citizenship were found in all of the science fields, but constituted more than half of all such students in only one of the centers. Across directorates, the largest percentages of foreign graduate students were found in the SBES and GEO centers. On this measure, STCs exceed the national average of 22 percent for all graduate students.

3.3.5 UNDERGRADUATE STUDENT AND HIGH SCHOOL TEACHER PARTICIPANTS

The number of undergraduate students affiliated with the centers expanded from a total of only 9 in all 11 centers combined at the outset of the STC program in 1989, to over 600 at all 25 centers in 1995, while high school science teachers working with the STCs increased from none during the first year to almost 250 by 1995.

In 1995, a total of 607 undergraduate students were reported to be participating in the STCs, or an average of 24 per center. There were enormous variations in the number of undergraduates, from a high of 147 at one center to a low of 5 or fewer at 5 centers. The average number for the directorates was highest among SBES and BIO centers, and uniform among the other centers.
Similarly, in 1995, a total of 249 high school science teachers worked with the STCs, or an average of 10 per center, and the number varied from 46 at one center to 5 or fewer at 15 centers. Great variability existed among centers affiliated with BIO, GEO and MPS, but the averages were similar; however, neither the SBES center nor the CISE centers reported any high school science teachers participating in their programs.

3.4 RESEARCH INSTRUMENTATION AND FACILITIES

Beyond statistics concerning the value of donated equipment, NSF has not gathered much structured data concerning research instrumentation and facilities at the centers. However, a variety of NSF reports and individual center documents have discussed this matter in some detail. Therefore, we begin this section with a brief summary of NSF and STC policies relevant to the role of instrumentation and facilities, and then provide a more qualitative review of these matters.

As part of their infrastructure, many centers maintain a number of advanced laboratories at their core institutions. For example, the Southern California Earthquake Center established a Portable

Broadband Instrument Center to provide researchers with year-round access to a pool of high-resolution, digital seismic recording equipment. The Center for Light Microscope Imaging and Biotechnology opened a general-use facility used to carry out pilot studies and joint projects with academic, medical, and industrial partners. The same facility is heavily used in educational outreach activities.

Many centers provide state-of-the-art instrumentation that would be beyond the range of any single investigator or small group. A Vector Scan electron beam lithography machine at QUEST involves machine technology development and the use of the machine for the fabrication of small structures. The STC for Superconductivity offers access to Argonne's Intense Pulsed Neutron Source and Northwestern's Atomic Resolution Analytical Electron Microscope.

All centers offer state-of-the-art computational resources. At the higher end of the spectrum, the Center for Research on Parallel Computation offers one of the most advanced collections of high-performance parallel systems in the world. State-of-the-art instrumentation available at the STC for Advanced

Cement-Based Materials (ACBM) includes instrumentation for holographic interferometry, digital image analysis and quantitative microscopy, environmental scanning electron microscopy, NMR spectroscopy, and rheometry and computer modeling.

Some centers maintain extensive databases or simulation models on specialized subjects that are used as resources. For example, the Southern California Earthquake Center has established a database of earthquake information for use by engineers and emergency preparedness personnel. The Center for Ultrafast Optical Science and the Center for Superconductivity developed a database for commercial superconductor device design and modeling data collected from industrial samples. Scientists at the STC for Advanced Cement-Based Materials, as part of the Cementitious Modeling Laboratory, have developed a Cement Microstructure Simulation Model based on observation of actual cement and concrete systems. The lab will establish databases to support modeling activities.

4.0 PRINCIPAL RESEARCH GOALS, ACHIEVEMENTS AND IMPACTS

> ***The science and technology centers are an excellent demonstration of the old axiom that the whole is greater than the sum of its parts***

The hallmark of a successful Science and Technology Center is the integration of a variety of research and research-related activities into a complex whole well beyond the managerial and fiscal capabilities of an individual investigator - and a hallmark of the Science and Technology Centers *program* is that there are almost as many different ways of achieving this ideal as there are centers.

The key *goals* stated by the centers can be divided into four categories:

- Acquire specific scientific knowledge
- Develop research tools
- Develop results aimed at non-research applications
- Strengthen the scientific foundations for a particular area of technology

However, the actual activities of the centers often extend beyond the key goals, identified in response to the study questionnaire, to encompass most or all of these categories. Even in their key goals, the centers cast a wide net, seeing their missions as not only to advance fundamental knowledge but also to both facilitate and leverage such advances by contributing to progress in research tools and non-research applications.

> ***The individual centers have produced significant research achievements in fundamental knowledge and the development of research tools, and have identified a range of downstream impacts of this work.***

The primary *achievements* of the centers are concentrated in the areas of fundamental knowledge and development of research tools. As with their goals, the centers tend to cover broad ground both individually and as a group. No center claimed achievements which were at variance with its character as defined by its stated goals.

The impacts identified by the centers can be classified into five categories:

- Expectation of impact, or statement about the availability of tools
- Interest expressed (by outside individuals or organizations)
- New paradigm
- Result or approach used by other labs
- Non-research application

The last three categories may be thought of as tallying "real" impacts, in the sense of tangible products or identifiable changes in the work of other researchers attributable to the center's work. *All of the centers report having one or more impacts in at least one of these three categories*. Nine of the centers report, either explicitly or implicitly, having created new paradigms for research; seventeen report that specific scientific results or research tools developed by the center have been pursued or adopted by other researchers; and nine centers report specific applications arising from center work.

The centers collectively have established a meaning for the **Science and Technology Center** ***concept.***

A key finding of this study is that as a group, the centers have breathed life into the term "Science and Technology Center", giving it a meaning which is distinctive but still very much in the service of *science*, as opposed to simply being a disguise for a program of applied research. While there is naturally much variation across the centers, *the Science and Technology Centers program as a whole behaves as an infrastructure program in the most profound sense*.

The breadth, depth and degree of integration of the centers' research activities mean that the program is much more than simply an instrumentation program. First, *the centers develop research tools in the broadest sense*, including not only new instruments but also new research methods, new modes of data analysis, and new approaches to organizing complex experimental programs to achieve results not obtainable previously. Second, and even more important, *the centers' tool development activities are deeply imbedded in productive research programs which both require the new tools and make possible their continued development*.

These fundamental characteristics of the program are valid across the full spectrum from basic to applied research, so that many different types of center can - and do - operate successfully under the STC framework. Thus, with the general program orientation of integrated infrastructure development as a foundation, the individual centers have taken a variety of approaches and developed distinctive identities.

The character of some centers is clearly centered on basic research. Others are explicitly focused on tool development, while a third group features a strong agenda of applied research targeted at specific technologies. The technology-oriented centers, with their overall emphasis and their integrated, full-cycle approach to applied research, bear much resemblance to Engineering Research Centers. Unlike the ERCs, however, their missions are not explicitly defined as including systematic curricular reform or even the systems-level orientation (though the latter appears to be present in practice).

A wide variety of approaches to the organization of research and ancillary activities has emerged

The center mode of operation opens the possibility of more elaborate forms of organization and coordination of research than would be possible in an individual investigator's lab or in informal collaboration among small groups of individual investigators. We find that the STC program has in fact realized that promise in large measure, encompassing a variety of organizational types reflecting the varied research missions of the centers, including:

- **Compact centers**, whose core participants are based in a single institution, in a single location

- **Compact centers with satellite labs**, whose core participants are primarily based in a single institution, but which include as core participants a small number of investigators (and their laboratories) in other institutions

- **Regional distributed centers**, whose core participants are distributed among a group of participating institutions, most or all of which are located in close geographic proximity

- **National distributed centers**, centers whose core participants are widely distributed nationally (or internationally)

- **Centers without walls**, which have an institutional focus for administrative purposes, but whose activities include a wide variety of participating investigators from many institutions organized on an *ad hoc* basis for specific purposes

Even the compact centers represent a relatively complex form of *intra*-institutional organization, usually involving the participation of investigators from multiple departments and even multiple schools or colleges of an institution.

The center mechanism, as implemented through the STCs, is seen by survey respondents as enhancing responsiveness, interdisciplinarity and unique approaches to research.

In the comments of center directors and external advisory board chairs, two general observations concerning the importance of the center mechanism stood out. First, the center mechanism was widely seen as enhancing *responsiveness* to scientific opportunity, and second, the center mechanism was seen as an advantage in addressing areas of research whose central problems demanded *expertise from multiple disciplines*. This second aspect of responsiveness is related to the other important general observation by respondents about the center mechanism, its connection with *multidisciplinarity*. While, in keeping with the recommendations of the Zare committee, the program solicitation did not make multidisciplinarity a requirement, we find that in practice, without exception, participation of multiple disciplines is characteristic of the centers' research activities.

Centers provide a *focus for interaction with industry, or with external organizations more generally*. This "focus" role is boosted by two things in particular - the role of the center in providing institutional visibility to the outside world, and the existence of center administration, providing support for and continuity in external interactions. The center mechanism can make possible activities requiring *large-scale coordination*. This includes the coordination of researchers and facilities for centers which are organized as distributed groups, as well as those whose research programs involve large-scale "special events" in which the activities of large numbers of participants from many different institutions must be effectively coordinated.

Other benefits of the center mechanism include the ability to build and operate *unique research facilities* whose funding and logistical requirements could not otherwise be met, the ability to pursue *lines of work which are not considered eligible for funding by traditional individual investigator grant programs*, and the ability to integrate multiple lines of research in order to apply a *full-systems approach to a particular technology*.

Almost half of the centers reported that either no policy changes of any kind, or at least no changes in formal policy were required by their parent institutions in order to accommodate the center. About one quarter cited increased flexibility in financial arrangements, introduction of new types of financial or grant administration arrangements, or new or modified policies on internal distribution of funds on the part of their parent institutions. About a sixth mentioned the creation of new or modified employment categories or career paths.

Essentially none of the centers claimed that their parent institutions had made *formal* changes in tenure/promotion policy in order to accommodate the center approach to research. In the absence of such changes, the long-term commitment of institutions to the center mode of research may be uncertain. However, there are a few cases where institutional actions suggest a very strong commitment to cross-disciplinary and/or center-type arrangements.

5.0 BIBLIOMETRIC ANALYSES OF RESEARCH PERFORMANCE

> ***STC scientists' journal publications were cited 1.69 times as often as the average U.S. academic paper published in SCI-indexed journals.***

Papers published by Science and Technology Centers in SCI-indexed journals during the period 1989-1993 were cited on average 1.69 times as often as the average U.S. academic paper published in the same journals for the same years. For two of the individual centers, data is insufficient to allow a calculation. Five more reported numbers of SCI papers for the 1989-93 period insufficient for a definitive judgment. Data for one of the centers may be biased by the publication of key papers in non-SCI journals. Of the remaining centers, one has a rate somewhat below average, seven have rates about average, six have rates somewhat above average, and three have citation rates substantially above average at more than double the expected levels. Analyzed by field of publication, STC papers achieved especially high relative citation rates in Physics, Biomedical Research, and Engineering and Technology, with the average citation rates of center papers exceeding the norms in these fields by factors of almost 1.8.

Analysis of the centers' 1989-1995 papers revealed that as a group the centers are publishing in journals with a somewhat higher influence than average. Averages for most of the individual centers are concentrated in a band of relative influence values between 1.0 (average) and 1.5; three centers have values somewhat below average, while four have values substantially greater than average.

> ***STC papers tend to be published in journals oriented more toward basic than applied research. STC papers in Mathematics and in Chemistry have unusually high representation of industrial organizations in their authorship.***

The orientation of SCI-indexed journals may be classified on a spectrum from very basic to very applied. A tally of this measure for the journals in which STCs have published from 1989-1995 shows Center research on a field-by-field basis to be overall about as basic as the SCI paper average; there is no evidence that STC research is tilted toward the applied end of the spectrum compared with the average papers in the Centers' respective fields.

1989-1993 STC papers in Mathematics and in Chemistry have, on average, more than twice as many industrial organizations represented among paper authors than did the average SCI U.S academic paper; industrial representation on STC papers in other fields is similar to or in some cases below the SCI average for the respective fields. Analyzed by directorate affiliation, the highest relative industrial coauthorship is found in papers from the CISE-sponsored centers, followed by papers from the MPS-sponsored centers.

1989-1991 STC publications in Mathematics and Biology have extremely high industrial representation among organizations citing the papers; STC papers overall have lesser but still relatively high industrial representation among citing organizations, typically 2-3 times the expected rate.

1989-1991 STC publications in four fields stand out as having relatively high outside subfield-to-inside subfield citation ratios - Mathematics, Biology, Engineering & Technology, and Chemistry. However, the overall outside/inside relative citation ratio for the 1989-91 STC papers is 1.13, only slightly greater than average (1.0).

Bibliometric data clearly establish the creditable publication record of the STC program as a whole. However, in the absence of data concerning the distributions of citation rates across publications by field, it is inappropriate to use center-specific data to establish rank-orderings of center performance.

6.0 EDUCATIONAL GOALS, ACHIEVEMENTS AND IMPACTS

The individual centers have developed a broad range of educational component and are achieving the objectives established under this program

These centers are building directly upon their specific research missions in establishing educational programs that reach K-12 students and teachers, undergraduate and graduate students, and the general public, as well as women and underrepresented minorities. In some cases, mid-career and faculty enhancement education is also a focus. This major conclusion is supported by a hierarchy of lower-order conclusions.

The STCs have achieved considerable support for their educational programs.

Considerable NSF and EHR Directorate support was provided to the STCs in support of Research Experiences for Undergraduates, Teacher Enhancement, and other educational programs Other Federal, state and industry sources also supported related educational activities..

According to PIs, the Center context is an especially effective one from which to develop and operate such initiatives.

Key factors supporting the educational component include the subject matter orientation of the individual centers, interdisciplinary orientation of the research, the ability to hire staff to specialize in these efforts, the availability of staff and students in support of these programs, and the longer term funding context within which these programs may be operated.

While all types of educational programs are supported, the most prevalent involve programs for undergraduate students, and outreach programs for underrepresented minorities at the undergraduate level. Precollege educational programs for students, and teacher enhancement programs were the next most frequently emphasized.

Two areas of emphasis that correspond to major NSF programs typified the building blocks of these programs: Research Experiences for Undergraduates, and the Teacher Enhancement programs. However, the centers' efforts went well beyond what these activities would involve as isolated efforts of an individual investigator.

Support to K-12 teachers, and university and K-12 students were most frequently cited by PIs as their key educational achievements. In many cases, women and underrepresented minority group students were significant beneficiaries of these programs.

PIs were able to document a broad spectrum of key achievements of their programs. Among the characteristics featured were the development of advanced scientific professional training programs, innovative uses of computers, working with other science centers (e.g., museums, aquaria, planetaria), and involvement of staff and students from the centers. PIs were especially enthusiastic about work with disadvantaged students. Finally, a couple of centers were especially enthusiastic about the results of faculty enhancement, industrial scientist advanced training, and mid-career training activities.

Educational impacts of these STCs, described by their PIs, include influencing their institution's educational programs, the upgrading of science and mathematics in the K-12 sphere, and a series of longer-term improvements in university level science education.

PIs were especially excited that their STC outreach programs were having an impact upon their universities' attitudes towards, and programs reaching out to, K-12 teachers and students. Many PIs reported that other academic departments and centers, observing the success of the STCs' activities, used them as a model for other K-12 initiatives. *Teachers and educators praised the STCs' activities for their impacts upon the level and quality of science education in their local school systems.* Closer to home, many new courses and curricula have been developed by these centers to educate graduate and undergraduate students about their science areas; most are interdisciplinary in character.

There were examples of some impacts of the STCs upon university policies and culture.

PIs cited examples of changes in university curricula and requirements and majors at the graduate and undergraduate levels, as well as requirements for dissertation committee membership and tenure, but these seem to be changes that are already evolving in the university in many cases. The most clear influence upon university culture would appear to be the increasing interest in and attention to K-12 science education matters. This latter influence appears to be building on various NSF and EHR efforts (e.g., Research Experiences for Undergraduates, Teacher Enhancement, Young Scholars, and various programs of the Division for Human Resource Development).

7.0 TRAINING SUPPORT AND JOB PERFORMANCE OF GRADUATES OF THE STCS

Almost two-thirds of STC graduates reported having their studies partially or wholly funded by STC-administered research assistantships.

Other commonly reported sources of funding were teaching assistantships and research assistantships supported by non-STC sources.

STC graduates report being well prepared for their subsequent careers - whether they be in academia, industry or federal laboratory.

STC graduates score highly on both self-ratings and supervisors' ratings of job performance compared to peers, across all sectors of employment and all dimensions of performance. Within this overall pattern of superior performance, graduates were most confident of their abilities along dimensions of general intellectual competence and technical knowledge and capability, and least confident of their abilities in certain skills related to functioning within organizations and subject to organizational constraints. Both graduates' self-ratings and supervisors' ratings indicated that STC graduates required less training than did other employees at the same level in their organizations before becoming net contributors to their organizations' work.

As a group, the STC graduates carry a variety of responsibilities in their current employment. However, their primary responsibility on the job, in all sectors, is research, with the focus in industry being primarily on applied research, but with both basic and applied research well represented in academia. The population of graduates in academia is polarized with respect to the extent of their responsibility for teaching, with relatively larger fractions of the respondents reporting either very great or no responsibility in this area, and smaller fractions reporting intermediate responsibility.

Certain aspects of the graduates' training can be linked to specific dimensions of job performance. Many graduates continue to participate in cross-disciplinary or industry-oriented research in their present employment.

The graduates report widely varying rates of participation in various activities - such as participation in certain types of courses or seminars, or participation in collaborative research -which are known to occur commonly as part of the graduate training experience in general or which have been hypothesized as likely activities of students affiliated with special center programs in particular. These variations likely reflect a number of factors, including varied definitions of "affiliation" applied by centers in identifying graduates for participation in the survey, the absence of uniform curriculum requirements within and across centers, and the wide variation in scientific fields represented by the centers.

Nevertheless, statistical analysis revealed correlations between certain training experiences and certain aspects of STC impact or of job performance. Among graduates employed in industry, graduates who had taken courses developed or sponsored by their STC were likelier to report that their STC experiences had had a very positive effect on their contribution to their companies' technical work. Also, industry employees who reported a relatively high emphasis on a systems approach to solving problems, in either their general graduate training or their STC-linked activities, tended to give themselves higher ratings in overall job performance.

For STC alumni working in academic settings, previous collaboration with STC corporate sponsors was strongly associated with high ratings in many areas of job performance. Academic employees who reported that their STCs had placed high emphasis on teamwork also tended to rate themselves better than average in transferring technology to or from outside entities.

Many STC graduates - typically half or more - in all sectors participate in cross-sectoral or cross-disciplinary collaborative research. However, few in industry continue to work on specific projects or technologies carried over from an STC. Graduates employed in academia report a high degree of participation in interdisciplinary research centers and a high degree of industry orientation as reflected in research focus on problems directly relevant to industry.

8.0 KNOWLEDGE TRANSFER GOALS, ACHIEVEMENTS AND IMPACTS

Knowledge transfer activities are seen by the Centers as stimulants to the development, use and dissemination of new center research.

The knowledge transfer activities at the Science and Technology Centers are based on the assumption that applications introduce new types of research problems that are important to stimulate applied and pure research. Most centers consider establishing communication links with researchers from different organizational affiliations, transferring center-related products and ideas to these groups, and doing collaborative research with industry and other groups as important knowledge transfer goals of the center.

Centers claim to have structured their knowledge transfer instruments to facilitate a bi-directional flow of information. This is based on the occasionally explicit assumption that disseminated information stimulates thinking on a broader scale, spurs further research, and catalyzes new insights and discoveries.

Most centers focus primarily on traditional academic mechanisms of knowledge transfer.

The most common mechanisms of knowledge transfer at the STCs are collaborating with other university, Federal lab and industrial partners within the U.S., providing continuing education for professionals via seminars and workshops, making presentations at professional meetings, and disseminating information via articles in scientific journals, newsletters, and the Internet. Only a handful of centers use personnel exchange, or other product/technology transfer modes to transfer knowledge.

In general, centers with a stronger focus on applications and tools also have more vigorous interactions with industry than do others.

At this stage, centers can demonstrate impressive achievements but have fewer measurable downstream impacts.

Center achievements include successfully collaborating with a wide variety of organizations, establishing effective channels of communication, obtaining patents and licenses, and disseminating and maintaining electronic data.

An achievement was deemed an impact when center research caused an actual change - process- or outcome-based - to occur in an industrial, governmental or research setting. Reflecting the young age of the centers, there have been relatively few measurable impacts. The ones cited most often were instances of transfer of center research results or their application in industry, or development of commercial products whose origins lay within center research. Other less frequently mentioned impacts included involvement of the center in the creation of spin-off companies and development of industry standards.

> ***Centers have taken measures to be responsive to the needs of the external community, and institutional changes have been made to accommodate knowledge transfer activities.***

On average, centers have been able to stay responsive by maintaining geographic and intellectual diversity, two features that give them the flexibility to respond quickly to changes in the research community, as well as by tapping directly into industry and other partners for feedback.

Universities have realized that university/industry relations are an important part of the research and education mission of their institutions. There is therefore an effort being made to bridge the two cultures so that effective translation of research can occur. Few universities claimed that they needed to make major changes in focus, institute radically new policies, or develop new mechanisms to respond to the knowledge transfer activities of the STCs.

> ***On average, industry partners consider their affiliations with the STCs to be immensely beneficial.***

Industry partners see their ability to find, demonstrate, and assess new technologies, and expand horizons and complement in-house research to be the key benefits of their participation in center activities. Having the opportunity to track and respond to emergent technologies, network with other researchers, find, explore, and test product improvements, and outsource portions of their own research programs were also considered as important benefits.

> ***Most industry partners also find many aspects of the center mechanism relevant to their needs.***

Industry partners identified a variety of features that characterize the center mechanism. A critical one is the *integration of the STCs into an academic setting.* Survey respondents felt that compared to individual investigators, centers can more effectively use their connections to other scientists on-site and elsewhere, both for dissemination and accumulation of information, and for access to specialized expertise when needed. Another critical element is the *research mode*. At most centers, problems are tackled by multidisciplinary teams that combine the expertise of a suitable number and mix of people, rather than only individual specialists, to address complex problems of interest to industry.

9.0 PATENTS

To date, relatively few patents - 76 - have been issued to the STCs as a group, and around half of these are credited to a single center, the Center for High Performance Polymeric Adhesives and Composites. In addition, the patents earned by the Centers are as yet too recent to allow direct measurement of their impact on subsequent technology. Therefore, any conclusions at this time must be tentative.

Nevertheless, analysis of the patents even with this limited period of time reveals several key points:

> ***STC patents have a relatively short technology cycle time (median age of the patents they cite).***

This would indicate that STC patent-related activities are operating in relatively rapidly moving areas of technology.

> ***STC patents are relatively heavily linked to science.***

This finding suggests that these areas of STC research are associated with cutting-edge technologies

> ***STC patents are linked to highly cited earlier patents.***

This finding indicates that the STCs are continuing the development of areas deemed important.

> ***A number of the STC patents are assigned to private companies.***

This finding would indicate a clear and direct linkage between the centers and U.S. industry.

> ***STC research papers are consistently cited by the universe of U.S. patents at a rate 2-4 times higher than the average academic paper.***

This finding clearly suggests that STC scientists, when compared to their academic peers, are making superior contributions to technology based upon their research activities. This finding is especially significant given that STC scientists tend to publish in journals that emphasize fundamental (as distinct from applied) research.

10.0 PROGRAM INTEGRATION

More than 80% of PIs stipulated that the three principal components (research, education and knowledge transfer) did, in fact, operate in a closely integrated fashion in their centers. In terms of other types of synergies, more than half of the PIs reported integration of various aspects of their research activities (e.g., interdisciplinarity of the activities), and institutional synergies (e.g., involving the benefits of close industry-university cooperation). One-third reported important synergies among activities of faculty, staff and students (e.g., graduate students serving as mentors in the laboratory for high school science teachers).

There are synergies among the three major program thrusts of the centers.

While this appears to have been accomplished in various ways, and taken different forms, the centers as institutions appear to achieve such synergies in a form, and to an extent, that would be less likely to occur in a more traditional academic department setting. One PI, whose observations were reasonably typical, wrote that the mission of the center "involves the tight integration of research, education, and knowledge transfer since it is impossible to make (his area of work) truly usable without program activities involving all three." He also notes that their "research activities led to developments that were strong enough to convince commercial software vendors that a (research product) was feasible" for commercial applications. "In addition, courses were developed by Center researchers... These activities were so tightly intertwined that they are not separable, and this model is repeated in project after project in the Center."

There are specific synergies among the scientific activities of the centers.

The PI from a MPS affiliated Center wrote that "a typical example is the MACHO project. The original microlensing idea proposed by Pazcinski was considered impractical by the astronomy community. The acquaintance of our Livermore collaborators with defense projects using large imaging capabilities, the familiarity of particle physicists with large computer processing projects, the general knowledge of our community of variable stars, and the electronic expertise of some of our experimental physicists converged to rapidly convince us that the project was indeed feasible. It allowed us, with the help of commercial vendors, to build in record time the largest electronic camera in use in the astronomy community, which received one of the 'R&D 100' awards by *R&D Magazine* in 1994." The PI for a BIO affiliated center wrote that "the problem of microbial community analysis is too complex for PIs to tackle, especially in an integrated manner. It requires methodology advancement from several fields, experts in several habitats, the theoretical framework from ecologists and of course the knowledge base of microbiologists", while another BIO PI wrote "communication between biologists, chemists, physicists, computer scientists and engineers inside the university and cross-institutional interactions occurred in a fashion not possible before the Center."

There are synergies found in working with industry, other universities, and other Federal or foreign laboratories.

To illustrate, one PI wrote that "linking science with technology requires close participation of industry with university research. A significant portion of the basic research is technology driven as compared to 'curiosity driven.' Technology driven research greatly excites students as well as faculty, and research accomplishments are more obvious as is, of course, the economic justification for the research." Another PI wrote that the real achievement of the Center is "the blending of the cultures of three academic institutions and a federal laboratory into a dynamic, creative entity in which the combination of individual talents, cooperative enterprise, and exceptional research infrastructure has enabled advances to be made in a very difficult research field that otherwise are unlikely to have occurred within the same time frame."

Centers are achieving fruitful working relationships among the faculty, staff, and students, and outside scientists and educators, as various research, educational, and knowledge

transfer activities are developed and implemented.

One PI wrote that their K-12 education program "would be far less effective if faculty and graduate student researchers had not 'bought into' it: an important component of the program has been the immediacy of the laboratory research experience, the day-to-day contact with working researchers, the transmission of the passion and beauty of research. Our graduate students, working as mentors in the education program, have learned the discipline, planning and communications skills that help them to grow as researchers." Another PI wrote that "as a result of interaction with Center faculty and students, several new development projects have been started by industry and a new commercial prospect will be introduced in the market nationwide. Center faculty and students visit industry and many ... former students are now working with our industrial affiliates. (These) students benefit greatly by regular visits by various industry representatives."

11.0 MANAGEMENT ISSUES

There was widespread support among the PIs, advisory board chairs, and deans for the use of a center mechanism as a funding device for the support of fundamental research in the university.

This was not seen as a replacement for individual investigator grants but rather as an appropriate mechanism to use in order to accomplish specific research goals which would be more consistent with this form of organization. Research that was interdisciplinary, complex and longer term would be one such example. A further example would be goals involving a combination of research, education and knowledge transfer.

A number of PIs were very positive in their assessments of the technical support they received through their directorate's technical staff.

The substantive relationship between the directorates and many of the centers appears to be quite good. Favorable comments were made concerning both proactive technical support, and reactive responses to requests for guidance.

Some PIs believe that NSF has backed off from the STC program, giving it lower status and support in the agency. In particular, the Foundation is seen by some as having given ownership of the program to the directorates and divisions in the face of some vocal critics of the program.

Individual PIs cited a number of actions taken that, in the aggregate, make the foundation appear to have "fathered an orphaned child". The STC program, as an experimental device, seems to have been abandoned as a coordinated whole despite the fact that some of the centers appeared to be achieving much of what they set out to accomplish.

There is a fairly widespread perception among PIs that there are problems with how the STC program is administered; that there is not adequate coordination between OSTI and the NSF directorates with which the centers are affiliated.

PIs voiced the opinion from a variety of perspectives that there is not a consistent policy with respect to the administration of the STC program. In the most general sense, there are important inconsistencies both among the directorates (in how they supervise operations of the various centers) and over time (with changes in policies governing any given center). In addition, the overall funding responsibilities appear to be confused. PIs cite uncertainty regarding whether funds are STC funds (for the experimental program) or the directorates' funds (to use in any way the directorates choose).

OSTI lost an important program (and possibly policy) mechanism through the cancellation of the STC Advisory Board.

With respect to program management, a number of PIs complimented OSTI's sponsorship of periodic conferences for center staffs that allow for exchange of ideas on problems and issues. However, several PIs expressed concern over the dissolution of the STC advisory committee which could make judgements and answer questions about the overall program. PIs expressed concern over the loss of a valuable source of feedback on how to do their job better. Moreover, in the STC Advisory Board's absence, others who chose to criticize the program, or to challenge it, could do so with no representatives of the scientific community available to respond.

OSTI and the directorates fail to adequately coordinate the STC site review process.

Some PIs believed that the site visits are not well coordinated between OSTI and the directorates, with conflicting messages being given by the review teams from different directorates in any given review cycle, or within a directorate over time.

There are problems with the volume and frequency of OSTI data requirements and other requests for information; related to this, there were problems with use of these data even when considerable effort have been put into improving the operating data base.

Many PIs complained about the extent and complexity of the reporting and review requirements placed upon them. Some PIs saw these as so intrusive as to interfere with the mission of the program. Moreover, when the contractor began working with the data supplied by OSTI, there were serious questions about the reliability of some of the data gathered annually due to unclear definitions of terms (e.g., the relationship between research funded under individual investigator grants to STC faculty by various Federal agencies, and the research they perform with STC support, is unclear). These data are gathered annually, but different centers may have different criteria regarding what to report, and what percentage of funding to allocate to STC related research where these other grants are reported.

Selection of the review teams may be excluding some of the most qualified reviewers.

Among STCs that are national leaders in their areas, candidate review team members may be excluded if they have had any contact with a center. Since the centers are often reaching out to, and involving, leading scientists from around the country, these individuals often may not serve on the team. This deprives the centers of outstanding reviewers.

While a number of the latter findings are somewhat critical, the first two conclusions presented are paramount. Namely, that there is widespread support among the PIs, advisory board chairs, and deans for the use of a center mechanism as a funding device for the support of fundamental research in the university, and that a number of PIs were very positive in their assessments of the technical support they have received from NSF.