White Paper:
Towards a Vision for the NEES Collaboratory

George E. Brown Jr. Network for Earthquake Engineering Simulation

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Consortium of Universities for Research in Earthquake Engineering

Version 3.0
October 1, 2002
EXECUTIVE SUMMARY

The National Science Foundation (NSF) launched George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) in October 1999. This 15-year program is part of NSF’s Major Research Equipment and Facilities Construction (MREFC) program. It is intended to transform the nation’s ability to carry out research vital to reducing vulnerability to catastrophic earthquakes and to educate new generations of engineers, scientists and other specialists committed to improving seismic safety. The collaboration enabled through NEES and the explicit integration within its programs of experimentation, theory formulation and validation, data curation, model-based simulation, high performance computing and education will accelerate substantially the development of technically sound and cost-effective approaches to earthquake loss reduction.

When fully operational in October 2004, the NEES program will provide an unprecedented infrastructure for research and education. As part of the NEES program, NSF is supporting the construction of unique, next generation equipment sites that will be operated as shared-use facilities. To help integrate research with education, these shared use facilities are located at major universities distributed across the US. To enhance opportunities for integration and synergism, NEES will be implemented as a powerful network-enabled collaboratory. Collaboratories incorporate a number of unique features and capabilities that will allow members of the earthquake engineering community to interact with one another, access unique, next generation instruments and equipment, share data and computational resources, and retrieve information from digital libraries without regard to geographical location.

The overall research needs in earthquake engineering are currently being identified in a study being undertaken by the Earthquake Engineering Research Institute. The National Research Council is concurrently assessing possible uses of NEES to address these needs, and developing a research plan for NEES. NSF has indicated that NEES is to be managed by a Consortium and, as mentioned, operated as a collaboratory. The NEES Collaboratory is to serve the needs of the entire earthquake engineering community. NSF has established a NEES Consortium Development project to develop community consensus on the nature of the NEES Collaboratory.

This White Paper summarizes some of the background of the NEES Program, specifically as it applies to the NEES Collaboratory. In consideration of the expectations of NSF for NEES and its other Major Facilities, the assessment of conditions surrounding research, education and application in earthquake engineering, and the opportunities for advancing earthquake engineering, a series of draft statements regarding the Mission, Vision, Guiding Principles and Goals of the NEES Collaboratory have been developed.

The overarching goal of the NEES Collaboratory is the integration of people, ideas, and tools in a collaboratory environment to accelerate progress in earthquake engineering. The NEES Collaboratory leads, coordinates and serves as the focal point of the George Brown, Jr. Network for Earthquake Engineering Simulation.

The Mission of the NEES Collaboratory is

• to facilitate collaboration by the earthquake engineering community in research and education, nationally as well as internationally;
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- to support and enhance the research capabilities of the nation’s earthquake engineering community;
- to foster innovative research leading to technically sound and cost-effective approaches to earthquake loss reduction and otherwise serving the critical needs of society;
- to promote the use of engineering knowledge through curated digital repositories and programs of information dissemination; and
- to integrate research and education in support of effective programs of education at all academic levels, from kindergarten to adulthood.

The vision of the NEES Collaboratory is that of an organization that energetically, systematically and effectively pursues all aspects of the above mission. The NEES Collaboratory is not just an administrative shell, but encompasses and engages broad array of participants and partners.

The following Vision Statement is recommended regarding the attributes of the NEES Collaboratory when it becomes fully operational. The NEES Collaboratory:

- enables the earthquake engineering community to carry out research critical to earthquake loss reduction by offering a superb array of services and networked resources for collaboration, communication, education and research,
- champions the integration of experimentation, theory formulation and validation, data curation, model-based simulation, high performance computing, visualization, education and information technology.
- engages the earthquake engineering community to assess critical gaps in knowledge and significant opportunities for innovation and discovery, to identify community priorities for research, and to identify the specific resources and services necessary to achieve community research goals.
- promotes the widespread use of engineering knowledge through curated data repositories and programs of information dissemination.
- actively partners with government, academia, industry and business to achieve the nation’s goals for earthquake loss reduction.
- serves the public in numerous ways, including informing the development of improved policies and more effective regulations for earthquake loss reduction, attracting and training a more diverse and capable workforce, and developing effective learning programs across the full educational spectrum.

This version of the White Paper incorporates comments obtained at the National Consortium Development Workshop, and suggestions submitted from external reviews by the broader earthquake engineering community. However, the White Paper should be viewed as a living document, and will be changed or superceded as a consequence of on-going comments by the earthquake engineering community and the formal development of the organizational structure for the NEES Consortium entity and the operating procedures, policies and practices for the Collaboratory. In the meantime, the White Paper will be utilized in various consortium development activities, ranging from developing policies on sharing data and facilities, enhancing various community building activities, establishing partnering discussions with other organizations, conducting more detailed planning, and formulating the specific organizational features of the NEES Consortium entity.
PREFACE

This White Paper has been prepared as a resource document to aid in the development of the Collaboratory that forms central vehicle for coordinating the operations of the George Brown, Jr. Network for Earthquake Engineering Simulation (NEES). The document is intended for individuals with a general background who may be interested in learning about the overall nature of the NEES Program, as well as for members of the earthquake engineering and information technology communities and others who may have more specific knowledge of and interest in the NEES Collaboratory. It was prepared, as part of the NEES Consortium Development Project, to identify issues that should be considered in developing the NEES Collaboratory, to stimulate discussion and comment, and to help build consensus on the Collaboratory’s mission, vision, and goals.

As a resource document, the White Paper includes general information on the origins and goals of the NEES program, as well as an overview of the various activities being undertaken to bring NEES online. Some readers, because of their experience or interests, may wish to skip portions of this background material.

Because NEES is a component of NSF’s Major Research Equipment and Facilities Construction program, information is provided in Chapter 2 regarding the purposes of this program and the criteria used by NSF for this and other similar programs. Because the NEES program is being implemented as an innovative network-enabled collaborative environment, considerable background information is also presented in Chapter 2 regarding the origins and objectives of this organizational structure and the special requirements, benefits, challenges and opportunities that it offers. Many of the issues described will impact the implementation of the NEES Collaboratory. Since the NEES Collaboratory is intended to serve the entire earthquake engineering community, Chapter 3 describes the nature and scope of this community, discusses the special requirements they may have for the Collaboratory, and examines the strengths, weaknesses, opportunities and threats related to the community that should be considered in developing a collaboratory in earthquake engineering.

In Chapter 4, the proceeding information is synthesized and presented in the form of draft mission and vision statements that might be considered for the NEES Collaboratory and a draft set of guiding principles and goals. Some specific issues related to the organization and implementation of the Collaboratory are also discussed.

Some aspects of the White Paper, especially Chapter 4, have been written in a declarative style, intended solely at this stage as a means of provoking discussion and comment. In its current form, the White Paper is intended to be a “living document;” one that will change in response to comments from the earthquake engineering community. As such, it is neither a strategic or implementation plan, nor a statement of the policy of the NEES Consortium Development Project, the National Science Foundation, other organizations or individuals. Is simply serves as a resource document to stimulate discussion and a framework upon which to base future improvements and documents.

This White Paper is not intended to address organizational and other aspects of the NEES Consortium entity. The vision developed for the Collaboratory will provide input and guide the development of the NEES Consortium.

Comments and suggestions on this document may be sent to: mahin@ce.berkeley.edu.
ACKNOWLEDGEMENTS

This work was supported primarily by the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) of the National Science Foundation under Award Number CMS-0126366.

The authors greatly appreciate the time and contributions of all those who have contributed ideas, offered their suggestions, and reviewed various material and drafts. The materials presented in this White Paper do not represent the policy or views of the National Science Foundation, the NEES Consortium Development Project, other groups or individuals.
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REFERENCES

Resource Document 3 -- How we operate (from NSF Strategic Plan, 2001-2006)
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Resource Document 5 -- NSF Merit Review Criteria
THE GEORGE BROWN JR. NETWORK
FOR EARTHQUAKE ENGINEERING SIMULATION

1.1 Background

In October 1999, the National Science Foundation launched a major new initiative known as the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). Through NEES, NSF will transform the nation’s ability to carry out research vital to reducing the nation’s vulnerability to catastrophic earthquakes, and educate new generations of engineers, scientists and other specialists committed to improving seismic safety. Over its anticipated 15-year life, NSF anticipates an investment of more than $82 million in new research facilities and several times this amount to support on-going research and operating expenses. The collaboration enabled through NEES and the explicit integration within its programs of experimentation, theory formulation and validation, data curation, model-based simulation, high performance computing and education will accelerate substantially the development of technically sound and cost-effective approaches to earthquake loss reduction.

The NEES initiative is part of the Major Research Equipment and Facilities Construction (MREFC) program at the National Science Foundation (NSF). Comparable initiatives in this program include the construction and operation of other major research facilities, such as the South Pole Station, Gemini Observatories, National Center for Atmospheric Research, Laser Interferometer Gravitational-Wave Observatory, and National Radio Astronomy Observatory. Significantly, NEES is the first of these initiatives to be undertaken by NSF’s Engineering Directorate. As such, it incorporates several new and unique features.

When fully operational in October 2004, the NEES program will provide an unprecedented infrastructure for research and education, consisting of networked and geographically distributed resources for experimentation, computation, model-based simulation, data management, and communication. Rather than placing all of these resources at a single location, NSF has leveraged its investment, and facilitated the integration of research and education, by distributing new shared-use equipment for experimentation among 16 universities throughout the US. To insure that the nation’s researchers can effectively use these resources, the NSF-funded equipment sites will be operated as shared-use facilities, and NEES will be implemented as a network-enabled collaborative. As such, members of the earthquake engineering community will be able to collaborate with one another, access unique, next generation instruments and equipment, share data and computa-
tional resources, and retrieve information from digital libraries without regard to geographical location [NRC, 1993].

Through NEES, the earthquake loss reduction community will be able to work together as never before possible to pursue new ideas, generate technically sound solutions, and verify their effectiveness. The diversity of talents, backgrounds, experience, and disciplinary concerns represented within the NEES Collaboratory, and the unparalleled resources available to its participants, will provide a critical mass of people, ideas and tools needed to challenge the most perplexing problems in earthquake engineering. During its 10 year scheduled period of operation, NSF has suggested that NEES should explicitly integrate experimentation, theory formulation and validation, data curation, model-based simulation, high performance computing and education to address certain general goals. NSF and others have suggested that these goals might include:

- Improve the seismic design and performance of the Nation’s civil and mechanical systems,
- Provide critically missing, quantitative knowledge regarding the multitude of complex factors that affect physical behavior and seismic performance of the built environment,
- Develop and validate more complex and comprehensive analytical and computer numerical models capable of reliably simulating seismic performance of complete systems, including their foundations and nonstructural subsystems,
- Devise, evaluate and demonstrate the value of new concepts for reducing the damaging effects of earthquakes through the innovative use of new or improved materials, elements, systems and theories,
- Though partnerships formed with the earthquake engineering community, develop and validate methods for the design, analysis, evaluation and construction of structures and infrastructure systems such that they are able to perform consistent with targeted expectations,
- Devise and evaluate methods for monitoring and assessing earthquake and other forms of damage,
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- Develop more effective methods to simulate, monitor, document and visualize seismic behavior in the laboratory as well as in the field,
- Engage students as well as broad segments of the entire earthquake engineering community in NEES, through meaningful opportunities to participate in research, take part in inquiry-based programs of education, and access an extensive curated knowledge repositories,
- Enlarge and diversify the pool of individuals knowledgeable and trained in the field earthquake engineering and allied fields, and
- Support and evaluate the effective use of network-enabled collaborations as a means of perusing technically challenging problems.

The specific short- and long-term research and operational goals for NEES are to be developed based on input from the broad earthquake engineering community, consistent with the mission of NSF and its expectations for NEES.

Currently, four major activities are being undertaken to bring NEES online. These activities include (1) constructing the shared-use equipment sites, (2) developing the standards, applications and advanced networking capabilities needed to allow the earthquake engineering community as well as to the public at large to interact with one another and with the NEES resources, (3) developing a community-backed research collaboratory and consortium that will carry out and manage NEES activities, and (4) identifying a research agenda for the NEES Collaboratory that addresses critical, high priority needs. These activities are briefly described in the following sections.

Other useful information related to NEES may be found at: http://www.nsf.gov/nees.

1.2 NEES Infrastructure and Tools

To support the basic research and education activities of the Collaboratory and to facilitate collaboration, NSF has undertaken the development of an integrated network-based system for connecting the NEES community to one another and to the NEES resources, and supplemented existing capabilities for experimental research by building major new or upgraded shared-use test facilities. These experimental facilities provide the earthquake engineering community with unique, next generation capabilities, including ones associated with geotechnical centrifuge test facilities, mobile field test facilities, reaction wall test facilities, shaking table test facilities, and tsunami test facilities.
These facilities are being located at universities throughout the US, based on peer-review of proposals submitted addressing high priority equipment needs. The first phase of eleven facilities is already under construction, and a second phase of five additional facilities was announced in early October 2002. The shared-use facilities awarded by NSF are:

Geotechnical Centrifuge Test Facilities
- A NEES Geotechnical Centrifuge Facility, University of California, Davis (Bruce Kutter, PI)
- Upgrading, Development and Integration of Next Generation Earthquake Engineering Experimental Capability at Rensselaer's 100 g-ton Geotechnical Centrifuge, Rensselaer Polytechnic Institute (Ricardo Dobry, PI)

Field Experimentation and Monitoring Installations
- Field Testing and Monitoring of Structural Performance, University of California, Los Angeles (John Wallace, PI)
- Large-Scale Mobile Shakers and Associated Instrumentation for Dynamic Field Studies of Geotechnical and Structural Systems, University of Texas at Austin, (Kenneth Stokoe II, PI)
- Permanently Instrumented Field Sites for Study of Soil-Foundation-Structure Interaction, Brigham Young University (T. Leslie Youd, PI)

Large-scale Laboratory Experimentation Facilities
- A System for Multi-Axial Subassemblage Testing (MAST), University of Minnesota-Twin Cities (Catherine French, PI)
- Fast Hybrid Test Platform for the Seismic Performance Evaluation of Structural Systems, University of Colorado, Boulder (P. Benson Shing, PI)
- Large Displacement Soil-Structure Interaction Facility for Lifeline Systems, Cornell University (Harry Steward, PI)
- Large-Scale High Performance Testing Facility Towards Real-Time Hybrid Seismic Testing, State University of New York, University at Buffalo (Michel Bruneau, PI)
- Multi-Axial Full-Scale Sub-Structuring Testing and Simulation Facility, University of Illinois at Urbana-Champaign (Amr El-nashai, PI)
- Real-time Multi-directional Testing Facility for Seismic Performance Simulation of Large-Scale Structural Systems, Lehigh University (James Ricles, PI)
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- Reconfigurable Reaction Wall-Based Earthquake Simulator Facility, University of California at Berkeley, (Jack Moehle, PI)

Shaking Table Test Facilities
- Development of a Biaxial Multiple Shake Table Research Facility, University of Nevada, Reno (Ian Buckle, PI)
- Large High Performance Outdoor Shake Table Facility, University of California, San Diego (Frieder Seible, PI)
- Versatile High Performance Shake Tables Facility towards Real-Time Hybrid Seismic Testing, State University of New York, University at Buffalo (Michel Bruneau, PI)

Tsunami Test Facilities
- Upgrading Oregon State’s Multidirectional Wave Basin for Remote Tsunami Research, Oregon State University, Corvallis, Oregon (Solomon Yim, PI)

Special attention is being focused on enabling investigators from off site to conduct or participate in research at the shared-use facilities as well as to share data generated at these and other NEES sites. Each shared-use site has agreed to adhere to high standards of documentation and quality assurance, and to facilitate use of their facilities by off-site collaborators. Advanced capabilities for teleobservation and teleoperation are being installed at each site to broaden opportunities for remote participation. To ensure a sustained high level of accessibility, NSF will fund the shared-use aspects of facility operation and maintenance.

Building from this core of shared-use equipment sites, other research facilities, both nationally and internationally, will be invited to join NEES. However, policies and procedures remain to be developed related to

**NEES GLOSSARY**

**NEES:** The George E. Brown, Jr. Network for Earthquake Engineering Simulation, a Major Research Equipment and Facilities Construction (MREFC) program of the Engineering Directorate of the National Science Foundation.

**NEES Collaboratory:** the sum of the components of NEES as they operate in the research mode, scheduled to be fully operational by 2004 and to operate for a decade.

**NEES Collaboratory Equipment Sites:** Facilities for experimental and computational research participating in the NEES Collaboratory, which agree to abide by various standards and operating policies, including ones related to teleobservation, teleoperation, quality assurance, documentation and sharing of data.

**NEES Consortium:** the non-profit corporate entity that will manage the NEES Collaboratory.

**NEESgrid:** The Grid-based architecture adapted by the System Integration team for the network links, services and applications to be used by the NEES Collaboratory.

**NEES Shared-Use Equipment Sites:** Engineering facilities for laboratory and field testing, constructed and operated with funding provided by NSF, that are available for shared use by the earthquake engineering community through the NEES Collaboratory.

**System Integration:** Development of the network, services, curated repository, and applications that tie distributed experimental sites, databases, computational resources and researchers together; scheduled to be completed by 2004.
items such as equipment compatibility, network protocols, and policies and procedures for sharing of facilities and data.

To enable broad-based collaboration by the earthquake engineering community using NEES resources, recent advances in information technology and computer science are being adapted and extended. The network-enabled systems being implemented are intended to provide convenient, secure and dependable access to NEES resources for experimentation and computation, along with a rich set of integrated tools for communication, telepresence, database curation, simulation and visualization. As such, NEES collaborators will be able to interact with one another, with NEES resources as well as with data. The Grid-based architecture being developed to provide network links, services and applications within NEES is known as NEESgrid. This system integration effort is led by the National Center for Supercomputer Applications headquartered at the University of Illinois at Urbana-Champaign (Daniel Reed, PI), in conjunction with a consortium of other universities and national laboratories (see http://www.neesgrid.org).

The shared-use equipment sites are linked with one another as well as with other participating resources for experimentation, computation, data curation, simulation and visualization through the NEESgrid network architecture being developed by the system integration team. Coordination of the communications and network infrastructure, shared use and other equipment sites, databases, and other resources needed to enable the NEES collaboratory will be overseen by a consortium.

1.3 The NEES Collaboratory and Consortium

NEES is to be managed by a single community-based and community-led consortium, and operated as a collaboratory.

While the experimental, computational and networking components of NEES will each have a dramatic impact on research and education, the long-term impact of NEES will likely be due to the fact that it is being implemented as a collaboratory. By bringing researchers, educators and students together with members of the broad earthquake engineering and information technology communities, providing them ready access to powerful experimental, computational, information management and communication tools, and facilitating their interaction as if they were "just across the hall," the NEES Collaboratory will be a powerful catalyst for transforming the face of earthquake engineering. The diversity of talents, backgrounds, experience and disciplinary concerns to be represented within the NEES Collaboratory will provide an unparalleled stimulus to intellectual inquiry and education. It is thus expected that the NEES Collaboratory will fundamentally change the processes by which earthquake en-
gineering research is initiated and performed, accelerate the generation and dissemination of basic knowledge, facilitate the development of effective educational programs, minimize the lag between knowledge development and its application, and hasten the attainment of the nation’s goals for earthquake loss reduction.

A project to develop the community-backed research collaboratory and establish the consortium that will operate the NEES collaboratory is now underway under NSF sponsorship. The specific tasks within the NEES Consortium Development Project are to:

1. Organize and engage the broad earthquake engineering community to gain community-generated input and broad consensus for the organizational structure and governance of the NEES Consortium;

2. Establish the NEES Consortium as a legal entity as early as possible (but no later than October 1, 2003); the NEES Consortium entity must submit a proposal to NSF by October 1, 2003 covering the 2004-2014 decade;

3. Facilitate the community-generated input and consensus needed by the NEES System Integration awardee for detailed design of the high performance network;


Thus, a basic aspect of the consortium development effort will be to engage the broad earthquake engineering community into activities that advance the vision of the NEES Collaboratory. This White Paper comprises a basic aspect of this effort.

To guide the consortium development effort, NSF has identified several basic tasks to be undertaken by the NEES Consortium related to leadership, facilitating the collaboratory and managing and administering NEES (NSF, 2000a). These tasks are:

Demonstrate leadership:

1. Lead, coordinate, and serve as the focal point for NEES

2. Conduct activities to enhance the interaction of the NEES Collaboratory with the earthquake engineering community to promote the development of integrated experimentation, com-
putation, theory, databases, and simulation

3. Pursue technology development opportunities to enhance the capabilities of the NEES collaboratory

4. Conduct and coordinate outreach and training activities for the NEES equipment sites, to encourage full participation in and use of the NEES collaboratory by the earthquake engineering community

Facilitate the Collaboratory

5. Operate the NEES Collaboratory, including management of shared-use operations at the NEES equipment sites and all components of the NEES Collaboratory

6. Operate under policies and procedures that address items such as shared-use access, user fees, and operating cost reimbursement policies for the NSF-funded NEES equipment sites and data protocols for the NEES curated repository

7. Develop connectivity and interactions with other relevant experimentation sites located at U.S. academic institutions, U.S. Federal and national laboratory sites, and international sites

8. Interface with NSF and other Federal agency earthquake hazards reduction programs

Manage the NEES MREFC program

9. Operate under ten-year strategic, business, and critical self-assessment plans

10. Operate under established bylaws for governance, and organizational and administrative structure

The NEES Consortium Development Project is being carried out by the Consortium of Universities for Research in Earthquake Engineering (Robert Reitherman, PI), in cooperation with the American Society of Civil Engineers (ASCE), Earthquake Engineering Research Institute (EERI), the Center for Research on Electronic Work (CREW) and other organizations. It seeks to engage broad segments of the earthquake engineering community into the definition of NEES Consortium and identification of the attributes of the NEES Collaboratory.

Additional information on the NEES Consortium development effort may be found at http://nees.org.
1.4 Time Frame for Bringing NEES on line and for the Consortium Development Effort

The construction of the shared-use equipment sites, the systems integration effort, and the consortium development activities are coordinated to bring the NEES collaboratory on line in October 2004. Detailed schedules and project execution plans for these activities may be found elsewhere (see http://nees.org and http://neesgrid.org).

The NEES Consortium development effort has a number of major milestones mandated by NSF. These and other activities are described in detail in the Project Execution Plan developed by the consortium development team. In addition to establishment of an interactive web site as the focal point for NEES activities and formation of task committees to seek community input and plan various aspects of collaborative and consortium operation, NSF stipulates the following milestones:

By October 1, 2002:
- Community-generated and community-supported workshop and task force reports posted on web;
- Plans completed for coordination of outreach and training activities with NEES equipment sites;
- First year critical self-assessment completed and documented.

By October 1, 2003:
- Documented evidence that a single community-led and community-based NEES Consortium has formed as a result of broad community-generated input and consensus among the earthquake engineering community.
- Completion of documents required for NEES Consortium formation, incorporation, governance and operation, including by-laws, policies and procedures, ten-year plans (strategic, business and self-assessment), and ten-year budget for operation and activities.
- A proposal submitted to NSF by the NEES Consortium for operation of the NEES Collaboratory from October 1, 2004, through September 30, 2014.
- Community-generated and community-supported workshop and task force reports posted on the web.
- Report on outreach and training activities coordinated with and implemented at NEES equipment sites
- Second year critical self-assessment completed and documented.
By September 30, 2004:
  o Completion of activities required to enable start-up operation of the NEES collaborative by the NEES Consortium beginning on October 2004,
  o All workshop and task force reports completed and posted on the web.
  o Final project year and cumulate critical self-assessment completed and documented, including recommendations for NEES Consortium operation.

1.5 Operation of the NEES Collaboratory and Consortium during 2004-2014

NSF intends to operate NEES for a ten-year period extending from October 1, 2004 through September 30, 2014 (FY 2005 – FY 2014). As indicated above, specific plans for the operation of the collaborative are to be developed on the basis of community input through the Consortium Development Project.

NSF intends to fund the activities and operation of the NEES Consortium, including the shared use aspects of the shared-use equipment sites and the operation of the NEESgrid, through a single award to the NEES Consortium. To effectively mobilize the earthquake engineering community to take advantage of NEES resources and to accomplish the goals of the NEES MREFC program, it is anticipated that NSF would also provide the earthquake engineering community with additional funds with which to use the NEES collaboratory over its initial ten-year operation. It is anticipated that funding on the order of four to five times the initial capital investment in NEES would be necessary for the earthquake engineering community to adequately address critical high priority research issues.

1.6 The Developing Research Agenda

NSF has funded two additional projects to help identify and prioritize the long-term uses of NEES and high priority research needs.

One of these efforts, being undertaken by the Earthquake Engineering Research Institute, focuses on identifying the overall research needs for reducing earthquake losses. A draft report on the EERI effort may be found at http://eeri.org/research.html.
The other effort, conducted by the National Research Council, focuses on the specific long-term uses of NEES. In particular, the NRC committee is studying methods to involve the broad community in identifying NEES-related research needs, procedures for prioritizing these needs and how to best take advantage of information technology within the collaboratory environment being incorporated within NEES, and developing a research plan for NEES including a cost-benefit assessment. Highlights of the NRC committee activities may be found at http://www7.nationalacademies.org/bice/.

In addition to these specific activities, NSF may under take additional efforts to identify and initiate research and educational programs using the NEES MREFC resources.

Similarly, the NEES Collaboratory provides unique opportunities for partnerships, nationally and internationally, with other private and public sector entities to pursue high-priority research, to demonstrate the validity of design concepts and guidelines, and to speed the transfer of research into reliable and cost-effective design guidelines and specifications. The integrated state-of-the-art features of the NEES Collaboratory may substantially assist in the realization of the missions of various federal, state and local government agencies as well as the achievement of the goals of industry, trade associations, professional organizations, and private companies, facility owners, and others. Ideas for such research projects and opportunities for partnerships to address critical research needs, and procedures for identifying any additional resource needs to achieve high priority research needs, will be developed as part of the consortium development process.
THE PARADIGM:
USE OF MAJOR RESEARCH TOOLS,
COLLABORATRIES AND CENTERS IN THE PURSUIT
OF FUNDAMENTAL ENGINEERING KNOWLEDGE
AND THE DISSEMINATION OF KNOWLEDGE THROUGH
TEACHING, TRAINING AND LEARNING

2.1 The NSF Major Research Equipment and Facilities Construction Program

NSF’s overall strategic vision embodies three interacting elements that guide its investments in science and engineering research and education: People, Ideas and Tools. Through the competitive peer-review process, NSF intends to carry out research on the best ideas by the most capable people. Nonetheless, NSF recognizes that this effort cannot achieve the desired outcome unless the research community has access to the right tools.

As a result, NSF undertakes numerous activities to improve the nation’s research infrastructure. For example, individual researchers and groups of researchers may include in their proposals items of equipment necessary to carry out their investigations. To support broader research-centric educational initiatives, institutions can request equipment and instrumentation through NSF’s Major Research Instrumentation program. NSF also supports the development of major state-of-the-art, shared-use tools which are broadly accessible to a community of researchers and educators. These tools are expected to enable the community as a whole to undertake pioneering or otherwise essential research, fundamentally improve education, and enhance workforce productivity and effectiveness. The George Brown Jr. Network for Earthquake Engineering Simulation is a key component of NSF’s growing array of such shared-use tools.

In the past, many of the resources associated with shared-use tools were often centralized at a single location. While centralization provides a number of benefits related to management and logistics, it can impose a substantial (and increasingly unnecessary) barrier to community access. Consequently, NSF’s Tools are now frequently implemented as Internet-enabled virtual environments, incorporating a wide variety of geographically distributed, shared-use resources such as high performance computing, research networks, major research equipment and instrumentation, software applications, digital libraries, and large databases. Whether centralized or geographically distributed, NSF’s Tools are intended to advance in a fundamental manner the processes of discovery and innovation in science and engineering.

Expenditures by NSF for the Tools program amount to about $1.1 billion annually. Current facilities in the Tools program include the Academic
Research Fleet, Advanced Networking Infrastructure, Gemini Observatories, Incorporated Research Institutions for Seismology, Laser Interferometer Gravitational Wave Observatory, National Astronomy Centers, the National Center for Atmospheric Research, the National Science, Technology, Engineering and Mathematics Education Digital Library, Ocean Drilling Program Facilities, Partnerships for Advanced Computational Infrastructure, and the Polar Science, Operations and Logistics program. The Tools program also includes the Major Research Instrumentation (MRI) and Major Research Equipment and Facilities Construction (MREFC) programs.

The MREFC program includes the construction and startup of major shared-use facilities. This program is funded at approximately $130 million per year and, for fiscal year 2002, includes the following MREFC projects:

- Atacama Large Millimeter Array (ALMA) Construction
- High-performance Instrumented Airborne Platform for Environmental Research (HIAPER)
- Ice Cube Neutrino Detector
- Large Hadron Collider (LHC)
- George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES)
- South Pole Station Modernization (SPSM)
- Terascale Computing Systems

For fiscal year 2003, with the completion of the HIAPER, two new MREFC projects have been proposed to Congress. These are the National Ecological Observatory Network and Earthscope.

Once MREFC facilities are commissioned, research and operational funding is usually provided through the overall Tools program budget, as well as through the Research and Related Activities (R&RA) and/or Education and Human Resources (EHR) programs. Several of the facilities within the Tools program are Federally Funded Research and Development Centers (FFRDC) operated by NSF (comparable to the Los Alamos National Laboratory operated by the Department of Energy).

Technically and organizationally complex endeavors such as NSF’s MREFC projects require special arrangements for operation and research support. To accomplish this, NSF provides overall policy level
guidance and detailed oversight. However, NSF typically awards the actual planning, construction, operation and management of the facilities to universities, consortia of universities, or non-profit organizations. In this manner, the creativity and intellectual vision of the research and academic communities is integrated with the oversight experience and skills of NSF. Using such arrangements, NSF has established an exemplary track record for operating unusual and complex research facilities.

2.2 Examples

To help understand the nature and scale of issues that may need to be addressed in developing the NEES Consortium and Collaboratory, a brief background is provided below regarding some of NSF’s activities related to Tools, collaboratories, centers and cooperative programs.

2.2.1 Tools and Major Facilities

Gemini Observatories – Starting in 2000, the Gemini Observatories offer the scientific community world-class capabilities and unique opportunities in optical astronomy. The core equipment of the Gemini Observatories consists of two 8-meter diameter telescopes, one located in the northern hemisphere on Mauna Kea in Hawaii and the other in the southern hemisphere on Cerro Pachon in Chile. The telescopes utilize adaptive optics to provide a resolving ability nearly twice that of the Hubble Space Telescope. The telescopes were developed and are operated through an international partnership including Chile, Canada, the United Kingdom, Brazil, Argentina and Australia. In addition to supplying their own instrument packages, and participating in “shared-risk” instrumentation/observation programs, researchers have access to a wide variety of shared-use instrumentation. Several general-purpose computer applications are provided for processing and interpreting data, and both public and science archival databases are being developed. More information on the Gemini Observatories may be found at the website for the National Optical Astronomy Observatory FFRDC website: http://www.noao.edu/usgp/

National Radio Astronomy Observatory (NRAO) – The NRAO is headquartered in Charlottesville, Virginia, and designs, builds, operates and maintains radio telescopes on behalf of the scientific community at sites in Arizona, New Mexico, and West Virginia. NRAO makes radio astronomy facilities available to scientists from around the world. It is operated under cooperative agreement with Associated Universities, Inc., a consortium of universities that has also operated other large research facilities for the federal government. The telescope sites provide staff support for on- or off-site use of the large
radio antennas, receivers, and other equipment needed to detect, measure, and identify radio waves from astronomical objects. As a result of recent NSF-funded construction, the Robert Byrd Green Bank (West Virginia) Telescope incorporates an adaptive reflective surface to sharpen radio images and the Very Large Array continues to be improved through a planned program of enhancements and expansion. Additional information on the NRAO FFRDC may be found at: http://www.nrao.edu.

Laser Interferometer Gravitational-Wave Observatory (LIGO) – Construction of the Laser Interferometer Gravitational Wave Observatory (LIGO) began in 1992 as collaboration between physicists and engineers at the California Institute of Technology and the Massachusetts Institute of Technology. Today, the LIGO scientific community has expanded to include more than thirty research groups across the US and abroad. LIGO consists of two widely separated installations, one in Hanford, Washington, and the other in Livingston, Louisiana. These are operated in unison as a single observatory. The facilities are dedicated to the detection of cosmic gravitational waves, conduct of fundamental physics experiments related to Einstein’s theory of gravity, and making data on gravity waves available to the science community. Additional information on LIGO may be found at: http://www.ligo.caltech.edu.

South Pole Station Modernization, and Polar Science, Operations and Logistics -- Research in the remote Antarctic continent is made possible by the NSF Polar Science, Operations and Logistics program. The shared-use facilities make possible critical studies on a wide variety of topics, including global climate change, polar ecology, meteorology, aeronomy, astrophysics, astronomy, and so on. Three, year-round Antarctic research stations are operated as part of the program - McMurdo Station on Ross Island, Palmer Station on Anvers Island, and Amundsen-Scott South Pole Station. Facilities also include ski-equipped, fixed-wing aircraft, helicopters, and ice-breaking research and logistics.
ships. Major renovations and additions are currently being made at the South Pole Station as part of the NSF MREFC program to accommodate nearly 150 researchers and support staff. Additional information on the South Pole Station may be found at: http://www.nsf.gov/home/polar/.

**Partnerships for Advanced Computational Infrastructure (PACI) and Terascale Computing Systems** – Through PACI, NSF provides and builds tools to improve the networking and computing infrastructure that supports the broad-based academic science and engineering communities served by NSF. PACI provides support for two national partnerships (National Computational Science Alliance and the National Partnership for Advanced Computational Infrastructure) and the Terascale Computing System. More than 20 high-performance computer systems are available through these efforts. Completed in late 2001, the Terascale Computing System at the Pittsburg Supercomputer Center is the most powerful computing system available to academic researchers today, consisting of a 3000-processor, 6-Tflop system. Other on-going PACI programs provide further access to, and support for, high-end computing and the development and application of the necessary software, tools and algorithms for use on scalable, widely distributed resources. PACI affiliated researchers are creating new Web-based tools to help computer scientists, as well as other scientists and engineers, by simplifying and consolidating tools for accessing the grid of advanced computing systems supported by NSF. The emphasis of NSF funding within PACI increasingly focuses on scaling application codes to the Terascale Computing Systems environment, developing resources for archiving and visualizing very large data sets, and undertaking education and training efforts to broaden and accelerate domain utilization of the high performance computing resources being developed. The National Computational Science Alliance is a partnership of 50 academic, government and industry research partners, and the National Partnership for Advanced Computational Infrastructure includes 46 domestic and four foreign partners. Additional information on the Terascale Computing System and PACI may be found at: http://www.paci.org.

**National Center for Atmospheric Research (NCAR)** -- National Center for Atmospheric Research facilities serve the entire atmospheric sciences research community and part of the ocean sciences community. Through its nine core divisions and programs, the NCAR FFRDC offers a wide range of experimental, computational, database and communications resources to its members. In addition to ground-based facilities for experimentation in the laboratory and field, NCAR provides research aircraft equipped with a wide variety of state-of-the-art sensors. Participants have access via the Internet to advanced computational resources well suited to the development and execution of complex
models, as well as for archiving, manipulating and visualizing large data sets. More than 1,500 researchers and students use the NCAR facilities annually. NCAR is operated by the University Center for Atmospheric Research (UCAR), a corporate entity with members from more than 65 academic institutions in the US. UCAR, through its Office of Programs (UOP), also undertakes related programs, which create, conduct, and coordinate projects that strengthen education and research in the atmospheric, oceanic and earth sciences. Among the eight programs currently underway is the National Science, Technology, Engineering and Mathematics Education Digital Library (NSDL), another new NSF major facility program. Additional information on NCAR may be found at: http://www.ncar.ucar.edu/ncar/.

**National Science, Technology, Engineering and Mathematics Education Digital Library (NSDL)** -- Responding to needs articulated by NSF, the academic community, and industry, a national, state-of-the-art digital library is being developed within the NSF Tool program. The NSDL focuses on science, technology, engineering and mathematics education, and is scheduled for initial operation in the fall of 2002. It is intended to provide “a forum for the merit review and recognition of quality educational resources; a mechanism for electronic dissemination of information about high-quality educational materials, pedagogical practices, and implementation strategies; a centralized registry and archive for educational resources; and a resource for research in teaching and learning.” In addition, NSF intends for the NSDL to provide an infrastructure to support and accelerate the impact of other NSF programs. The NSDL is a cooperative project conducted by UCAR, Cornell University and Columbia University. Overall project management and integration, as well as community building and outreach efforts, are being conducted through UCAR. Cornell team members have primary responsibility for software development and networking infrastructure, and team members at Columbia are addressing issues related to intellectual property and digital rights management. Additional information may be found at: http://www.nsdl.nsf.gov/indexm.html.

**Incorporated Research Institutions for Seismology (IRIS)** -- Created in 1986, IRIS is a not-for-profit, university-based consortium that operates a global network of seismometers, provides portable seismometers and data acquisition systems for regional studies, maintains a data management system to provide on-line, distributed access to data on global seismic activity, and carries out educational and other outreach activities. IRIS programs are intended to contribute to scholarly research, education and earthquake hazard mitigation. In addition, a portion of the Global Seismic Network operated by IRIS provides an integral component of the nation’s nuclear test ban treaty monitoring capabilities. With its corporate headquarters located in Washington DC, IRIS carries out four major operational programs (i.e., the Data Management System (DMS), Global Seismographic Network (GSN), Program for the Array Seismic Studies of the Continental Lithosphere (PASSCAL), and Education & Outreach) to support the science community. Data and other centers are located in the states of California,
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Massachusetts, New Mexico, South Carolina and Washington as well as abroad. Additional information on IRIS may be found at: http://www.iris.edu/.

EarthScope – NSF has proposed to Congress the addition of a new MREFC project in 2003 called Earthscope. EarthScope will apply modern observational, analytical and telecommunications technologies to investigate the structure and evolution of the North American continent and the physical processes controlling volcanic eruptions and earthquakes. Four new national facilities would be established through EarthScope: 1) the San Andreas Fault Observatory at Depth (SAFOD), a deep observation hole drilled into the San Andreas fault, 2) USArray, a continental scale seismic array of permanent and portable seismometers, 3) the Plate Boundary Observatory (PBO), a large scale network of permanent and portable GPS receivers and strain meters deployed along the plate boundary, and 4) interferometric synthetic aperture radar (InSAR), a dedicated satellite capable of providing spatially continuous strain measurements over wide geographic areas. These new facilities combined with funding for integrated earth science research and education provide a framework for basic and applied geologic research across the United States and neighboring countries. Additional information on the proposed features of EarthScope program may be found at: http://www.earthscope.org/.

2.2.2 Collaboratories

While NEES is likely to share many of the basic attributes of the other major facilities operated by NSF, its implementation as a community-based collaboratory will give it a unique flavor. William Wulf, currently president of the National Academy of Engineering, coined the term “collaboratory” in 1989 while he was at NSF. This term describes the concept of using information technologies to enable multiple, geographically separate research units to function as a single laboratory. Since then, NSF and other entities have undertaken a number of programs to develop tools for collaboratories and to fund pilot collaboratory projects [NSF, 2000d]. Some early adopter projects funded by NSF and other agencies include:

- The NSF-sponsored Upper Atmosphere Research Collaboratory (UARC). – This collaboratory, now called the Space Physics and Aeronomy Research Collaboratory (SPARC), allows space physics researchers around the world to control and gather data from more than a dozen instruments located around and above the globe, and to communicate readily with one another. More information on SPARC may be found at http://intel.si.umich.edu/sparc/.

- The DOE-sponsored Materials Micro-Characterization Collaboratory (MMC) – This collaboratory (see http://tpm.amc.anl.gov/MMC) conducts research on the microstructure of advanced materials, and involves three DOE laboratories (Argonne, Lawrence
Livermore and Oak Ridge National Laboratories), the National Institute for Standards and Technology (NIST), and the University of Illinois.

- The Environmental Molecular Science Laboratory -- A collaboration similar to MMC has been developed by the Pacific Northwest National Laboratory in Richland, WA to allow scientists at many sites and in different disciplines to work together on environmental problems, sharing instruments, expertise, and a powerful supercomputer (see: http://www.emsl.pnl.gov/docs/collab/).

- The DOE-sponsored Diesel Combustion Collaboratory – This effort focuses on the control of diesel engine emissions and facilitates the interaction of three DOE national laboratories, researchers at the University of Wisconsin, and several diesel engine manufacturers. (See: http://www-collab.ca.sandia.gov/snl-dcc.html).

- The Research Collaboratory for Structural Bioinformatics (RCSB) is a non-profit consortium dedicated to improving understanding of the function of biological systems through the study of the 3-D structure of biological macromolecules. RCSB members work cooperatively and equally through joint grants, and develop free resources that further the fields of bioinformatics and biology. Collaboratory members include Rutgers, NIST and the San Diego Supercomputer Center. Additional information may be found at: http://www.rcsb.org/.

- The Collaboratory for Research on Electronic Work (CREW). This program is a research unit within the School of Information at the University of Michigan. By working with government, academic and industrial entities, CREW researchers focus on the design of new organizations and the enabling information technologies related to voice, data, and video communication. Funding for CREW is provided by NSF as well as by other government and industry partners. (See: http://www.crew.umich.edu/)

As articulated by Wulf and others, shared access via the Internet to electronic notebooks and whiteboards, videoconferencing capabilities, databases and digital libraries, experimental equipment and instrumentation, computer simulation and visualization tools and other such resources can enhance the feeling of being "just down the hall" even though collaborators may be on opposite sides of the country. The powerful shared-use resources within a collaboratory can substantially leverage the ability of a single investigator or a small group of investigators to undertake pioneering research.

Sharing may likely involve multiple users from different sites using a single major scientific resource, such as large radio telescope, or it may involve a single researcher or a small research team using, either concurrently or sequentially, multiple components of a network of integrated instruments and other research equipment (such as real-time sensors,
database repositories and computers that may be physically separated by considerable distances).

However, in many collaborations (as well as at many of NSF’s major facilities), the relevant research community is able to unite and direct its combined talent and creativity towards the solution of large, perplexing problems of great national scientific and societal importance. As such, one of the key common activities of major facilities and collaborations is the engagement of the relevant research community in an on-going process of identifying high priority research goals, including so-called “grand challenge” type campaigns, and developing of strategic action plans for achieving these goals.

### 2.2.3 NSF Centers and Cooperative Programs in Earthquake Engineering

NSF undertakes a number of other activities to encourage research in high priority areas by teams of researchers, educators and industrial partners. These activities include the Engineering Research Centers program and the Science and Technology Research Centers program. NSF also develops, in response to strategic goals set by NSF or recommendations developed by a community of researchers and educators, less structured research programs by issuing formal community-wide solicitations for proposals.

The Engineering Research Center (ERC) program has had a significant overall impact on engineering research. This program was started in 1985 to strengthen the contribution of academic engineering to industrial competitiveness. Every year since then, roughly 20-25 engineering research centers have mobilized multidisciplinary, and often multi-institutional, teams that address issues of importance to industrial competitiveness. The centers accomplish their goals by integrating traditional disciplines, applying a systems approach to research planning and management, and forming university-industry partnerships. These centers also strive to change university culture by highlighting industry as well as academic perspectives, integrating education and research, involving more undergraduate students in research, and expanding the diversity of engineering graduates.

The overall NEES program has not been implemented as a center, and will not be operated as such. It is, however, instructive to examine briefly how the engineering research centers operate, and the strategic tools they use to manage their collaborative activities.

For example, ERCs engage in regular strategic planning activities to develop specific, well-articulated research visions, plans and goals. Each of the ERCs utilizes a systems-oriented framework to plan and carry out its activities. A three-plane framework is utilized, schematically illustrated in the box shown below, to relate the conceptual and operational activities related to the overall engineering system being investigated,
the needed enabling technologies, and any efforts required to supply fundamental knowledge. A best practices manual related to the technical and operational management of ERCs has been developed and available at: http://www.erc-assoc.org/manual/bp_index.htm.

To address some of the challenges specific to the field of earthquake loss reduction, NSF has within the ERC program three Earthquake Engineering Research Centers (EERCs). These are the Mid-America Earthquake Center headquartered at the University of Illinois, Urbana-Champaign (http://mae.ce.uiuc.edu/), the Multidisciplinary Center for Earthquake Engineering Research headquartered at the State University of New York at Buffalo (http://mceer.buffalo.edu/), and the Pacific Earthquake Engineering Research Center headquartered at the University of California at Berkeley (http://peer.berkeley.edu/).

To carry out their mission, the EERCs bring together and harness the capabilities of multi-institutional, multi-disciplinary teams of investigators that interact with design professionals, industrial partners, policy makers, regulatory agencies, emergency managers, and other segments of the earthquake engineering community. The centers explicitly use the systems approach described above in formulating their research programs so that the appropriate aspects of engineering, seismology and earth science, and societal response are integrated. As a result, the research conducted provides the knowledge base, design and evaluation tools, and technology needed by industry, the design profession and
regulatory agencies to help reduce the particular aspect of earthquake loss being addressed by the center. Because of the resources associated with being an NSF center, the EERCs undertake important education and outreach programs, and develop partnerships with industry and the public agencies responsible for earthquake hazard mitigation at the regional, state, and local levels.

NSF, in conjunction with the US Geological Survey and others, has recently renewed the Southern California Earthquake Center (SCEC) for an additional 5-year period. SCEC was started as a NSF Science and Technology Center, and now includes researchers from 14 core institutions and 25 affiliates. This center gathers information about earthquakes in Southern California, integrates this information into a comprehensive, physics-based model of earthquake phenomena, and communicates its findings to the public in order to increase earthquake awareness, reduce economic losses and save lives. In addition to its base grant, SCEC receives additional funds from the NSF Information Technology Research (ITR) Program to development an online "collaboratory" system that will organize information about earthquakes and allow scientists to conduct their research interactively and more efficiently. Additional information regarding SCEC may be found at http://www.scec.org.

As noted previously, NSF also issues from time to time solicitations for research proposals in particular areas. Some examples of such programs in earthquake engineering include the current US-Japan Cooperative Research Program on Urban Earthquake Disaster Mitigation (NSF Program Announcement 98-36), and past programs such as the five phases of the US-Japan Cooperative Earthquake Engineering Research Program Utilizing Large Scale Testing Facilities. Over the 20 year duration of the latter program, hundreds of researchers have carried out innovative research related to the seismic safety of structures constructed from reinforced concrete, structural steel, precast concrete, reinforced masonry, composite and hybrid systems (http://www.eng.nsf.gov/engnews/1998_News/u.s.-japan_cooperative_large-s.htm).

Other cooperative programs have focused on topics such as the repair and rehabilitation of existing structures, structural control, and auto-adaptive (smart) systems. NSF has also fielded major cooperative research programs to maximize learning following major earthquakes, such as the 1989 Loma Prieta and 1994 Northridge earthquakes in the US and after recent seismic events in Japan, Taiwan and Turkey.

Often, a degree of coordination has been provided in NSF program solicitations; for example, researchers may be required to attend periodic meetings to discuss, share and informally coordinate their research with others. Even with such informal coordination, a high degree of synergism is usually achieved. However, these efforts typically lack the resources, such as those associated with an ERC or STRC, necessary to develop and implement long-term, broad-based education, training and outreach programs. As such, the research, education and practical
benefits of discoveries made through these efforts are often not as direct, far reaching or long lasting as they might be.

2.2.4 Examples of Other Coordinated Research Programs in Earthquake Engineering

Coordinated research programs related to earthquake engineering have been initiated by other national, state and local government entities, as well as by industry, trade associations and various business concerns. For example, the agencies participating in the National Earthquake Hazards Reduction Program (FEMA, NIST, NSF and USGS), the Departments of Defense, Energy and Transportation, and several other federal entities administer their own research programs or fund others to carry out research and development programs related to earthquake engineering. Some state government entities also undertake in-house research programs or sponsor research activities by consultants and universities related to seismic safety. Professional organizations, such as the American Society of Civil Engineers, the Applied Technology Council and the Earthquake Engineering Research Institute, and academic consortiums, such as the Consortium for Universities for Research in Earthquake Engineering, undertake significant efforts in conducting research or coordinating research efforts funded by others.

Many industrial organizations and private sector entities, including professional firms, undertake important research or development efforts. However, these efforts frequently lack access to resources and data, and lack capabilities to integrate and disseminate their findings.

Some recent earthquake engineering research efforts involve substantial multidisciplinary collaboration and joint sponsorship by numerous entities including government agencies, industry, trade and professional associations, universities and professional firms. A recent example of one such effort is the Program for the Reduction of Earthquake Hazards in Steel Moment-Resisting Frames Structures. Core funding for this effort was provided by FEMA to a level of about $12.5 million. The overall effort in this area had substantial additional funding from NSF and NIST, along with substantial contributions of materials, services, and staff time from structural steel shape producers, building fabricators, erectors, inspection agencies, building departments, various professional and trade associations, and universities. This organizational complex and technically challenging program was managed by the SAC joint venture, comprised of the Structural Engineers Association of California, the Applied Technology Council and California Universities for Research in Earthquake Engineering.

The FEMA/SAC steel program lasted six years, and involved hundreds of participants, and culminated in a set of guidelines for the design and evaluation of new steel buildings and the evaluation, retrofit and repair of existing ones. It involved more than 100 inter-related research projects conducted at several dozen universities, research institutes and
professional firms. Topics covered ranged from material science, mechanics, welding, nondestructive inspection, destructive testing, structural modeling, dynamic analysis, reliability modeling, design theory formulation, and social/economic studies. These studies were integrated into programs to develop and evaluate improved design guidelines and to establish professional training programs. At the heart of the program was a performance-based theoretical framework.

These efforts, as well as several others like it, clearly demonstrate the potential for major acceleration of progress in earthquake engineering through collaboration and creative partnerships among funding agencies, industry and universities. However, these programs today suffer from the lack of modern facilities for research and collaboration. For instance, the carefully documented experimental data recorded during the more than 500 tests archived as part of this program are no longer generally available, less than two years after the end of this monumental effort.

As a result, programs like these would be tremendously assisted by the resources provided for research, data curation, communication, collaboration and education to be provided by the NEES Collaboratory.

Logical Network Diagram for the FEMA Program to Reduce Earthquake Hazards for Steel Moment-Frame Structures

2.2.5 Observations

The tremendous pace of discovery and innovation possible through the inherent creativity and energy of the earthquake engineering research community (through NSF’s EERCs, coordinated research programs, and individual investigator grants as well as through efforts of other government and private sector entities) has been substantially diminished by the absence of an integrated community-wide infrastructure supporting communication and collaboration, as well as by the lack of resources to
enable world-class research. These barriers to discoveries and innovations critical to earthquake loss reduction and to the dissemination of knowledge to the broad earthquake engineering community are central issues being addressed by the NEES program.

### 2.3 Collaboratories

The increasing complexity, scale, and multidisciplinary nature the problems challenging the scientific and engineering research communities necessitates collaboration at many levels. The potential synergistic benefits of tackling such problems by mobilizing multidisciplinary teams of investigators from the research, education and professional communities are self-evident. Direct and indirect collaboration may also occur through interactions between:

- individuals (through sharing of expertise, experience, knowledge and “how to” tips, mentoring of students and junior members of a community, active collaboration on joint projects, etc.),
- individuals and information (efforts to synthesize, analyze and re-analyze information extracted from literature, data and metadata),
- individuals and resources (use of experimental facilities and instrumentation, network services, high-performance computing systems, user-level software applications for simulation, data analysis and visualization, etc.), and
- resource/service providers (integration of services offered by different resources, developing fundamentally new capabilities by enabling resources to work together, improving services, developing or exploiting new technologies and instrumentation, etc.).

It is expected that a properly functioning, network-enabled collaboratory, providing community access to integrated next-generation tools for communication, experimentation, computation, model-based simulation, database curation, and analysis and visualization of data, would have a dramatic impact on these interactions. The impact would likely be felt tremendously by individual researchers (and small teams of investigators) due to the leverage created by the increased access to expertise and resources. Such a collaboratory would also provide a powerful vehicle enabling the science and engineering community to unite and attack critical “grand challenge” type problems as never before possible.

Among the simple benefits often cited of collaboratories [Ross-Flanigan, 1998] are:

- Scientists can avoid going to scientific instruments in remote locations.
- Many more universities, scientists, and students can participate in or observe experiments.
• By connecting computation to experiments, scientists can better and more quickly integrate experiments and theory. Theorists and experimentalists can work together in real time, greatly reducing the time required to analyze experiments.
• Scientists can put together quick videoconferences to discuss the data.
• Students can participate in experimentation much earlier in their careers than before.

Clearly, other benefits and capabilities are possible. The community developing a collaboratory needs to consider carefully the capabilities and attributes that it would like to incorporate.

The following sections highlight some basic capabilities and attributes associated with collaboratories in general and describe some of the underlying benefits and challenges that need to be addressed in implementing a collaboratory. More detailed information on collaboratories may be found in National Collaboratories: Applying Information Technology for Scientific Research [NRC, 1993], from which the writers have adapted much of the following material.

2.3.1 Core Capabilities

While specific implementations of collaboratories take different forms, depending on the nature of the problems being addressed and the needs of the collaborating community, all collaboratories generally incorporate certain basic capabilities. These capabilities include mechanisms for:

Sharing data – It is generally acknowledged that the progress of discovery and innovation is accelerated by rapid dissemination of knowledge. In the context of a collaboratory, a wide variety of information may need to be shared; for example, data obtained from experiments or analyses, metadata describing the procedures and conditions under which the data was obtained and processed, computer software applications, computational models, and written narratives. Data may take on many forms (numeric, symbolic, audio and visual) and be obtained from many different sources. Thus, a network-enabled collaboratory should include a core capability that permits timely, seamless and scaleable sharing of high quality information of all kinds.

Sharing software – Another common need of a collaboratory is user level, network-enabled applications for the storage, retrieval, manipulation, analysis and display of data. In addition, many collaboratories encourage and provide support for community-defined, community-developed (i.e., shared-risk) simulation software applications and models. In a collaborative environment, a high premium is usually placed on providing application modules that have the inherent intelligence to detect and work seamlessly with other modules, that import and export
data sets in readily recognizable formats, and that have user interfaces to have a similar "look and feel" and that employ common conventions. It is expected that community resource software to be thoroughly documented (describing the underlying theory, assumptions and implementation approach). Policies, processes, toolkits, testbeds, and explicit software development efforts that encourage documentation, common user interfaces, enhanced software capabilities, improved algorithms, and so on are highly valued in collaborative environments.

**Sharing facilities** – Many items essential to the research enterprise are complex, and are costly to build and operate. As such, they are generally available in only a few locations worldwide. Thus, most collaboratories adopt the concept of shared-use facilities, in which unique equipment and instruments are shared, operated by skilled and trained staff, and accessible via the Internet to remote users.

**Communicating with remote colleagues** – To facilitate communication and collaboration, an array of multimedia work-group systems are needed. For electronic work to be productive, features should be easy to use, and based on sound principles of organizational and human behavior. Provisions are generally required for both real-time and asynchronous communications. Other desirable features include ones that automate routine tasks, such as scheduling of communication modalities, such as videoconferences, and locating and reserving instrumentation, equipment and other resources.

**Share-Risk Tools** -- Another increasingly common feature of collaboratories is the development of “community-owned” resources, such as comprehensive models, instruments or software applications. Often these “shared-risk” efforts are a major mechanism for advancing the science or engineering mission of the community. Development of community resources is often coordinated or “hosted” by the collaboratory.

### 2.3.2 A Systems Approach to Collaboratory Functions

A systems approach is suggested in *National Collaboratories: Applying Information Technology for Scientific Research* [NRC, 1993] for organizing the various functions of a collaboratory. These may be viewed as interrelated layers, with each layer involving similar functions or activities related to the operation of the collaboratory. The five hierarchical levels, schematically illustrated in the figure below, are research facilitation functions, collaboration functions, collaboration tools, enabling technology, and network infrastructure/services.

It is likely that every collaboratory will have different specific functions or activities at each level. However, every collaboratory would usually include activities at each level.
This taxonomy groups functions and activities together that relate to one another according to their role in the collaboratory operations. As such, these activities have many features in common and are otherwise interrelated. However, another perspective would be to organize the collaboratory in terms of how it interfaces with a user; for example, community building and outreach activities, education and training, incubating research ideas into projects, conduct of projects and campaigns, disseminating results, communications, etc. From this perspective, a particular set of activities extend vertically through the various collaboratory functions and tools identified in the figure shown above. This vertical integration is a key aspect of the systems approach to the collaboratory development and operation.

Parallels to the “three-plane” chart systems approach used to plan and manage engineering research centers can be easily drawn. The three-plane chart, however, relates to the planning and integration of research activities, whereas the five-layer chart shown above relates to the operational aspects of actually conducting the research within a collaboratory. Other parallels might also be made to the hierarchical layers often used to organize and describe the architecture of networked computer applications and systems. While fundamental differences in character exist, one might simplistically view these three system models as a continuum, with the research layers on top, the operational collaboratory layers in the middle, and the enabling network applications and infrastructure providing the foundation.
Some of the aspects of the five functional layers of a collaboratory are described below. For the purposes of this discussion, we will assume that a well-conceived research plan has been established. In designing a collaboratory to facilitate the planned research, it is useful to anticipate activities that take place before, during and after the research program. It is also useful to consider needs for collaboratory services from various perspectives: for example, from that of those generating data, those using data that has been generated, and those who are providing the collaboratory services.

**Research Facilitation Functions** -- Ideally, a collaboratory supports those functions and activities that are typically encountered in all research projects, whether they are conducted as part of a collaboratory or not. Thus, support would generally be provided for group activities such as developing the underlying theoretical framework for the problem being investigated, devising a research plan, mobilizing the material and human resources needed to carry out the plan, managing the project, analyzing and interpreting results, developing conclusions, preparing publications, making presentations, responding to community feedback, and so on.

On an on-going basis, a collaboratory would naturally need to devote considerable energy to community building as well as to training and educating users and potential users on the use of its various features. Prior to a project, the collaboratory needs to provide services that help the community mobilize to take advantage of the collaboratories resources, help the user community identify research challenges and priorities, assist those with ideas for research projects (or those with a need for particular information) find others with similar interests, allied expertise or resources, alert the community to upcoming projects where opportunities for collaboration exist, and so on. Following a project, there are continuing opportunities for collaboration, where individuals may want to use data obtained in prior campaigns, synthesize and analyze data obtained from several campaigns, interpret and curate data to put it and other related information into forms useful to the broader community, and so on.

In NSF-supported collaboratories, there are significant needs and opportunities to develop and implement functions related to education, enabling students to participate directly in research at remote sites, as well as to observe on-going research projects and make use of research results as a part of their learning process. Similarly, opportunities exist for developing capabilities within a collaboratory for continuing education and outreach.

**Collaboration Functions** -- At this level, the specific collaboratory activities needed to support the research and scientific functions cited above are addressed. For example, where training and education programs are identified at the research function level, the collaboration function level focuses on the actual activities necessary to develop, offer and evaluate specific training and education programs.
Similarly, this level may include specific activities to nucleate new research efforts by conducting regular activities to solicit ideas from the community for research, establish a knowledge-base where community members may locate expertise, resources, and information, identify potential collaborators, and provide services where groups can gather to discuss, plan, and decide to initiate new research efforts.

Once research programs start, a wide variety of activities are needed on sustained basis related to project management (aligning resources with technical requirements, scheduling, negotiating and allocating scare resources, monitoring, etc.), communications (telepresence, electronic work tools), operations (management, operation, maintenance and upgrading of physical resources, databases, simulation and visualization applications, and network services), administrative (back office) functions, and so on.

Collaboratories can also facilitate the dissemination of knowledge in a variety of ways. These include maintaining on-going virtual forums for community review and comment on work in progress (or preview drafts of publications), providing mechanisms for publishing data and metadata, providing collaborative work tools for development of joint papers and presentations, convening or facilitating participation in symposia, conferences and workshops, nationally or internationally and enabling broader virtual participation in such events. Methods to incorporate research into the educational process and curriculum can also be explored in this context.

Inherent in any collaboratory will be sustained efforts to provide and enhance vehicles for communication among members of the community, whether face to face or virtually. These activities include informal communications, project or task committee meetings (where automated scheduling, note taking and archiving of handout/whiteboard material may be desired), distributed seminars, and special purpose workshops and symposia.

In a manner analogous to research projects, a collaboratory can facilitate related activities, such as those focusing on educational programs and outreach. Ideally, these efforts are incorporated as an integral component of all research projects, but the collaboratory can facilitate these efforts if desired by a particular project, and overall community-wide educational initiatives can be facilitated or conducted by the collaboratory.

**Collaboration Tools** -- To carry out the specific collaborative functions mentioned above, a wide variety of collaboration tools are needed. For instance, to implement a sustained program of user training and education, distance learning technology, courseware development toolkits, staff, production facilities, multicasting servers, and other resources are need to be identified, assembled and coordinated.
To support the community knowledge base, digital libraries and databases need to be developed. These require the development of community-backed definitions related to the nature of the information stored, as well as to quality standards and any restrictions that may be placed on access. Rich sets of tools need to be developed or assembled for mining, analyzing, visualizing and interpreting data, and for distributing curated data to targeted segments of the community.

Similarly, a wide variety of tools are needed to support the routine conduct of the collaboratory’s research and education functions. These might include structured work group tools, group decision support systems, automatic resource schedulers, and extensive support for telepresence as well as various standard project management tools (scheduling, budgeting, etc.).

Tools to aid in dissemination of knowledge include those items mentioned above for education and training programs, but also may include software and hardware for publishing of data and metadata, automated meeting schedulers, applications for co-authoring documents, public discussion spaces, and so on. Policies are needed to support the implementation and operation of these tools.

A variety of collaboration tools are needed to support personal interactions. These include managed email services, videoconferencing services, conference and meeting facilitation and coordination, archiving of meetings (videos, notes, handouts, etc.) and so on. Automated capabilities for scheduling face-to-face and virtual meetings, as well as a meeting notification system, are desirable features of a collaboratory.

**Enabling Technology** – In addition to the general tools for collaboration, the collaboratory needs to support tools and technologies required to conduct the scientific and engineering research. Tools at the disposal of a collaboratory include its core resources for research, such as facilities, experimental equipment, instrumentation, databases, user-level software, platforms for computation and visualization, and so on. A wide variety of standards and protocols related to research functions are needed at this level to be able to implement the collaboratory tools and functions. In particular, metadata definitions and protocols to obtain (automatically, if possible) and synthesize this information from various sources are needed.

To support the common needs of the community, many collaboratories support or coordinate development of user-level application software for carrying out complex, system level simulations and for the development of domain models, as well as special purpose applications for interpretation and visualization of data. The various collaboration tools for telepresence (teleobservation, teleoperation, teleconferencing, web casting, etc.) being enabled by the collaboratory need to be integrated into the facilities available for research. In particular, research equipment and processes (analysis software) may need to modified to
permit teleoperation and “instrumented” to obtain the metadata necessary to allow remote users to understand research conditions. Incorporation of haptic and other augmented reality interfaces, including the use of personal robotic avatars and immersive environments, may help extend usability of the research tools.

**Enabling Network Infrastructure System and Services** – This level includes the basic network linkages, protocols and services necessary to link and integrate the various database, computational, simulation, visualization, equipment, and instrumentation resources. This level must be built upon sound information technology and management principles. As such, this layer is fundamental to the functioning and growth of the collaboratory.

Each collaboratory needs to adapt these and other considerations into an integrated system suitable for its needs. In doing this, it needs to consider carefully the nature of the research being conducted and the specific educational and outreach goals being pursued, as well as the capabilities and aspirations of the participating community. It is expected that attributes and capabilities will evolve and increase with time in response to the needs of the community.

### 2.3.3 Attributes That Encourage Participation and Increase Productivity

Based on feedback from participants in early collaboratories, a number of key attributes were identified in *National Collaboratories: Applying Information Technology to Scientific Research* [NRC, 1993] that encourage broad-based and effective participation. These attributes should be considered in the planning and design of a collaboratory. Some of these attributes are summarized below:

- Collaboratories by nature tend to work well where goals are well defined, where the communities involved have a history of collaboration or are predisposed to collaboration, and involve disciplines that rely heavily on quantitative data. Thus, careful consideration needs to be exercised in developing portions of collaboratories where new communities or segments of a broad community are brought together, or were non-quantitative information is employed in the research activities.

- Collaboratory projects that are launched from the bottom up tend to function well. Such projects are initiated in response to inquiries and efforts by groups of researchers who recognize the need to collaborate and understand the potential benefits of applying and using better information technology. As such, an important role of the collaboratory is to bring together elements of the community in a strategic and systematic fashion so that they can identify research projects of great intellectual and societal importance that are well suited to collaborative research.
• A collaborative should be developed so that its major features have a direct, immediate and positive impact on participants. The collaborative features should focus on how to accomplish specific research outcomes desired by participants. That is, focus needs to be placed on developing a smoothly operating, integrated system, rather than only on developing a disjoint patchwork of highly sophisticated applications.

• Collaboratory features should be easy to use, dependable and stable in operation, and provide users with a high degree of confidence in the quality of the data produced and available for subsequent use. The features implemented should free participants to focus more effectively on their disciplinary work, rather than requiring them to overcome a new set of hurdles or struggle over incomplete or problematic applications. Early collaboratories found that Internet congestion, the lack of reliability with some tools, and rapid changes in software reduced acceptance of the collaboratory and impeded research.

• It has been noted that Internet-assisted virtual communication is often less effective in building trust between researchers than face-to-face communications. As such, it is not believed that face-to-face communications will be entirely eliminated, and in fact, may increase due to the overall increase in the level of collaboration.

• Procedures and policies are needed to manage virtual interactions. It appears that collaboratories may increase the frequency and, often, quality of communications. Improved mentoring of younger members of the research community is reported as a positive outcome of increased virtual accessibility. However, a large number of irrelevant, trivial, or unwanted communication interactions may become an annoying distraction or an impediment to productivity.

• In developing the collaboratory, it is important to insure that funding agencies recognize the added effort required of researchers participating in a collaboratory. In particular, it is essential for the success of a collaboratory that the community does not perceive the collaboratory as reducing the financial or other resources available for conducting research by an individual or by the community as a whole.

• Well-executed collaboratories energize their community and have a synergistic effect on discovery and innovation. Thus, collaboratories undertake activities that build the participant base and develop a sense of community. Sense of community tends to increase as the scale, quality and scope of shared information available in the collaboratory grows. Participation in collaboratory activities can confer a sense of shared purpose, teamwork and community that can become self-sustaining in other activities undertaken by the community.

• Collaboratories are encouraged to establish liaisons with other collaboratories. This allows for sharing of experiences, lessons
learned, skill sets and technologies, and the development of better policies and practices for operations. Co-development or sharing of resources and enabling capabilities with other collaboratories may provide benefits to the collaboratory.

2.3.4 Anticipate and Mitigate Barriers to Operational Effectiveness

There are a variety of barriers to participation in a collaboratory, and to its effective use. Because collaboratories are a new mode of conducting research, minor difficulties in use may be perceived as major impediments by some users and may be used by others as an excuse to continue with old ways of conducting research. Thus,

- Well planned and executed testbeds and demonstration projects, where participants can achieve some personal success, can help improve perceived tradeoffs between the risks and rewards of participating in a collaboratory. These testbed exercises can also identify gaps in collaboratory services, and areas needing improvement.

- Costs of increased interactions due to collaboration need to be acknowledged and funded. Unfunded mandates lead to resentment that can impede a collaboratory.

- An important activity conducted by collaboratories is an active training program on the use of collaboratory components as well as on the nature and benefits of collaborative research. Frequent training courses, and well-prepared on-line resources (such as tutorials, manuals and knowledge bases of frequently answered questions) are necessary. In addition, helpdesks are common elements of collaboratories. Researchers follow irregular schedules, and time is often critical, especially at certain stages of an investigation. Thus, on-call, 24/7 assistance is an option worth considering. To minimize the need for such assistance, easy to use, or at least consistent, user interfaces should be the norm (thus, careful attention to human factors and usability engineering in the development of tools is essential).

- Efforts are needed to ensure reliable service. Frustrations with intermittent or interrupted service, system crashes and lost data can undermine the best organized collaboratory.

- Policies and procedures adopted by a collaboratory should be clearly written and easily accessible. These need to not only cover the operation and management of resources, but also clearly define the “rules of the road” for collaboration. This is a high priority in any collaboratory.

In view of the preceding comments, it may be better to do fewer things well, than for a collaboratory to try to bring too many things online before their time. Because of the need to assess capabilities before bringing
them on line, the normal iterative development process inherent in the information technology arena may be best facilitated through specific projects, early-adopters, and testbeds. Other approaches may be tried to account for and mitigate tensions due to differences between the systems approach adopted in engineering and the iterative discover process frequently adopted in information technology and computer science.

2.3.5 Anticipate and Mitigate Barriers to Individual Participation

Ideally, individuals would be attracted to participate in a collaboratory. The ability to participate in ground-breaking research of national importance utilizing next-generation tools is a powerful magnet for participation. In addition, potential participants should appreciate the leverage provided by the community-based resources within a collaboratory. Today, researchers are often less effective than they could be because they cannot readily find or access needed expertise, data or resources, or must devote tremendous energy to tasks not central to their mission, expertise or interests. For instance, investigators often need to spend considerable time and energy:

- Converting data from the literature and heterogeneous data sources to a common format to be able to carry out their research,
- Modifying computer programs developed by others to work on their computer systems,
- Adapting simulation software developed for one application to consider the particular circumstances they are investigating,
- Developing single-use applications to aid in the visualization and interpretation of data,
- Maintaining and upgrading complex computer systems, electronic instrumentation and experimental equipment, and so on.

While disciplinary researchers can and often do perform outstanding work in these task areas, the efforts are often ad hoc; executed to enable only the task at hand. As a result, the products may lack the documentation and generality needed for use by other investigators, even at the same institution. Moreover, the funds and efforts devoted to these efforts may detract from the project’s primary research objectives. When such redundant, but non-synergistic activities are repeated by investigators across an entire research community, they detract from the overall impact of the research enterprise. The resources and support services within a collaboratory should alleviate many of these issues, and help coordinate the efforts that are done so that their effect is synergistic, cumulative and longer lasting.

Nonetheless, there are a number of special risks that individuals may perceive as impediments to participation in a collaboratory. By antici-
pating such barriers, a collaboratory can take effective actions to mitigate their impact.

**Balance Risks with Tangible Incentives and Rewards** -- By long standing tradition, individuals within the science and engineering research communities have worked competitively. Rewards within many university and research environments are based largely on the publication in peer reviewed scholarly journals of individually initiated work and on becoming distinguished as an individual. In areas with limited resources and funding, competitiveness is especially acute. As a result, many view collaboration or the facilitation of collaboration with skepticism, as it does not represent a direct means to acclaim, promotion and increased research funding. In such circumstances, abstract arguments (citing the common good) or top down directives (vague encouragement to pursue multidisciplinary research) may be met with resistance and fail to lead to fundamental changes in behavior.

Consequently, a collaboratory should develop strategies for providing individuals with tangible rewards and incentives that outweigh the perceived risks of participating in the collaboratory. Some strategies that have been suggested include:

- **Mechanisms to facilitate acknowledgement of an individual's contribution through peer reviewed publications.** In most collaboratories, co-authorship of publications by data users and the data generator are encouraged. In fact, this is a requirement of some collaboratories as a condition of accessing data. In any event, numerous opportunities for joint authorship exist in large collaborative projects. Many collaboratories include resources to assist in the preparation of joint publications. Additionally, new publications and innovative modes of publishing work may be developed by the collaboratory (see below) to further acknowledge contributions, individually and collectively.

- **Efforts to systematically (gradually) transform merit review criteria so that greater recognition is given to the value of important contributions to collaborative research as well as to the leadership and management of effective collaboratories.**

- **Encouragement of funding agencies to target additional funds specifically for participation in the development of the collaboratory and for collaborative research.** This funding would provide a direct and tangible incentive for participation. In this regard, it is desirable to provide special funding of: (1) testbeds to assess collaboratory capabilities, (2) specific efforts that enhance these capabilities (as special projects or as part of a broader disciplinary-oriented research effort) and (3) activities involving multidisciplinary teams to expand the capabilities and scope of the collaboratory in a meaningful and productive manner. Funding opportunities within the collaboratory for individual and collaborative research directed towards high priority, high impact...
research goals would substantially increase participation in the collaboratory.

- Consideration by funding agencies of an individual’s record of past successful collaboration when making funding decisions for collaborative research.

**Overcome reluctance to share data** – The need to share data is another issue that may make individuals reluctant to participate in a collaboratory. Several reasons are often cited for this reluctance. In traditional approaches to research, individuals generally want to use the data they generate to the greatest extent possible before sharing it with others. Because of the reward system mentioned above, they may want to derive as many publications from it as possible. They have also invested considerable intellectual capital and physical effort in obtaining the data. As such, they may be naturally reluctant to share data with those who have not contributed tangibly to its discovery. Lastly, many investigations lack the tools or resources to adequately document the data obtained or the circumstances under which it was obtained. As such, they are hesitant to share data because other users may not understand the peculiarities of the data or the conditions under which it was acquired.

To overcome these impediments, some collaboratories place temporary restrictions on need to share of data. For instance, data sharing might not need to occur until after a fixed period of time, or only portions of the data might be shared initially, or sharing might be limited to those involved in a joint research project. In these cases, data and metadata are prepared according community-backed standards, and eventually released to the community at large.

In other cases, all data is shared soon after it is generated. Although there are apparent disincentives for immediate sharing, there are several tangible rewards and incentives for this, including:

- Sponsors can require such sharing as a condition for participating in special collaboratory only research programs. Sponsors may favor this because they can leverage the value of costly data by having it accessible to many investigators, thereby accelerating the achievement of the sponsor’s mission. For instance, the National Institutes of Health have announced the intention to require those receiving grant funds to share all data obtained, and to provide funding to enable grantees to share. Details on this policy may be found at: http://grants.NIH.gov/grants/policy/data_sharing/index.htm.

- Sponsors can provide supplemental funds to those who contribute data to such databases. These supplements may be made to recognize the extra effort necessary to prepare the data, to fund supplemental use of the data itself using collaboratory tools for data analysis, interpretation and visualization, or to enhance the capabilities of these tools.
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• Special support is generally recommended for groups (including the researchers who generated data) to synthesize and analyze data and put it into formats that are of special value to the community. When the community values these interpreted forms of data, researchers are encouraged to have their data included and they want to participate in the interpretation efforts.

• Funds can be provided to investigators who share data for special equipment, software, training and personnel support to facilitate data sharing and interpretation.

• Investigators would be encouraged to share data, if that in turn gives them quick access to related data generated by others. This data would be valuable to them in their own work. Similarly, investigators would be prone to share when they work jointly with experts from other disciplines who use the data they generate. If all data were shared immediately, researchers would have an opportunity to see who was using their data, and to participate in or comment on its use.

• Some collaboratories require joint authorship of papers, where those who generate data are included on papers written based on that data.

• Some scholarly journals require data upon which a paper is based to be archived in a community database.

• Publication-like recognition can be provided for public posting of data and metadata. To achieve the desired level of recognition, peer review of the data may be required. However, by copyrighting the data within the collaboratory database, and providing a formal citation system for the dataset so that it can be referenced in publications, data generators may be able to gain faster recognition for their work than possible otherwise. First, the dataset itself would constitute a referenceable publication in this situation. Secondly, users of the data would cite the copyrighted data set in their work, and the frequency of such citations could be used by an individual as a quantitative measure of the importance of the work leading to the data.

• Other forms of peer-reviewed publications may be developed by collaboratories to provide recognition for individuals within collaborative projects. Electronic journals of quick findings or on the use of collaboratory tools are possible.

• An investigator will also have convenient permanent access to their own data, even after the personnel involved in generating it are no longer available. Sadly, the ability access inadequately archived data is now often lost after just a few years with rapid changes occurring in personnel and computer equipment.

In any event, clear and explicit “rules of the road” regarding policies and practices for sharing of data are needed. These should be established for the collaboratory as a whole. Special requirements can be
developed as necessary by individual research programs operating within the collaboratory.

**Assure high quality data** – In addition to making information easily accessible, investigators need to be confident that data obtained from the collaboratory is of high quality and understand the peculiarities associated with its generation, collection and processing. Data must also be secure from accidental loss due to equipment failure, or intentional tampering by unauthorized individuals. Unless researchers can fully trust the accuracy and integrity of data, they will not use it in their research.

**Provide convenient and reliable operation** – Ideally, a collaboratory will free an individual to pursue work central to their disciplinary interests and concerns. However, if the implementation of the collaboratory’s features introduces more work and frustration than it alleviates, the collaboratory will usually be avoided. Examples of sources of frustrations include user level resources that are:

- Expensive to acquire, operate and maintain,
- Prone to crashes and loss of data,
- Slow in execution, confusing to use, and incompatible with other modules, and
- Require too much training or have poorly written documentation.

Thus, substantial attention to human factors and usability engineering should be devoted to the development of collaboratory features.

**Acknowledge individual expertise and contributions** – While researchers are recognized in many ways for their achievements, there are fewer forms of recognition for those who facilitate collaboration or develop the technology used to carry out research. For collaboratories to excel, they need to recruit and retain a wide variety of intelligent and skilled professionals, paraprofessionals, scientists, engineers and technicians. Despite their important contribution to a collaborative research effort, such individuals may feel that they are relegated to a secondary status in the projects that they support. Collaboratories have found it important to involve these individuals as collaborators in projects and to acknowledge by various explicit means their expertise and contribution.

For example, information management specialists, computer scientists and engineers, and experts in allied technical fields gain recognition in their own fields through the use of their expertise in major applications. As such, they will be rewarded most professionally, and the collaboratory similarly benefit the most, when they are involved as collaborators in projects in which their expertise can be exploited and highlighted.
Special care is also needed to ensure proper respect and acknowledgment of the contributions of the professional and technical staff at shared use facilities. They are assigned a great deal of responsibility, and often operate under high stress. As such, proper attention to their management is required.

2.3.6 Issues for Individual Institutions

Institutions participating in a collaboratory directly, or those having members that participate in the collaboratory, may also have concerns that can impede progress of a collaboratory. Some of these issues are discussed below.

In some fields, universities and other research institutions are especially concerned about the intellectual property rights associated with discoveries, and the distribution of income that these discoveries may generate through royalties or licensing fees. The nature of collaborative research leads to issues over joint ownership of intellectual property. These need to be addressed by a collaboratory.

Collaboratories often utilize infrastructure at shared use sites that overlaps with the normal operations at the host institution. As such, administrative issues arise related to the costs of use for these items and services, as well as over scheduling. As such, collaboratory management needs to budget for all relevant costs associated with end-to-end operations. Otherwise, various subtle and explicit institutional barriers to productivity in the collaboratory may arise.

Staff at a shared-use site may also split their attention between collaboratory activities and the work of the host institution. Efforts that may be rewarded within the collaboratory may not be rewarded or held in high regard by the management of the host institution, and visa versa. In some cases, it may be useful to isolate the activities of the collaboratory within a host institution (having the shared use functions staffed by personnel assigned entirely to the collaboratory activities). However, this may not be practical or desirable for a variety of reasons. In any event, careful management is required by the local management team, as well as by the collaboratory itself, to anticipate and avoid such potential problems.

2.3.7 Importance of Education and Training on Use of Collaboratory Features

Special training will be required for those wanting to participate in a collaboratory. Some of this will be general in nature, focusing on the overall capabilities and benefits of the features incorporated within the collaboratory. Other programs will address the use of particular facilities and tools. The need for training will be particularly acute at the startup of the collaboratory, and for new users.
To maximize use of the collaboratory, the training time required by users must be minimized. Otherwise, the multitude of demands on the time of potential investigators will deter them from learning how to use the collaboratory. Training needs can be reduced by careful design of easy to use, productive and well-integrated tools. Thus, tools should be developed from the perspective of user needs.

A number of options are frequently considered in collaboratories to assist with training. These include:

- Explicitly funding of projects carried out within a collaboratory for the time and resources needed for training of users at all levels.
- Development of on-line tutorials,
- On-line manuals and documentation,
- On-call help desks or similar services,
- Knowledge base of frequently asked questions,
- Development of effective user community learning programs. Distance learning technology may be well suited for training on the use of collaboratory features due to the emphasis within collaboratories on telepresence. However, extended "boot camp" type training programs, and special hands-on seminar style programs are often considered.
- Extended site visits should be encouraged through pre- and post-doctoral fellowships, professional fellowships, visiting professorships, individual and group exchanges, and so on.
- Inclusion of the use collaboratory tools and collaboratory databases as explicit part of academic learning curriculum will build over time a cadre of well-educated users.

### 2.3.8 Sustaining Cross-Cutting Partnerships with Experts in Information Technology, Computer Science and Engineering and Organizational Transformation as a Basic Operational Attribute

Collaboratories are a fusion of domain research with information technology, and represent a new way of organizing and conducting research. It is desirable to build and sustain strong collaboration and other forms of interaction between domain researchers and those who specialize in developing network-centric tools (such as experts in information technology, and computer science and engineering) and building innovative workgroups (such as experts in organizational behavior and management of technology). This fusion defines the notion of a collaboratory. Moreover, it is expected that such collaboration would yield throughout the operation of the collaboratory tools and systems that are more capable, serviceable and generally applicable than possible otherwise. Of course, researchers and other users must be intimately
involved in definition, design and evaluation of these tools and systems, but they can be freed to a large extent to focus on their domain concerns. In this manner, intellectual and other benefits can accrue to all parties.

Based on past experience, various tensions can be anticipated between engineering researchers, practitioners, and information technology experts and computer scientists due to the different cultures and perspectives associated with these communities. These tensions can be constructively managed with the help of experts in organizational behavior and transformation. Individuals trained in the sciences are often motivated by discovery and an iterative model for system development is frequently utilized. This is often at odds with the training of engineers who typically focus on a systems approach in which tools are expected to work nearly perfectly the first time. Many segments of the broader user community may have pragmatic concerns at odds with the methodology and long-term perspectives characteristic of the basic research community. These differences in values and approaches need to be recognized and addressed, with each group learning of the needs and approaches of the other group, and establishing a set of common expectations.

Ideally, one of the core components of a collaboratory would be to fundamentally advance capabilities for conducting collaborative research and for building and operating collaboratories. This can be best done by the active collaboration of disciplinary experts with specialists in information management, computer science and engineering, and organizational behavior. Liaison with other existing collaboratories, and the mentoring of other groups attempting to initiate collaboratories, would be integral aspects of this effort.

2.4 Performance Criteria and Metrics

In establishing any organization, it is useful to consider the criteria by which its success will be measured by internal as well as external entities. In a commercial enterprise, success can normally be judged in a financial context. In a mission-oriented organization, one can measure how far the enterprise advances toward its mission. For example, for a group that has a mission to lessen earthquake losses, one might logically use as a measure the potential or actual impact of activities on losses in earthquakes. For a service or education focused organization, especially one that is research based, criteria may include items such as the number of projects conducted, quantity of students and others educated, rate of publication in scholarly journals, and so on. Thus, it is apparent that different participants in a collaboratory may emphasize different objectives and criteria, and that different criteria might be applied to collaboratory management, education and outreach functions as well as for the research programs that are conducted within the collaboratory.
As such, in establishing the vision for the NEES research collaboratory it is useful to review criteria that may be considered by its sponsors (in this case, NSF) as well as by members of the earthquake engineering community. The Government Performance and Results Act of 1993 (GPRA) mandates that federal agencies account for program results through strategic planning, budgeting, and performance measurement. As such, the NSF strategic plan [NSF, 2000] provides considerable information on NSF’s expectations for the programs it supports and the performance metrics that will be used. Information regarding NSF merit review criteria, its overall strategic goals, and the specific goals NSF sets for the tools and large facilities it supports is provided below. Comments on user community needs will be addressed in later chapters.

2.4.1 Merit and Other Review Criteria Used by NSF

In the review of projects to be undertaken, NSF uses two primary merit review criteria and two additional criteria. The primary merit criteria relate to the (1) intellectual merit and (2) scientific, engineering and societal merit of the work. These factors are integral to NSF achieving its overall strategic goals. NSF merit criteria state:

**Intellectual Merit** – “How important is the proposed activity to advancing knowledge and understanding within its own field or across different fields? How well qualified is the proposer (individual or team) to conduct the project? (If appropriate, the reviewer will comment on the quality of prior work.) To what extent does the proposed activity suggest and explore creative and original concepts? How well conceived and organized is the proposed activity? Is there sufficient access to resources?”

**Broader Impacts** – “How well does the activity advance discovery and understanding while promoting teaching, training, and learning? How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)? To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships? Will the results be disseminated broadly to enhance scientific and technological understanding? What may be the benefits of the proposed activity to society?”

In addition, NSF has a strategic goal to foster integration of research and education. As such, it judges the merit of its programs and projects in terms of their efforts to improve education, incorporate research results into curriculum, provide opportunities for students at all levels to participate in research, and so on. NSF has traditionally devoted the majority of its resources to efforts undertaken at colleges and universities. NSF notes, “These institutions provide abundant opportunities where individuals may concurrently assume responsibilities as researchers, educators, and students, and where all can engage in joint
efforts that infuse education with the excitement of discovery and enrich research through the diversity of learning perspectives."

In order to promote the health and vitality of science and engineering, NSF seeks to broaden participation of all citizens into all of the activities it supports. Consistent with its commitment to the principle of diversity, NSF expects the programs and activities it supports to broaden opportunities for women and men, underrepresented minorities, and persons with disabilities.

2.4.2 Highlights from NSF Strategic Plan

The criteria articulated above, are developed in the context of NSF strategic goals. These revolve around an overall vision to enable “the Nation’s future through discovery, learning and innovation.” To accomplish this vision, NSF is authorized to “initiate and support: (1) basic scientific research and research fundamental to the engineering process, (2) programs to strengthen scientific and engineering research potential, (3) science and engineering education programs at all levels and in all fields of science and engineering, and (4) an information base on science and engineering appropriate for development of national and international policy.” NSF has a number of research and management goals that guide its management activities as well as its investments in research. With regards to research, NSF has outcome goals associated with people, ideas and tools. These include:

**PEOPLE** -- *To develop a diverse, internationally competitive and globally-engaged workforce of scientists, engineers and well-prepared citizens.* This goal supports the parts of NSF’s mission that are directed at items 2 and 3 above.

**IDEAS** -- *To provide a deep and broad fundamental science and engineering knowledge base.* This goal supports item 1 above

**TOOLS** -- *To provide widely accessible, state-of-the-art science and engineering infrastructure.* This goal supports items 2 and 4 above.

NSF’s strategic plan also includes a number of statements to provide greater definition on how it intends to implement these objects. These are presented in the form of “How we operate” statements. More information can be obtained from NSF's strategic plan. (See Resource Document 3.) Some of these include:

“We partner with a dynamic and diverse education and research community, working in a close trusting partnership while maintaining an independent perspective. We encourage partnerships among agencies, industry, academe, the states, and other nations when collaborative efforts further our goals.”
“We integrate and synergize the knowledge and skills of diverse disciplines and constituencies. We promote the mutual sharing of knowledge and resources. We integrate the processes of discovery, innovation and learning, and connect them to societal use.”

NSF also identifies in its strategic plan a number of attributes to which it strives, and that it presumably values in the programs and projects that it supports. Some of these are (see Resource Document 4 for a complete listing):

Open - “NSF is committed to the sharing of information and a free marketplace of ideas. It demonstrates an openness and facility for relating to all key constituents within and outside the organization.”

Inspiring – “Through leadership and creative flair, NSF inspires agency staff and the community it serves to strive for the greatest levels of accomplishment.”

Pace-setting – “In identifying and supporting ideas with the greatest creativity, embracing new thinking, and using information technologies in innovative ways, NSF helps chart new paths for the science and engineering community.”

Influential – “In both the global community and the corridors of science and technology policymakers, NSF is viewed as a creative catalyst – credible, relevant and timely – as well as an excellent, statesperson-like organization that brings together other high-level decision makers.”

Agile – “NSF quickly and effectively responds to changing needs and opportunities. It embraces change through effective systemsthinking and appropriate feedback mechanisms. NSF is a learning organization that is committed to self-improvement.”

2.4.3 Highlights from NSF Guidelines for Planning and Managing Major Research Equipment

NSF also provides specific guidance for planning and managing Major Research Equipment and Facilities Construction programs [NSF, 2000] This information indicates that performance of a major facility program, such as NEES, is judged successful when:

“in the aggregate, results reported in the period demonstrate significant achievement in the majority of the following (relevant) indicators:

- Development or provision of tools that enables discoveries or enhances productivity of NSF research or education communities,
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- Partnerships with local, state or federal agencies, national laboratories, industry or other nations to support and enable development of large facilities or other infrastructure;
- Development or implementation of other notable approaches or new paradigms that promote progress toward the TOOLS outcome goal.”

Examples cited for Tools developed by MREFC programs include “research and education infrastructure, like large centralized facilities, or integrated systems of leading-edge instruments, or databases, or widely utilized, innovative computational models or algorithms, or information that provides the basis for a shared-use networked facility.” Examples cited for new approaches and paradigms include “broad-based, program-wide results that demonstrate success related to management/utilization of large data sets/information bases, or development of information and policy analyses, or use of the Internet to make science, technology, engineering and mathematics (STEM) information available to NSF research or education communities, or exceptional examples of broadly accessible tools shared by NSF research and education communities.”

2.4.4 Metrics Used in NSF Engineering Research Centers

The Best Practices Manual for NSF Engineering Research Centers [http://www.erc-assoc.org] suggests a number of approaches for quantifying the overall intellectual and academic impact and achievements of these centers. These include traditional measures of academic achievement, such as number of papers published, patents issued, software products developed, students graduated, and so on. However, due to the nature of engineering centers, several other measures are suggested that may be relevant to the NEES Collaboratory. These measures include:

- “Develop specific milestones, deliverables and milestones associated with the strategic plan and goals for the center. Success can be measured qualitatively and quantitatively on the basis of whether these planned goals have been reached. For each milestone, success can be quantified in terms of a relevant parameter such as the number of papers, number of participants, whether new and relevant knowledge has been created, the degree to which additional research funding has been obtained, and so on.”

- “Specific metrics related to the incorporation of new knowledge into existing curriculum, the development of new courses, the development of new and expanded modes of delivery of course material, faculty hired, and course enrollments. These metrics are significant due to the overall goals of improving education.”

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• “Metrics related to attracting and educating a larger and more diverse workforce in engineering disciplines. This relates to NSF commitment to broadening diversity in the workforce.”

• “Due to the goal of industry-university collaboration, useful measures of accomplishment include the involvement of industry in projects (short and long term), visits by industry participants to the centers and attendance at meetings as well as visits to industry by students, faculty and other researchers.”

• “Application by industry of knowledge or technology developed by the center is a key metric. Thus, an important measure of impact is how engineering is accomplished by industry.”

Some metrics suggested are less tangible than others, but they are considered highly important nonetheless. For example, indicators of success include:

• “Articulating a strategic vision that is considered ahead of its time, and having it gradually adopted by the academic community and industry as a result of the efforts of the center.

• A center may become recognized as a national resource.

• The center may be used as a model to be emulated by other centers or endeavors.

• Commercial companies or divisions of existing companies may start up as a result of the technology developed.

• The center may be asked to keynote a major national or international symposium or conference, organize sessions at such events. Similarly, the hosting of well-attended international conferences provides a measure of status.”

Because the goals of an ERC differ from those of a collaboratory, the actual metrics used in each case may differ substantially. Nonetheless, it is useful to consider these and other criteria when contemplating those that might be employed for the NEES Collaboratory.

2.5 Organizational and Management Lessons from other NSF MREFCs and Collaboratories

Any new organization should learn from the experiences, both good and bad, of other similar organizations. As such it is useful to consider lessons learned by other NSF Tools and Research Centers.
2.5.1 “Best Practices” Manual for NSF Engineering Research Centers

The Engineering Research Center Association has developed a Best Practices Manual that distills the knowledge and experience of the management teams at NSF’s Engineering Research Centers. This well-written document is intended as a practical resource manual of ideas and lessons learned for those involved in, or contemplating, the start-up, operation and management of such a center.

The Best Practices Manual contains specific chapters related to the role of the executive management of a center in providing leadership and strategic direction, research management, education and outreach programs, partnering and knowledge transfer to industry, administrative management (including financial, personnel and facilities), and interactions with NSF. Key issues and concerns are identified in each category relevant to different stages of a centers operation (start-up, mid-term, maturity).

While the Engineering Research Center’s have a different strategic mission than major facilities in the MREFC program, many of the basic management lessons are relevant nonetheless. The Best Practices Manual is available for download at: http://www.erc-assoc.org.

2.5.2 Advice Provided by Directors of other NSF Major Facilities

The special character of the research communities served and historical differences in their development has led to a wide variety of management approaches and organizational structures for NSF’s tools and major facilities. Nonetheless, a number of useful lessons can be derived from the experiences of these facilities. The NEES Consortium Development Program invited members of the management teams from several other NSF-supported major facilities to attend the NEES grantee meeting held at NSF in December 2001 and to comment on issues that should be considered in initiating a collaboratory. (See presentation materials archived at: http://worktools.si.umich.edu/)

Among other points, Gary Sanders of the California Institute of Technology offered the following observations based on his recent experiences in starting up the Laser Interferometer Gravitational-Wave Observatory (LIGO). He noted that LIGO and NEES were similar in several ways, such as both being built on a strong collaboratory framework, and both are scheduled so that the collaboratory develops near the completion of the facilities’ construction phase. He noted that there are differences as well. For instance, LIGO faces the challenge of developing an entirely new community in a new field of science, whereas NEES’s challenge is to integrating elements from several major existing disciplines to work together synergistically and collaboratively. Additionally, LIGO facilities are centralized at two major installations that operate in unison; as a consequence, tests are managed by observatory staff, and collaboration...
revolves around identifying community consensus for tests to be performed and analyzing data. In contrast, he believes that the diverse and geographically distributed nature of NEES facilities will lead to a wider distribution of operational and implementation responsibilities than in LIGO. As a result, the central organization in NEES will need to have a stronger coordination role, and devote greater efforts to integration and synthesis.

Dr. Sanders also stresses the need for a collaborative to establish an appropriate balance between the imperatives of overall (big science) management and the imperative to support the best science possible driven by small groups of investigators. He indicates that the processes of managing a big science (engineering) research enterprise “must be planned, predictable, robust, and transparent, enabling ongoing assessment of progress against the plan.” On the other hand, he contends, “Small science is often creative, independent, obscure and opaque.” Overall, the collaborative should nurture and facilitate collaboration by the community being supported, and provide an effective, productive and accountable environment within which that community can make scientific advances.

Tim Killeen, Director of the National Center for Atmospheric Research, noted that NCAR has evolved over its 40-year existence into a collaborative environment that unites the entire atmospheric science community. In addition to providing the science community access to major facilities, NCAR conducts substantial in-house research, with more than 850 employees, including numerous scientists, and has undertaken on behalf of NSF and other sponsors the management of major multi-institution, multi-investigator, collaborative research programs. Dr. Killeen noted NCARs continuing role in providing resources for high performance computation and in supporting the development and validation of complex, community developed models of atmospheric and other related processes. He noted that collaborative projects have a common challenge of integrating experimental, computational, software, networking and other resources to best suit the needs of the community served.

David Simpson of the Incorporated Research Institutions for Seismology, Inc. noted numerous parallels between IRIS and NEES. For instance, both operate geographically distributed facilities and work with large datasets.

Dr. Simpson noted several specific factors that have contributed to the success of IRIS and that may be of value to other collaboratories. These factors relate to community-based planning, responding to feedback and stability of operations.

For instance, IRIS engages its community and management team in extensive planning activities intended to develop short- and long-term science plans that, in turn, lead to program design goals and the technical specifications for its undertakings. The management approach
implemented seeks regular feedback from the community so that its programs remain flexible and responsive to community needs and external events (earthquakes). In addition, IRIS has adopted governance structure and related policies that ensure community participation at all levels of planning. This feedback process also helps align facility development plans with research needs. Dr. Simpson also stressed the importance of stability of operations for the well being of the community. IRIS has avoided the travails of some organization through the recurring 5-year cooperative agreement arrangement it has with NSF. Employing well-trained, professional staff, and the adoption and adherence to explicit, community-endorsed procedures, formats and quality control protocols are examples of actions that have also provided the community with a sense of stability and confidence.

In developing a management plan, Dr. Simpson suggests fitting the form of the organization to its function. He believes that initial efforts should be placed on identifying the activities and culture desired for an organization, and then identifying an organizational and management structure to supports these objectives. He notes that there is a tendency in the development of many organizations to be overly structured and restrictive. He suggests that greater flexibility can in the long run lead to a stronger organization, and that focus should be directed at identifying key principles, rather than prescriptive management processes. Dr. Simpson also indicates that some caution is needed in identifying an organization's long-term mission. An organization can outgrow its initial mission if it is defined too narrowly, but if the mission is initially too broad, it may not pull together sufficiently to succeed at its basic tasks.

Dr. Simpson stresses the need for a NSF-supported major facility to focus on achieving quality in the activities it undertakes. He notes that achieving this quality will require time and funding. However, in the long term this quality will infuse all of the activities of the organization.

IRIS has learned that liaisons with other organizations and entities in its domain are important. In particular, Dr. Simpson notes that turf battles undermine the health of a collaborative organization and the community it serves.
3.1 Towards a cohesive, vital and diverse NEES community

NSF has mandated that NEES serve the entire earthquake engineering community. This community is large, diverse and dynamic. By its very nature, earthquake engineering is multidisciplinary, drawing expertise from numerous fields across engineering and the sciences. A wide array of complex issues and problems challenge the ingenuity and creativity of the scientists and engineers working in each of these fields. It is, however, through the systematic interaction and integration of these discipline-focused activities that earthquake engineering achieves its unique interdisciplinary character.

As such, the overall community to be served by NEES is large, and comprised of individuals and groups having quite different interests and needs. While the NEES Collaboratory must identify and address the overall research needs of this community, it is not likely or necessary that all segments of the entire earthquake engineering community participate in the research collaboratory. As such, the collaboratory must plan how it will interact with the larger community it supports, while addressing the specific needs of the collaboratory participants.

By aligning its resources and activities with the needs of the overall community, the NEES Collaboratory will be a powerful magnet attracting those working in the field earthquake engineering, substantially broaden participation, and accelerate innovation, discovery and learning. To accomplish this, barriers to participation in the NEES research collaboratory should be minimized.

It should also be recognized that the operational, management and administrative functions of the NEES Consortium differ from the collaborative research, educational and other activities undertaken within the NEES Collaboratory. As such, the membership and organizational structure of the NEES Collaboratory and Consortium might differ to facilitate these differing operational and functional needs.

As an integral component in NSF’s major facilities program, the NEES Collaboratory should provide the US engineering and scientific community ready access to world-class resources for research, education and collaboration, and provide a stimulating intellectual environment within which the earthquake engineering community can collaborate on inno-
vative and challenging research of national importance, integrate and interpret results, and develop new and effective learning programs for students at all levels.

It is anticipated that individuals may participate within the NEES Collaboratory, often concurrently, in a number of different ways:

- generating new data from their own research,
- devising new tools that extend the types of research that can be accomplished,
- developing new models and software applications for simulating seismic response,
- simulating seismic response using models and data developed by others,
- applying NEES-generated knowledge to real world problems or in the development of improved design criteria,
- formulating new educational material, and
- expanding their own expertise through specialized learning programs.

This involvement may be sustained, or last only for the duration of a particular project. Some individuals may just participate in the initial phase of the Collaboratory to insure that it gets off to a good start, while others may become involved later as they become aware of the Collaboratory or as the Collaboratory develops new capabilities suitable for their particular needs. As such, the collaboratory is expected to grow and adapt to the needs of its community, providing an exciting and vital environment that broadens participation. To accomplish this, the needs of this extended community must be regularly assessed and integrated into the planning of the Collaboratory’s activities and in the development of its resources and services.

In the remainder of this chapter, the overall community supported by the NEES program is described in greater detail. Some of the fundamental needs of the participants in the NEES Collaboratory are also outlined. Because the NEES program is just getting underway, strategic activities needed to build the Collaboratory participant base are also discussed. Finally, a brief assessment is provided of the strengths and weaknesses of the NEES community, as well as of opportunities and threats that should be considered in planning the NEES Collaboratory.

### 3.2 The Earthquake Engineering Community

A wide variety of individuals, organizations, businesses, industries, and other public and private entities engage in activities related to earthquake engineering. Some characteristics of the individuals and organizations that make up the earthquake engineering community are described below.
3.2.1 Individual Participants

It would be expected that the NEES community would include individuals from disciplines involved in traditional aspects of earthquake engineering, especially earthquake engineering simulation. For the Collaboratory to achieve its overall goals and to function effectively, significant involvement is essential by individuals with other backgrounds and expertise. Some of the key communities contributing to earthquake engineering and the NEES program are highlighted below.

**Earthquake Engineering Research Community** – A wide variety of disciplines are involved in improving knowledge of the factors that affect earthquake response and damage, in predicting performance, and in devising design methodologies or innovative methods for improving performance. These disciplines include architecture and allied disciplines, geotechnical engineering, structural engineering, systems engineering, and tsunami engineering. Also central to the NEES community is expertise related to earth science, seismology, computational, theoretical and experimental methods of analysis, design theory, mechanics, dynamics, statistics, risk analysis, decision theory, construction engineering, and so on. Individuals working in other disciplines (such as, material science and engineering, welding and fastening, sensors, health monitoring, actuation, control, and mathematics) have made and will continue to make important contributions to earthquake engineering. Ideally, NEES will increase the participation and diversity of individuals and disciplines active in earthquake engineering research. As earthquake vulnerabilities should not be considered in isolation, it is desirable to attract individuals to NEES with expertise related to threats and countermeasures associated with other natural and man-made hazards.

**Computer Science and Engineering Community** – While the field of earthquake engineering already relies heavily on computer methods of analysis, the network-centric nature of the NEES Collaboratory necessitates incorporation and integration of expertise on information technology and computer science and engineering as a fundamental aspect of collaboratory activities. As such, the NEES Collaboratory must foster collaboration by those in the traditional earthquake engineering communities with scientists and engineers with expertise in high performance computing, networks, databases, information technology and so on. Because of the reliance of the work of the Collaboratory on vast amounts of data, specialists are also required with backgrounds in information management, digital libraries, data authentication and security, and the analysis and visualization of large data sets. Recent developments in computer science and engineering related to embedded sensors, remote sensing, wireless technologies, and so on are also particularly relevant to earthquake engineering research and practice.
Social, Behavior and Economic Sciences Community – Experts in the social, behavioral and economic sciences, business administration, urban and regional planning, and related fields are essential contributors to the overall earthquake engineering community, and provide an important resource for developing the NEES Collaboratory. While such experts may not directly utilize much of the data generated by the shared-use experimental sites, their participation can be enlisted to develop and interpret parameters used to quantify the impact of response quantities and physical damage (e.g., safety, cost of repair, downtime, perceptions related to the impairment of function and safety, etc.) and as collaborators in various NEES-related projects that use this data to develop and assess more effective countermeasures.

Similarly, computational simulation of seismic performance of individual facilities as well as of lifeline systems and metropolitan regions can provide those working in this community with powerful tools and testbeds for assessing the impacts of future earthquakes. Such synthetic earthquake disasters, when generated using validated models, can be with greater confidence that currently possible to evaluating the effectiveness of various countermeasures.

Moreover, experience with the NEES database may suggest opportunities to facilitate collection and interpretation of data of direct value to the social, behavioral and economic science and planning community. For example, the database might be adapted to facilitate large-scale field studies related to earthquake impacts, and documentation and analysis of physical damage, economic losses and other performance measures following earthquakes.

Education, Training and Outreach Community – Important aspects of the NEES collaboratory involve the training and cross-disciplinary education of NEES participants, and the use of NEES-generated data in the development of learning programs at all levels. Consequently, it is important for the NEES community to encompass individuals with expertise in developing curriculum, deploying distance learning systems, measuring the effectiveness of educational programs, and so on. This expertise will facilitate development of instructional material and new courses that will attract new students to earthquake engineering, in particular, and science, and engineering, in general.

Earthquake engineering research can be divided into two classes: (1) technical research aimed at solving the problems of safe and economical design of earthquake—resistant structures and facilities, and (2) more general research aimed at assessing the optimum effort that should be devoted to coping with the earthquake problem.

- George Housner, 1976
Design and Construction Community – Particularly productive and synergistic collaboration is anticipated with individuals engaged in the process of design, construction, evaluation, and rehabilitation of engineered structures and systems. Practicing professionals involved with earthquake engineering have considerable knowledge and expertise that will substantially enhance the effectiveness of NEES activities.

Through their participation as members of research teams, and through explicit partnerships of research programs with professional associations and organizations engaged in the development of design regulations and guidelines, knowledge gained in NEES can be quickly assessed and transferred to practice. Professionals involved with earthquake engineering also provide rich source of technical problems that might be addressed by NEES collaborative. NEES would also benefit from the involvement of individuals with experience related to earthquake-resistant construction, such as those involved with the production of traditional and innovative construction materials, procedures for construction, retrofit and repair, and manufacture of nonstructural components and systems, including electrical and mechanical systems. It is noteworthy that many professionals and firms have specialized in fields that may be of special value to NEES projects, including the development and implementation of innovative methodologies, structural systems, equipment or devices that reduce the effects of earthquakes. Other firms develop commercial software applications for the prediction of the response of facilities to earthquake ground motions, the evaluation of seismic risk, the design and detailing of structural and nonstructural elements, and so on. The interaction of such firms within the NEES community would be mutually advantageous.

Business and Financial Community – The owners, developers and managers of buildings, infrastructure systems and other facilities that must resist the effects of earthquake comprise an important segment of the overall earthquake engineering community. Financial institutions and insurance (and reinsurance) companies may have a direct interest in the information being developed by the NEES Collaboratory and may along with other decision makers wish to participate in research programs undertaken within the NEES Collaboratory.

The goal of our research is not to satisfy curiosity or to gain knowledge for knowledge’s sake…The only acceptable goals of earthquake engineering research are to provide increased safety for people at a cost that can be afforded and to reduce the impact of major disasters on society as a whole as well as for each individual. To achieve these goals, eventually the results of the research must be used by the professional engineer…

- Henry Degenkolb, 1976
Regulatory and Public Policy Community – Information developed within the NEES Collaboratory can have a major impact on the reliability and cost effectiveness of regulations and guidelines for the design and evaluation of structures that may be subjected to earthquakes, and inform the development of effective policies to address the earthquake threat. Similarly, the involvement in research collaborations of officials, engineers and others involved in developing regulatory standards and guidelines can substantially speed adoption of innovations derived from research into practice. As such, it is desirable to include in the NEES community public officials, building officials and representatives of organizations and agencies that develop building codes and other provisions for earthquake-resistant construction.

General Interest Community – Because of the impact of earthquakes on the lives of citizens, the NEES Collaboratory should make special efforts to address the needs of the public, the media and public officials.

3.2.2 Participation by Organizations and Institutions

In order to serve the entire earthquake engineering community, NEES will need to interact with several types of organizations and institutions. In some cases, individuals identified above may serve as representatives of these groups, while in other cases more formal organization-to-organization arrangements may be required. These organizations and institutions may include:

NEES Collaboratory Facilities – Institutions directly involved with the day-to-day operation of the NEES Collaboratory will require special liaison with the NEES Collaboratory and NEES Consortium. These institutions include not only the NEES shared-use equipment sites (note: shared-use operation and maintenance costs are to be funded through the NEES Consortium), but also encompasses facilities providing the NEES Collaboratory with computer, network, database and visualization resources as well as other US and international research facilities voluntarily participating within the NEES collaboratory. Close operational, management and administrative liaison and coordination are needed to ensure smooth functioning of the NEES Collaboratory and to anticipate and respond to scheduling, budgetary, and equipment needs. Because these facilities and institutions have direct, day-to-day contact with research program participants, they will be an essential source of information for the NEES Collaboratory on issues related to scheduling, use of facilities, and enhancements needed to improve productivity and better meet user needs.
Other Scholarly, Academic and Research Organizations and Consortia – To realize the goals of the NEES program, coordination and collaboration is desirable among universities, consortia and other organizations involved in research and education, both nationally and internationally. As such, the NEES Collaboratory should incorporate mechanisms to facilitate communication and collaboration among such organizations. These organizations would also be logical participants in any discussions on standards for communications and telepresence, and for documenting and archiving data. They would, along with individual participants, provide valuable input regarding the need for various types of data curation, software applications for earthquake response simulation and visualization, and user tools for the mining, analysis and visualization of data. The types of organizations and institutions that will likely be interested in participating in the NEES Collaboratory include:

- Individual colleges and universities
- NSF Earthquake Engineering Research Centers (i.e., the Mid-America Earthquake Engineering Research Center, Multidisciplinary Center for Earthquake Engineering Research and the Pacific Earthquake Engineering Research Center)
- Other research centers funded by NSF or other NEHRP agencies related to earthquakes and earthquake engineering (e.g., Southern California Earthquake Center) as well as to computation, simulation and information technology (e.g., National Center for Supercomputer Applications, San Diego Supercomputer Center, Internet 2, etc.)
- University-based consortia related to earthquake engineering (e.g., Consortium of Universities for Research in Earthquake Engineering, University Consortium of Instructional Shaking Tables, etc.)
- Federal, state and local government agencies with internally funded, on-going research and education programs related to earthquake engineering (e.g., various national laboratories funded by the Departments of Defense and Energy, the National Institute for Standards and Technology, the US Geological Survey, the Federal Highway Administration, various other federal, state and local agencies addressing transportation, emergency management, infrastructure and lifelines, housing, medical care delivery, geology, and so on)

The aim of the broad concept of earthquake engineering … is to save lives, reduce injuries, reduce damage, and mitigate social and economic disruption in the event of earthquakes and earthquake induced phenomena, and to find means of doing so at a cost reasonable enough that society can afford the necessary actions.

- Nathan Newmark, 1976
• Research laboratories and programs funded by industry, professional organizations and companies (e.g., Concrete Technology Laboratory, Civil Engineering Research Foundation, etc.)

• Conventional and digital libraries focusing on earthquake engineering research and education, emphasizing those funded by NSF (e.g., National Information Service for Earthquake Engineering (NISEE), MCEER Information Services i.e., Quakeline), National Science, Technology, Engineering and Mathematics Digital Library (NSDL), etc. and publishers of printed and on-line journals.

• Organizations related to education and training of engineers (e.g., American Association for Engineering Education, etc.)

• International associations, centers, and organizations with functions similar to the NEES collaboratory

Professional, Industrial and Regulatory Organizations – The NEES collaboratory needs to be responsive to the needs of professional and trade associations, government agencies and regulatory entities for information that would accelerate the dissemination and adoption of appropriate knowledge into practice and into design guidelines and standards. Such organizations (and their representatives) have considerable interest in the detailed requirements regarding the quality, integrity, security and accessibility of the data and other information generated through experimental and computational simulations, as well as the curation, synthesis, analysis, and visualization of this material. As such, close liaison should be maintained with numerous groups, including:

• Professional organizations (e.g., American Association of Civil Engineers, American Association of State Highway and Transportation Officials, Earthquake Engineering Research Institute, National Association of Structural Engineers, and so on),

• Federal, state and regional agencies and programs involved with standards and provisions development (e.g., Federal Emergency Management Agency, National Institute for Standards and Technology, National Earthquake Hazard Reduction Program, National Earthquake Program, Interagency Committee for Seismic Safety in Construction as well as various federal, state and regional agencies associated with emergency management and establishing standards for transportation and other infrastructure facilities and systems, healthcare delivery systems, regional planning and so on ),

• Construction standards and provisions organizations (e.g., American Association of Civil Engineers, American Association of State Highway and Transportation Officials, Building Seismic Safety Council, International Code Council, etc.),

• Industrial and trade associations (American Concrete Institute, American Institute of Steel Construction, National Forest Products Association, etc).
Other Organizations – A variety of other organizations and institutions should be involved in the NEES Collaboratory.

- Various policy and planning agencies may have considerable interest in the activities undertaken in the NEES Collaboratory or the findings derived from these results. For example, formal interaction may be desirable with FEMA, National Earthquake Hazard Reduction Program, National Earthquake Program, Interagency Committee on Seismic Safety in Construction, Office of Science and Technology Policy, as well as various government and private groups responsible for emergency management and land use planning.

- There may be specific needs to coordinate with other organizations due to the unique nature of the collaborative environment. For example, interaction with the Institute of Electronic and Electrical Engineers may be useful to establish and promulgate standards for storage and distribution of data and metadata. Organizations involved with management of technology and innovation, or collaborative work, may be useful partners (e.g., Center for Research on Electronic Work)

- Liaison with certain organizations may be associated with the conduct of specific research and outreach programs (for example, the American Institute of Architects for programs involving nonstructural components)

- Because the scope of interests of NEES participants extends beyond the traditional fields of earthquake engineering, there may be a need to interact with organizations that address the disciplinary and professional interests of these participants (e.g., information technology, social and behavioral sciences, etc.).

As mentioned above, arrangements are needed at the international level. Topics might include development of cooperative research agenda and joint research programs, sharing of one-of-a-kind facilities, exchange of personnel, instrumentation and data, establishment of internationally accepted protocols and standards for documenting, recording and curating data/metadata and for telepresence (teleobservation, teleoperation, etc.).

3.3 Participants in the NEES Research Collaboratory

Collaboratories have traditionally focused on the needs of researchers and scientists working within a single disciplinary field (and, in some cases, on the needs of a small and highly specialized group of researchers within a discipline). As noted in National Collaboratories: Applying Information Technology for Scientific Research [NRC, 1993], extension of the traditional collaborative concept to encompass researchers from several disciplines, as well as individuals who are not directly involved in research or education, creates special challenges.
The strong sense of community that already exists within the field of earthquake engineering lessens some of these challenges, and provides unique opportunities for rapid advances as a result of intra- and inter-disciplinary integration and synergism. Nonetheless, for the NEES research collaboratory to operate effectively, its membership should be consistent with its long-term strategic vision and with its operational and functional capabilities.

As demonstrated in the previous section, the overall earthquake engineering is large and diverse. The participants in the NEES research collaboratory would be drawn from this extended community. The collaboratory would naturally include individuals from traditional academic settings involved with research, learning and teaching related to earthquake engineering, in general, and the physical and computational aspects of earthquake engineering simulation, in particular. The Collaboratory would also actively embrace participants from outside of the university environment who are interested in planning and conducting research in earthquake engineering, in applying research results, or in gaining a better understanding of the effects of earthquakes on the built environment.

In planning and managing the NEES Collaboratory, it is useful to characterize participants in terms of their needs for resources and services. A number of different approaches may be taken to classify user needs. For example, the basic communities identified previously may help define certain affinities and interests. Traditional categories associated with disciplinary expertise or professional interest may also be useful in certain contexts. For instance, geotechnical engineers may have particular interest in resources for experimentation and computation related to soils and foundation. Regular strategic planning activities can and should be undertaken by the collaboratory to determine the precise capabilities and resources that will allow each affinity group and disciplinary area accomplish its high priority research objectives.

3.3.1 Key Collaboratory Activities Undertaken by Participants

It is also helpful to consider participants according to the type of services they require of the Collaboratory. In the simplest case, participants might be categorized according to whether they are data users or data generators. Following this general approach, it is useful to consider NEES research collaboratory participants from the perspective of the following general categories:

- General use of research results, including education

  Individuals and organizations in this category comprise the basic outreach and education audience addressed by the NEES collaboratory. This group would most likely need application software that is validated and ready-to-run, databases containing digests of key parameters, and documents or tools that synthe-
size, analyze, interpret and present data in a form useful to a particular audience.

- General aspects of earthquake engineering research
  This broad category comprises those actively involved in earthquake engineering research, or who use detailed results of particular physical, theoretical and computational simulations. As such, input from these individuals and groups is needed to help plan Collaboratory activities, such as developing standards for the type and quality of data archived, developing protocols for processing, managing, manipulating and visualizing data, identifying policies for access to and use of shared use facilities, developing shared-risk resources such as open source software applications, and identifying new collaboratory resources and services necessary to achieve the community’s near- and long-term research priorities. Similarly, the collaboratory needs to develop programs to educate those in this category on the benefits, capabilities and use of the Collaboratory’s resources and help them mobilize to conduct research utilizing these resources. Similarly, matchmaking services should be provided to assist those with ideas for research projects find others with similar interests, allied expertise or needed resources, as well as to alert members to projects in the development stage where opportunities for initiation of collaboration exist.

- Specific research projects that use collaboratory resources or data
  Individuals and organizations involved with active NEES projects, either conducted individually or as part of a multi-investigator national challenge program, will require special services from the Collaboratory. In addition to specific information and training on the use of the facilities involved in the particular project, various management and administrative functions are needed to allocate and schedule resources, and to ensure that collaboratory policies and procedures are followed.

- NEES resource providers
  The various facilities supporting the research, collaboration and education infrastructure of the NEES collaboratory (i.e., resources for experimentation, computation, network services, information management and so on) need to be coordinated, budgeted and managed so that the Collaboratory operates smoothly.

Clearly, an individual or organization can pursue more than one of these activities at the same time, and roles may change from time to time. That is, a researcher in geotechnical engineering might carry out a research project, use data obtained previously by someone else, learn about general aspects of a discipline outside his or her field of expertise, and participate in the management of a shared-use equipment site. Similarly, a design professional may retrieve data to calibrate a computer model, collaborate with others on a research project, help identify
future research priorities, and participate in educational programs. A student may access data needed for classroom assignments, conduct independent research projects using NEES simulation and communications tools, interact virtually with experts on a subject of abstract inquiry, or work as a part of a research team. A computer, earth or other domain scientist may participate as a key player in a research project, help expand the capabilities of the NEES Collaboratory, identify problems that challenge their scientific skills or take advantage of their scientific discoveries, and participate in education programs that inform the engineering process.

It is clear from the roles highlighted above that different types of collaborative membership may be needed. Membership in some categories may be open to all those who are interested and willing to participate, while other categories may impose various restrictions, responsibilities and, potentially, costs. As mentioned previously, membership in the more administratively focused NEES Consortium that manages and operates the collaboratory may differ from that of the collaboratory itself.

Also, to expand the involvement of the community using NEES, it is essential to recognize the different interests, backgrounds, experience and skills of those who will use the various features of the Collaboratory. This is clear from the disciplinary concerns described previously. However, even within one discipline, or within one particular aspect of using the collaboratory, there may be a substantial range of interests that need be considered. For example, even within the earthquake engineering research community, there will be significant differences. For instance, researchers involved with experimentation, or interested in becoming involved with experimental research, will have different needs if they are:

- Located at NEES shared-use equipment sites,
- Located at a major experimental research facilities that is not part of the NEES shared-use portfolio,
- Located at established earthquake engineering research institutions without experimental facilities, or
- Located at institutions with small programs or in larger programs without a critical mass of people in the area of earthquake engineering.

For individuals not involved with experimentation, there are different needs depending if they are interested primarily in:

- Computationally-based simulation
- Numerical modeling
- Development and validation of theoretical or empirical models for predicting behavior or for performance-based design

These and other needs of the community need to be carefully considered in order to maximize utilization.
3.3.2 Building the NEES Collaboratory Community

Collaboratory participation will change with time. Some individuals and organizations may choose to be involved primarily during the critical start up phase, to ensure that NEES gets off to a good start. Other individuals and organizations may be involved only for the duration of specific projects. Many will sustain their participation throughout the entire operation of the collaboratory. Still others may join at later stages of operation, as they become interested in or aware of the activities of the NEES Collaboratory or as the Collaboratory’s activities and resources evolve to suit their particular needs.

The individuals, organizations and institutions identified in Sections 3.2 provide a preview of the fully operational NEES community. It may take several years to realize this vision completely.

At startup, critical activities are expected in all of the categories of participation described above. That is, participants will be involved with:

- Providing NEES resources
- Undertaking specific research projects
- Enabling general collaboratory research functions
- Facilitating general use of research results, including education

The level and nature of the efforts in each of these categories will evolve with time. At startup, efforts will tend to focus on getting research projects underway, bringing core services on line, identifying and filling gaps, and engaging in vigorous community building efforts. It is expected that startup efforts will be have substantial participation from the traditional earthquake engineering research community, as well as from significant numbers of individuals with backgrounds in computer science and engineering, organizational transformation, design practice and construction. However, strategic representation from the other segments of the broad earthquake engineering community outlined in Section 3.2 should be sought, especially with regards to planning future collaboratory activities and services. At maturation, activities will include more complex research activities, greater focus on synthesis, analysis and interpretation of data, undertaking a wide range of education and outreach programs, and greater collaboration by broader segments of the community.

3.4 Assessment of Community Strengths, Weaknesses, Opportunities and Threats

In planning, it is useful to take advantage of the strengths of the individual and organizational participants and to compensate for their weaknesses. Similarly, plans should leverage opportunities that maximize possibilities for success, while mitigating the adverse
consequences of potential risks. Thus, as background to the development of the NEES Collaboratory, a brief assessment is made of the strengths and weaknesses of the NEES community, and of the opportunity and threats that lay before it.

3.4.1 Strengths

A wide range of strengths may be readily identified that support the development of the NEES Collaboratory and point to several opportunities for early successes. These strengths include:

Consistently high capabilities across collaborating groups -- The earthquake engineering community in the US is recognized worldwide for its accomplishments, as well as for the energy and creativity it devotes to the technical and societal problems of earthquake loss reduction. Many of the major advances in earthquake engineering during the past four decades have been conceived or developed to the point of practical application by US researchers. A pool of highly capable and energetic individuals is active in each of the technical fields contributing to earthquake engineering. Because of the comparable levels capabilities, vitality, and quality in these heretofore largely separated disciplines, opportunities for integrative and synergistic collaboration are particularly strong.

Another significant strength of the field is the growing cohort of young researchers and professionals who are highly trained, not only in their disciplinary field, but also more generally in some multidisciplinary aspect of earthquake engineering. This group may be able to collaborate and exchange ideas more readily than previous generations.

General recognition of need for and benefits of collaboration – Today, there is unprecedented recognition by the earthquake engineering community, decision makers and the public of the need for and benefits of collaboration. Public awareness of the potential catastrophic consequences of major metropolitan earthquakes in the US is higher than ever, and societal acceptance of the human, social and economic losses associated with major earthquakes is at its lowest point ever. While earthquake engineering is viewed as being able to mitigate these problems, decision makers are moving away from a willingness to accept recommendations based solely on expert judgment, and towards assessments of seismic performance (and of the potential benefits and costs of countermeasures) that are substantiated and expressed in objective, quantitative terms. While theoretical frameworks and tools have been developed to carry out such performance-based assessments, current methodologies are generally based on simplified models and limited knowledge. As such, they remain largely unverified. The active interest of many individuals and organizations from the research, professional, regulatory and other segments of the earthquake engineering com-
munity in the development of performance-based methods provides a very powerful driving force that strengthens the NEES collaboratory.

From a research perspective, it is increasingly recognized that progress is thwarted by lack of ready access to information and expertise. To develop more realistic and reliable models and tools for simulation of complex nonlinear phenomena, analysts need to work with experimental data and those with expertise in physical behavior. Earth scientists need input from those assessing performance so that they can better identify the damaging features of potential ground motions. Social scientists need response data from simulations that are expressed in terms of performance variables meaningful to the decision making process. Professional engineers need data that be used to develop and calibrate models of complex and important facilities, and software that can help them characterize and improve performance.

Thus, strong social and technical driving forces currently exist for the development of the experimentally derived and validated, model-based simulation tools that, and for mechanisms that will facilitate collaboration and communication by various segments of the earthquake engineering community. These issues are the heart of the NEES Collaboratory.

Agility in responding to opportunities and external events – The earthquake engineering community has repeatedly demonstrated an exemplary ability to adapt and respond to unique opportunities and to adapt new ideas and technologies from other fields. For example, the community has demonstrated the agility necessary to quickly mobilize in response to earthquakes and to maximize learning from the consequences of these events.

Outstanding capabilities in computer technology -- Earthquake engineering researchers have a tradition of leadership in the development of advanced procedures for computer-based simulation. Engineering education emphasizes computer technology and the development and use of computers to simulate response. The practice of earthquake engineering has radically transformed in the past decade, so that design professionals today utilize computer software in the analysis and design of nearly every project. As such, the earthquake engineering community stands ready to take advantage of the opportunities possible through NEES Collaboratory and the aggressive application of information technology.

Improved tools for computer-based simulation are readily accepted -- Current software applications and models have improved but they still have significantly limited abilities to simulate realistically the seismic performance of structures, or to identify effective approaches for improving this performance. The complexity of the phenomena occurring during seismic response and the lack of avail-
able data to support development of realistic models has led to the reliance on simplifying idealizations and standardized analysis approaches that limit the confidence that can be placed in the results obtained. This lack of confidence in turn provides a substantial impediment to the adoption of advanced simulation capabilities in design and evaluation. However, the professional community stands ready to use more realistic and reliable capabilities. Most codes and guidelines for seismic design and evaluation in the US currently permit and, in some cases, require nonlinear analysis. Additionally, tremendous activity is currently underway within the research, professional and regulatory communities to develop performance-based methodologies that would directly utilize design criteria based on the results of such analyses.

At the forefront of experimentation and instrumentation – Many of the innovations in experimental methods of analysis, and instrumentation, were conceived or developed to the point of application in the US, and subsequently implemented throughout the world. These include the development and use of shaking tables, geotechnical centrifuges, hybrid (pseudodynamic) simulation methods, and high-speed electronic data acquisition systems. Current trends include the deployment of wireless MEMS and other types of advanced sensors for the capture and processing of experimental data. Thus, broad-based expertise exists for conducting innovative experimental research and for devising and implementing more capable methods of experimentation.

Demonstrated efficiency and productivity – The earthquake engineering community has demonstrated the ability to accomplish a lot with limited resources. This comes in part from the ingenuity and creativity of the community, but is also due to the dedication of the community to the intellectual, practical and social aspects of earthquake loss reduction. This economy of operation also results from numerous instances of cost sharing and volunteerism by organizations and individuals alike.

Community has experience with collaborative activities -- From the perspective of the NEES Collaboratory, a major strength of the NSF-supported earthquake engineering research community is its long and distinguished history of cooperative activity, at the national and international levels. Cooperation extends from the experimental to the theoretical and computational aspects research. As mentioned in Chapter 2, examples of such collaboration and cooperation include the NSF Earthquake Engineering Research Centers program, the Cooperative Program for Retrofit, Rehabilitation and Repair of Structures, the five phases of the US-Japan Cooperative Program for Earthquake Engineering Research utilizing Large Scale Testing, and the US-Japan Cooperative Program for Mitigation of Urban Earthquake Disasters. Some of these activities are cooperative in nature, with mechanisms provided to bring together researchers
working on similar projects. Others are more directed and focus on as specific problem.

Because earthquakes are worldwide phenomena, US researchers and engineers have regularly cooperated with counterparts at an international level. As seen in the previous paragraph, many programs at NSF for cooperative research in earthquake engineering revolved around opportunities for international cooperation. These efforts include international exchanges of faculty and students, sharing of data, and participation in cooperative research projects.

Many individuals in the NSF-supported research community also actively collaborate with professional engineers and organizations. This is frequently done by involving professional engineers in research projects, as participants or advisors. Funds are generally inadequate to allow for a lot of this type of collaboration. However, pilot programs such as the FEMA/EERI Professional Fellowship allow more extensive, direct participation by professional engineers in research projects. Many researchers are indirectly involved with research through their participation in the technical and standards committees of professional organizations.

Increasingly, other programs by FEMA, NIST and other state and federal entities bring researchers and professional engineers together to participate in directed programs focused on developing detailed provisions or guidelines addressing a particular design problem. Recent examples of such programs include the FEMA/SAC Program to Reduce Earthquake Hazards in Steel Moment Frame Structures. As mentioned, it carried out more than a hundred individual research projects, ranging from materials science to the development of improved computational models. These research efforts were directly integrated into parallel efforts by professional engineers, researchers, regulatory officials and others to develop reliable and cost-effective guidelines for the design, construction, evaluation, retrofit and repair of welded steel moment frame buildings. Similar directed approaches have been adopted by other agencies to address seismic performance issues related to woodframe buildings, bridges, and so on.

Community members often share data -- Compared to many fields of science and engineering, the earthquake engineering research community has established a widespread culture of sharing of data and ideas. This is particularly significant in formal programs such as those described immediately above. However, numerous instances of informal data sharing exist. Sadly, a major impediment to sharing data heretofore has been the lack of standards and resources for permanent archiving of data and metadata. As a result, information has been often lost or difficult to obtain after only a few years.

Community integrates research and education -- Earthquake engineering research in the US, unlike in some countries, is mainly
conducted at colleges and universities. As such, there has been a strong component of education in research activities, with research results being introduced regularly in curriculum and by having researchers teach courses. Universities and professional associations regularly host continuing education programs based on the latest research results.

Community committed to principles of diversity – The earthquake engineering community has a strong record of promoting creativity and diversity. Individual investigators and the organizations that they are associated with undertake considerable efforts to attract, educate, mentor and retain the best individuals to work in earthquake engineering from the full pool of talent, including men and women, underrepresented minorities, and persons with disabilities.

### 3.4.2 Weaknesses

The strengths of the earthquake community, while substantial and impressive, are resisted by a number of important barriers. For example, current problems associated with inadequate access to state of the art resources for experimentation and computation will be resolved to a great extent as a result of the facilities construction phase of the NEES program. Barriers to high quality and productive research and to effective collaboration should be taken into account in formulating other attributes of the NEES Collaboratory.

Current research efforts are often disjoint and uncoordinated – The impacts of research efforts are often not as large or timely as they could or should be. Today, researchers are often less effective than they could be because they cannot readily find or access needed expertise, data or resources, or must devote tremendous energy to tasks not central to their mission, expertise or interests. As described in Chapter 2, the wide array productivity enhancing tools and services common in collaborations can substantially improve innovation and productivity in research.

Moreover, the current preponderance of single investigator grants favors innovation at the cost of opportunities for collaboration, integration and synergism. In a multidisciplinary and rapidly advancing field, such as earthquake engineering, the lack of robust multifaceted resources for communication, data sharing and collaboration adversely impedes overall progress. Similarly, efforts by individual investigators to promote the scientific, educational and practical impacts of their research are necessarily limited in scope and often cannot be sustained beyond the end of a particular project. Thus, the current absence of mechanisms to mobilize and integrate the education and outreach efforts of the entire research community is viewed as a significant weakness.
On a positive note, NSF-supported earthquake centers do carry out coordinated programs of research, education and outreach that result in considerable synergism. However, even in these cases, resources are quite limited relative to overall programmatic needs, and centers are unable to address the entire range of needs of the broad earthquake engineering community. While other organizations and institutions also have important roles in identifying research needs, conducting research, developing and implementing education and outreach programs, or interpreting research results for possible adoption in practice, none have the mandate or resources to allow the community to effectively integrate and coordinate these processes.

While various approaches to research management and resource allocation could overcome many of these problems, NSF does not, by policy, directly participate in the planning and management of the research efforts it supports. Rather, it relies on the creativity and energy of the supported research team in conjunction with regular and broad-based peer review and adherence to proven management policies to achieve its goals. This approach is generally effective for managing individual projects, but is less effective in identifying overall community priorities for research, and aligning resources with community identified research needs.

Thus, the inability of the community to mobilize, organize, prioritize, plan and collaborate on research, education and outreach programs is a general weakness that should be addressed by the NEES Collaboratory.

Community elements may have low expectations – While many in the earthquake engineering community have high expectations for the NEES Collaboratory, many have had disappointing experiences with past programs sponsored by NSF and other groups that have been inadequately funded or poorly executed. As such, a portion of the community may adopt a skeptical attitude; waiting until they can see positive demonstrations of the collaboratory’s deeds prior to investing their own time and energy. As such, collaboratory activities should be carefully planned to achieve early tangible successes targeted at overcoming reluctance to participate.

Community elements may have excessive expectations – On the other hand, many in the community may have unrealistically high expectations for the type, scope, quality and timing of services provided by the NEES Collaboratory. When these expectations are not achieved, these individuals and groups may become disappointed and withdraw their commitment. As such, it is important to stress the central notion that a collaboratory is a shared risk environment that builds largely on the cumulative efforts of its participants. Nonetheless, it is important that regular and transparent efforts be undertaken to align Collaboratory resources and services with community needs for research and education.
Uneven experience with collaboration – While major efforts are currently underway involving cooperative and collaborative research, these activities have not extended to all elements of the earthquake engineering community. Moreover, these activities are generally voluntary and cooperative, rather than truly collaborative. Since professional advancement within academic and research environments usually depends on individual accomplishment and frequently relies on competitive comparisons with an individual's peers, many in the community do not willingly or enthusiastically collaborate. As discussed in Chapter 2, a collaborative needs to develop appropriate incentives and rewards to overcome this potential weakness.

Diversity of disciplines, cultures and values -- While the diversity of ideas and technologies represented by the broad earthquake engineering community provides a powerful opportunity for rapid advancement, it also raises important impediments. As mentioned in Section 2.3.3, collaboratories work best when participants have a history of working together or have a strong affinity of interests. The breadth of interests among the potential participants in the NEES collaboratory is a weakness, as well as a strength, that must be carefully considered in planning the collaboratory.

Limited experience with operating and managing large system of distributed facilities and resources – The NEES Collaboratory breaks new ground in several areas related to the operation and management of a large, complex and geographically distributed system of networked resources for experimentation, computation, theoretical development, network services, visualization, data management and communication. The individuals and organizations involved with particular facilities and the integration and management of these facilities have in many cases not worked together previously, come from different disciplines, and have different levels of managerial experience. A user-focused, systems approach can be used to plan and manage NEES, but as noted in Chapter 2, substantial effort and personnel will be required. As with other aspects of the Collaboratory, a community-backed consensus process is needed to identify management priorities, operational policies and to monitor and assess effectiveness.

Funding uncertain – It is unclear whether sufficient funds will be able to operate the NEES Consortium and Collaboratory at a level consistent with community expectations. Close liaison with NSF and other funding agencies is needed to assure adequate support for research, education and outreach programs.

3.4.3 Opportunities

Clearly, wide variety of specific accomplishments related to research, education and application can be achieved using the next-generation
capabilities of the NEES Collaboratory for experimentation, computation, network services, model development, information management, visualization and communication. However, as profound as these individual advances may be, the NEES Collaboratory provides an opportunity to transform the field of earthquake engineering in four strategic ways. These relate to (1) how earthquake engineering research is identified, conducted and transferred to practice, (2) achieving a rapid, quantum improvement in the scope, quantity and quality of research results through the synergistic and integrative benefits of collaboration, (3) increasing the impact of research on education, training, outreach, professional practice and decision making, and (4) building a more diverse and vital earthquake engineering community.

Transforming the conduct of earthquake engineering research—Collaboratories are by their very nature intended to transform how research is carried out. As such, the NEES Collaboratory has the opportunity to set the standard for doing engineering research in a new and better way. (Neitlich, 2001). It is expected that the NEES Collaboratory will expand, diversify and strengthen the earthquake engineering community, fundamentally change the processes by which earthquake engineering research is initiated and performed, accelerate the generation and dissemination of basic knowledge, facilitate the development of effective educational programs, minimize the lag between knowledge development and its application, and hasten the attainment of the nation’s goals for earthquake loss reduction.

Quantum improvement in the scope and quality of research – As indicated previously, substantial advances have been made in earthquake engineering during the past four decades. Today, all of the disciplines contributing to earthquake engineering research are quite active and have similarly high capabilities. Moreover, the engineering profession and decision makers are at the forefront of the push towards performance based design criteria, and are eager for the information and model-based simulation tools necessary to implement these methodologies. State-of-the-art resources for experimentation and computation will be readily available with the completion of the NEES facilities. However, numerous instances are acknowledged where a substantial advance is made in one field and many years pass before further progress can be made due to the lack of data needed from an allied field to validate or advance the theory. What is missing is an efficient mechanism to identify critical data needs and to facilitate dissemination of this data with those who need it. By providing an infrastructure for coordination and collaboration, along with the necessary financial support, NEES provides a once-in-a-generation opportunity exists to achieve rapid and unprecedented advances in earthquake engineering.

Synergism in education, outreach and application – As mentioned in the section on weaknesses, one of the major barriers to progress today is the lack of mechanisms to support and synergistically
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integrate the multitude of educational and outreach activities undertaken by the earthquake engineering research community, especially those undertaken by individual investigators. The impact of these individual efforts can be disproportionately amplified through relatively modest levels of sustained service and coordination. Moreover, the diversity of talents, backgrounds, experience and disciplinary concerns represented within the NEES Collaboratory will provide unparalleled opportunity to integrate research with all levels and aspects of education. These interactions will in turn provide a wider range of perspectives from which to pursue research. Such endeavors also prompt broader use of data, through efforts to synthesize, analyze, interpret and summarize findings in a manner suitable for various audiences. The educational and outreach programs will help train an expanded pool of specialists able to use these next generation capabilities and apply the results obtained.

Expanding the community – The energy and synergism exhibited by the NEES Collaboratory will be a powerful magnet attracting individuals from a wide variety of disciplines to study and work in earthquake engineering and related fields. A preview of this community is described in Section 3.2. To build this community, significant efforts are needed to monitor the research, educational and other needs of this community and develop effective training and outreach programs that address these needs.

Other opportunities – Clearly, the NEES collaboratory would enable the community it supports to respond to unplanned external events in an unprecedented manner. For example, NEES facilities for field investigations, laboratory testing, simulation, database management and communications would allow the community to respond to future earthquakes as never before possible. As mentioned previously, new uses of NEES resources may suggest themselves as the collaboratory evolves and attracts new members. The facilities and resources within the collaboratory might also be extended to the study of the effects of other man-made and natural hazards on the built environment.

3.4.4 Threats

Impediments to the success of the NEES Collaboratory include failure to adequately address the weaknesses cited above. In addition, several practical and operational issues pose additional threats.

The complexity and scope of interactions needed to manage the NEES Collaboratory requires a systems approach to insure that the essential services are performed. While there are a multitude of important operational and administrative issues to be addressed, planning needs to focus strategically on desired outcomes. To achieve this, clear management structure is needed, lead by single identified manager with overall authority (Nietlich, 2001). This will allow the Collaboratory to be
responsive to the needs of the user community, and to respond appropriately to unanticipated external and internal events.

Community perceptions of the Collaboratory need to be managed, so that high standards are achieved for an identified, minimum set of functions. Thus, trying to do too many things, and not doing them well, may turn off the user community. Thus, a set of minimum functions needs to be carefully defined, widely publicized and well implemented. Longer-term functions and capabilities can be identified, articulated and used as goals for the NEES community to work towards.

Community building efforts and research progress may be stalled if users find it difficult to access shared-use facilities and data, and if facilities, services and other resources are not available, are frustrating or difficult to use, do not live up to announced specifications, or are not finished. Thus, proper attention need be devoted to so-called “last mile” implementation issues and to providing user-friendly systems.

Similarly, if NEES or NSF decision making is viewed as being too slow, timid, inconsistent, or opaque, the core service providers and members of the broader community will not develop the trust necessary for effective operation (Nietlich, 2001).

Another possible risk is that unclear or conflicting missions may lead to turf battles with other organizations, individuals and groups participating in NEES.

An important threat to be considered is that smaller community participation develops than anticipated. Low participation would depend on several factors, including the nature of the services provided, the ease of use and reliability of the Collaboratory’s resources, the culture of openness established by the Collaboratory, and the level of funding provided. Mechanisms need to be established to insure funding of programs identified by the community as having high priority.
A STRATEGIC VISION FOR THE NEES COLLABORATORY

4.1 Introductory Remarks

The George E. Brown, Jr. Network for Earthquake Engineering Simulation will provide unprecedented resources and opportunities for the broad earthquake engineering community to carry out research and educational programs vital to reducing the nation’s vulnerability to the earthquakes and other natural and human-induced hazards. The central component of this network is the NEES Collaboratory. However, as discussed in the previous three chapters, there are many different strategic and programmatic activities that can be undertaken to address the research and education needs of the earthquake engineering community and numerous factors that should be considered in implementing an efficient and effective Collaboratory.

In this chapter, information from the previous chapters is analyzed to develop a set of statements describing the intended membership of the NEES Collaboratory, its specific mission, a vision regarding what it intends to accomplish by the year 2014, and some guiding principles and values that can help identify the types and character of activities it may undertake to achieve this vision. In addition, a number of strategic goals that the NEES Collaboratory may wish to pursue are identified, along with some comments regarding strategies for implementing these goals. More detailed discussion of the issues highlighted here may be found in the previous chapters.

Issues related to the nature of the Consortium entity that manages and administers the NEES Collaboratory are intentionally not addressed in this chapter. It is expected that the organizational and management structure of the Consortium would be adapted to fit the functional requirements of the Collaboratory.

4.2 An Overarching Goal for the NEES Collaboratory

NEES Collaboratory is intended to transform the nation’s ability to (1) carry out research vital to reducing the nation’s vulnerability to catastrophic earthquakes, and (2) educate new generations of engineers, scientists and other specialists committed to improving seismic safety. The collaboratory concept embedded in NEES refers in large part to the harnessing of information technology to: (1) bring researchers, educators and students together with members of the broad earthquake engineering community and public, (2) provide them ready access to powerful experimental, computational, database, information management and communication tools, and (3) facilitate their collaboration, without regard to geographic location, as if they were “just across the hall.” By mobilizing, uniting and leading the earthquake engineering
community, and providing it with a rich array of unique, world-class resources for research, collaboration, and communication, it is intended that the NEES Collaboratory vastly accelerate the pace of discovery and innovation in earthquake engineering, and the application of new knowledge to practical application. As such, a fitting overarching goal for the NEES Collaboratory is the integration of people, ideas and tools within a collaborative environment to accelerate progress in earthquake engineering. In this context, a collaborative is not a “research center” per se, but rather, a proactive and supportive virtual environment that facilitates the activities of its participants.

4.3 Participants in the NEES Collaboratory

NSF has mandated that the NEES Collaboratory serve the entire earthquake engineering community. Various facets of this issue were examined in Chapter 3. Based on these discussions, it appears that the Collaboratory should be open to all those individuals and organizations that wish to participate. As envisaged, the NEES Collaboratory would not only include individual members, but would also encompass various organizations and a broad federation of resource providers. This concept is schematically illustrated in the figure below.

Chapter 3 examined the benefits of addressing the needs of a broad scope of individual participants, ranging from members of the traditional earthquake engineering research and professional communities, to individuals with backgrounds in information technology, behavioral and
social science, management and planning, construction, manufacturing, public policy, regulation, education, sensor technology and so on. A diverse array of institutional participants would enrich the NEES Collaboratory and leverage its ability to attain its goal. Given the research and educational focus of NEES, participation will likely be self-limiting. It was previously noted that some participants might only be involved in a particular aspect of NEES or in a specific project, while others may sustain a broad interest in a broad range of activities.

As noted in the above figure, the NEES Collaboratory (by mandate of NSF) incorporates not only the initial shared-use equipment sites and the resources being provided as part of the system integration effort, but also other facilities, nationally as well as internationally, for experimentation, computation, data analysis, visualization and so on. As noted in Chapter 2, collaboratories generally incorporate a number of specific capabilities to facilitate sharing of data, sharing of software, sharing of research facilities, developing “shared risk” community-based resources, and communicating with remote colleagues, and undertake sustained activities to facilitate research and to otherwise mobilize, unite and engage the community it serves. By bringing this diverse array of people and institutions together with a superb complement of resources for research, collaboration, communication and education, the NEES Collaboratory will provide a fertile environment for the advancement of earthquake engineering.

4.4 The Mission of the NEES Collaboratory

As indicated previously, the intent of the NEES Collaboratory is not to plan and undertake research itself but to support and enhance the research and educational objectives of the earthquake engineering community. As such, the following statement might best represent the specific mission of NEES Collaboratory.

The Mission of the NEES Collaboratory is

- to facilitate collaboration by the earthquake engineering community in research and education, nationally as well as internationally;
- to support and enhance the research capabilities of the nation’s earthquake engineering community;
- to foster innovative research leading to technically sound and cost-effective approaches to earthquake loss reduction and otherwise serving the critical needs of society;
- to promote the use of engineering knowledge through curated digital repositories and programs of information dissemination; and
- to integrate research and education in support of effective programs of education at all academic levels, from kindergarten to adulthood.
This mission directly supports all of the specific strategic goals of NSF for its research programs and for its major research facilities (summarized in Sections 2.4.1 and 2.4.2).

4.5 A Vision for the NEES Collaboratory

It is a good planning principle to identify the characteristics a new organization should have when it matures. This avoids undue focus on specific short-term issues, where actions are often dictated by limited resources, unforeseen opportunities, competing personalities, and so on. An organization will likely respond best when it follows a path consistent with its long-term objectives. In navigation, this technique might be referred to as the “pole star” approach, where one identifies a distant star as point of reference and sets one’s course relative to this point regardless of currents, winds and ports-of-call along the way. Thus, while one may be temporarily deflected from the proper course, one will arrive there in the end. In a similar way, by focusing on a long-term vision, an organization can avoid frequent, abrupt changes in direction by following its long-term vision. In the case of the NEES Collaboratory, this vision should describes what the collaboratory would like to be in 2014, the end of its planned period of operation.

In this regards, it is important to recognize that current efforts in the overall NEES program are largely directed at bringing the shared-use equipment sites online and developing the basic resources and services for network connectivity. Nonetheless, NSF has indicated that a priority for NEES is conducting collaborative research that integrates experimentation, theory formulation and validation, data curation, model-based simulation, high performance computing, visualization, education and information technology. As such, the demands on the NEES Collaboratory will undoubtedly change substantially with time. Looking to the future, it appears reasonable to anticipate a shift in focus from the mechanics of experimental simulation and documentation of test data and metadata, to one where integration of experimental and computational forms of simulation is emphasized. Ultimately, the focus will likely center on information, and the use of experimentation, computation and information technology to deliver expeditiously the information needed. Thus, one might view NEES and the NEES Collaboratory ultimately as a means of “getting information to those who need it in a form most useful to them.” As such, facilitating ready access to information, through fundamental experiments, reliable computations or access to curated knowledge bases, and promoting information literacy, may be key long-term goals for the NEES Collaboratory.

NSF has also mandated that the NEES Collaboratory “leads, coordinates and serves as the focal point of the George Brown, Jr. Network for Earthquake Engineering Simulation.” As such, another key aspect of the vision of the NEES Collaboratory is to be proactive, professional and effective in coordinating the resources and services that support the
overall goals of the NEES program, but also to mobilize and facilitate collaboration by the earthquake engineering and allied communities in research and education.

A concise vision encompassing the diverse goals of the NEES Collaboratory is presented below.

The Vision – The NEES Collaboratory:

- enables the earthquake engineering community to carry out research critical to earthquake loss reduction by offering a superb array of services and networked resources for collaboration, communication, education and research,

- champions the integration of experimentation, theory formulation and validation, data curation, model-based simulation, high performance computing, visualization, education and information technology.

- engages the earthquake engineering community to assess critical gaps in knowledge and significant opportunities for innovation and discovery, to identify community priorities for research, and to identify the specific resources and services necessary to achieve community research goals.

- promotes the widespread use of engineering knowledge through curated data repositories and programs of information dissemination.

- actively partners with government, academia, industry and business to achieve the nation’s goals for earthquake loss reduction.

- serves the public in numerous ways, including informing the development of improved policies and more effective regulations for earthquake loss reduction, attracting and training a more diverse and capable workforce, and developing effective learning programs across the full educational spectrum.
4.6 Core Values and Guiding Principles

Implementation and operation of the NEES Collaboratory involves a multitude of decisions. To help guide these decisions towards the vision articulated for the NEES Collaboratory, consistent with the responsibilities of an NSF major facility, it is useful to identify a set of core values and guiding principles. The values and principles in the adjacent box concisely define the essence of the NEES Collaboratory.

The Core Values and Principles that Guide our Actions

- We strive to exemplify excellence in all of our activities
- We acknowledge the primacy of public service
- We value activities that increase understanding of the effects of earthquakes on engineered facilities and systems, and lessen the risk of loss
- We value discovery, understanding, creativity and innovation
- We value activities that lead and support the earthquake engineering community
- We value cooperation and collaboration, and as such, we:
  - support and lead activities that integrate and synergize across the full range of ideas, tools and disciplines,
  - champion opportunities for synergism between information technology and earthquake engineering
  - partner willingly and constructively with other organizations to achieve our mutual goals
  - develop policies through an open, inclusive and transparent process
- We value the intelligence, commitment and contributions of the community we serve, and strive to support them in the realization of their goals and to recognize their individual accomplishments
- We value education and open dissemination of knowledge, especially activities that:
  - contribute vitality and diversity in earthquake engineering through the integration of research and education at all levels
  - inform the development of improved policies, guidelines, and regulations related to earthquakes
- We value activities that build a creative, skilled and energetic workforce epitomizing diversity of ideas and backgrounds
- We value innovation and renewal of our program in response to the changing needs of the earthquake engineering community and in light of new engineering, scientific and technological developments.
- We value our employees and instill a commitment to excellence, diversity and service, foster professional development, and to recognize accomplishment.
4.7 Goals

To assist in strategic and operational planning, it is useful to identify specific long-term goals that embody the mission, vision and values that have been set for the NEES Collaboratory. When fully operational, the NEES Collaboratory will provide real and virtual environments where the earthquake engineering community can conduct research, communicate and collaborate: an environment where ideas are openly expressed and constructively critiqued, new generations of earthquake engineers are mentored, individuals having an affinity of interests or concerns can find one another, and new initiatives for research can be identified, nurtured and planned. Through the support provided by this environment the earthquake engineering community can flourish.

To realize this ideal, several interrelated efforts should be pursued. These include providing, maintaining, and enhancing the core research resources, undertaking activities to facilitate collaboration and communication, partnering with other organizations, improving the effectiveness of education and outreach efforts, enhancing the potential of network-enabled collaboratories, and implementing sound management practices. Clearly, the scope and character of these activities will depend on available fiscal and human resources, and the priorities set by the NEES community.

4.7.1 Resources

To achieve its vision, the NEES Collaboratory will support and enhance a world-class portfolio of resources for research, collaboration, communication and education, including:

- A multifaceted, networked environment of resources and services, and related activities that enable seamless collaboration across disciplines, tools and databases without regard to geographic location;
- An unparalleled network of widely-accessible, shared-use equipment sites – along with other facilities, tools and services for next-generation experimentation – tailored to enhance productivity and to achieve community identified research needs;
- Powerful resources for curating and sharing information, and for the synthesis, analysis, visualization and interpretation of large, heterogeneous data sets and information bases;
- A supportive high-performance computing environment for developing and validating new approaches and paradigms for model-based simulation, performance-based evaluation, reliability assessment, system identification, and optimization;
- Network services and partnering arrangements allowing the NEES community to access a broad federation of resources for experimentation, computation, data curation, collaboration and education.
operated by academic institutions, federal and state government entities, and private sector organizations located in the U.S. and abroad;

- A skilled, service-oriented engineering, technical and administrative staff committed to enabling the earthquake engineering community to bring the full weight of the Collaboratory to bear on the most complex and important problems in earthquake engineering.

### 4.7.2 Services

In addition, the NEES Collaboratory should support a variety of services and activities for its participants, including:

- Regularly and systematically engaging the broad earthquake engineering community, including partner organizations, (1) to assess critical gaps in knowledge and significant opportunities for innovation and discovery, (2) to identify community priorities for research, (3) to facilitate collaboration by the community to develop research plans, and (4) to identify the specific resources and services necessary to achieve community research goals;

- Regularly and systematically engaging participants to assess their changing needs for services related to (1) collaboration, education and outreach, or (2) management policies, procedures and practices;

- Facilitating the conduct of multiple “national challenge” programs of research and education involving large interdisciplinary teams from multiple institutions, without losing the ability to support the innovative and creative activities of individual investigators, or small groups of investigators;

- Promoting and facilitating the fundamental fusion in research of experimentation, theory formulation and validation, data curation and interpretation, model-based simulation, high performance computing, information technology and knowledge dissemination;

- Encouraging or hosting the development of community-developed, “shared-risk” resources and tools. A few examples of such shared-risk tools might include the development and validation of advanced methodologies for hybrid simulation, special instrumentation, comprehensive “master” models representing engineered systems, and integrated environments for model-based simulation, database access, performance interpretation, visualization and design improvement.

### 4.7.3 Education and Outreach

As noted in Chapter 3, many of the impressive efforts currently undertaken by the earthquake engineering community related to education
and outreach lack the long-term impact desired. Thus, one of the important activities of the NEES Collaboratory is to provide sustained resources and services that will enable individuals or teams of investigators and educators to synergize and integrate their efforts to:

- Speed the application of new knowledge to practice;
- Fuse educational programs at all levels with research;
- Adapt new approaches for delivering knowledge and inquiry-based learning experiences to a broad and diverse set of constituents;
- Attract and help retain the best and the brightest from a diversity of disciplines and backgrounds to the field of earthquake engineering; and
- Inform the public and policy makers.

4.7.4 Partnering

The NEES Collaboratory should partner with government entities, academic institutions, industry, professional firms, trade associations, regulatory bodies, scholarly organizations, and others, nationally and internationally, as appropriate to:

- Help identify research and education needs;
- Develop new sources of funding to support broad-based, community-backed programs of research and education;
- Leverage available funding and resources through joint ventures and similar partnerships to speed realization of the mission of the NEES collaboratory;
- Improve transfer knowledge and technology to application;
- Inform policy formulation and decision making, and otherwise; and
- Advance the goals of the Collaboratory and its participants.

4.7.5 Advancement of Collaboratory Capabilities

Ideally, the NEES Collaboratory becomes recognized for the exemplary fashion in which it implements network-enabled collaboratories as a means of perusing challenging multidisciplinary problems in engineering. As such, it is expected that the NEES Collaboratory would demonstrate leadership in this area, both internally and externally, by:

- Integrating information technology as a sustained force driving many of the activities, and improving the capabilities, of the NEES Collaboratory, and embracing information scientists as full partners in earthquake engineering research;
- Encouraging full participation in, and use of, the NEES Collaboratory by the broad earthquake engineering and information technology communities; and
Stimulating, through deed and example, the broader academic and practitioner realms of civil engineering and related disciplines; the new style of NEES research should benefit and excite those working on non-seismic aspects of engineered facilities and systems.

4.7.6 Management Practices

As a major NSF facility, the NEES Collaboratory must operate and communicate in a professional, effective and accountable manner. As a minimum, it should:

- Value the ideas and opinions expressed by its sponsors, the NEES resource providers, those who utilized these resources, and the broad earthquake engineering community.
- Strive to meet to the needs of the earthquake engineering community. As such, the NEES Collaboratory should continuously assess its performance and monitor the changing needs of the earthquake engineering community. Operating under sound policies and principles, it is flexible and responsive to the needs of the community we support;
- Effectively build consensus for new ideas and directions;
- Operate under well-publicized, and unambiguous management policies and procedures. These should be built upon sound, well-established business principles and best practices; and
- Celebrating diversity of people and ideas, demonstrating through policies and actions a commitment to individual professional growth and career development, and recognizing individual achievement.

4.8 Some Strategic Issues

A variety of important strategic, programmatic, organizational and administrative issues need to be addressed so that the NEES Collaboratory can achieve the mission, vision, and goals identified in the previous chapter. These are being strategically addressed by the various activities being undertaken by the NEES Consortium Development Project and its various Task Committees (for details see: http://www.nees.org/) as well as by the NEES System Integrator, the various shared-use equipment sites, EERI and NRC. Details of these efforts and the issues involved are beyond the scope of this document.

However, it is useful to discuss a few items that bear on near-term discussion of implementation activities. Issues related to core operating capabilities, implementation, and the emerging research agenda are described below.
4.8.1 Core Operating Capabilities

There are many far-reaching and high impact activities that the NEES Collaboratory can undertake to achieve its vision and goals. However, strategic planning is needed to identify and integrate those activities most critical to realizing these goals. As noted in Chapter 2, a collaboratory will maximize success by offering services and resources that are closely aligned with the needs of the community it serves, and if these are integrated, easy to use, enhance productivity, reliable, and secure. It was also suggested that it would be better to do a few things well, that to implement capabilities that are poorly documented, unstable in operation, incompatible with other resources, etc. Thus, it would be expected that resources and services should be improved and expanded over time in response to community input.

Nonetheless, it is desirable to identify a specific set of core resources and services that will be provided (Neitlich, 2001). Based on the Vision and Goals articulated above and the discussion of ideal collaboratory features in Section 2.3.4, the NEES Collaboratory might initially focus on basic capabilities for:

- Sharing Facilities and Resources
  
  The NEES shared-use equipment sites provide world-class capabilities for experimental research. A key test of the Collaboratory is whether these sites are open in meaningful way to off-site investigators. In addition to the policies and procedures currently being developed to assure accessibility, it has been recommended (Seible, 2001) that a full-time site manager (senior scientist) be provided at each shared-use site to facilitate shared use. Partnerships also need to be developed early on with other existing laboratory facilities as well as with entities that can provide Collaboratory users with high-performance computing, data from existing repositories, and so on..

- Sharing data
  
  The rapid and convenient distribution of high quality data and metadata are central to the notion of a collaboratory. Issues related to defining, acquiring, curating, and sharing various types of data and metadata are being discussed by various groups within NEES. Significantly, several other major sponsors are beginning to require sharing of data (e.g., National Collaboratories, [NRC, 1993] and http://grants.nih.gov/grants/policy/data_sharing/index.htm).

- Sharing software
  
  Given the vision and goals of the Collaboratory, efforts are needed to facilitate the distribution of public domain software applications, and the to plan and develop community-developed, community-
owned models and simulation tools. Policies and procedures for data sharing are currently being developed.

- Communicating with collaborators

As indicated in Chapter 2, there are a wide variety of activities that can be undertaken to facilitate communications. These efforts are the vehicle by which collaboration can be achieved. The NEES collaboratory provides an outstanding focal point of the NEES program as well as for information and communication about its activities.

A versatile and multi-faceted web site is a key component of any communications strategy. As suggested in the mock-up shown below, such a web site can provide general information on the NEES activities and specially tailored information and services for various constituencies, such as the profession, researchers, educators, students, the news media and the public. It can also provide workspaces for general community-wide discussion on ongoing projects, projects in the development stage, as well as on topics of continuing interest, such as instrumentation, experimental methods, applications and so on. It can provide similar workspace specifically for the collaboration of project teams. Other features consistent with the goals identified previously might include:

- Information services for searching diverse data bases and information sets, analyzing and visualizing data, finding and retrieving technical literature including specially prepared summary documents, software applications, archives of information sets on experiments, models, and analyses, and so on.

- Access to on-line training programs, knowledge bases and tutorials on use of collaboratory resources, registration for hands on instructional courses, opportunities for intern- and externships, and so on.

- Resource locators to find available facilities, equipment, resources and expertise, individuals with similar interests, opportunities for collaboration, on-going projects, mentors, and so on.

- Educational programs and opportunities, for all levels of interest.

Other forms of communication, both synchronous and asynchronous, are currently being developed. These include email management systems, videoconferencing, webcasting, and capabilities for teleobservation and telepresence.
4.8.2 Implementation Issues

As noted previously, the NEES Collaboratory operates as a facilitator, not a center. It bringing together people, ideas and tools and helps them through the collaborative environment provided to advance earthquake engineering.

NSF has funded the Earthquake Engineering Research Institute and the National Research Council to identify overall research efforts needed in earthquake engineering and the specific opportunities for use of the NEES Collaboratory, as well as to develop the detailed research plan for the NEES Collaboratory. Consequently, specific plans for the actual research activities to be undertaken within the Collaboratory are not discussed herein. However, periodic efforts will be required prior to start up to insure that the NEES Collaboratory capabilities align with the research plan being developed by the NRC.

Regardless of the specifics of the research plan, some of the key activities of the Collaboratory would be to (1) help individuals and groups in the community identify, plan and execute projects and programs, and (2) maximize the synergistic impact of these efforts through long-term,
sustained and integrated education, knowledge dissemination and outreach programs.

In planning the NEES Collaboratory, effective mechanisms must be devised for identifying and conducting research and education programs, allocating resources, and maximizing opportunities for the community to realize through the NEES Collaboratory its goals for research and education. It doing this, it is useful to consider separately management and organizational activities associated with (1) the core facilitation and collaboration functions, (2) the development and operation of resources, and (3) administrative activities.

From the systems approach to collaboratory operation described in Section 2.3.2, the first item relates to the Research Facilitation Function and Collaboration Function levels, and the second item to the Collaboration Tools, Enabling Technologies, and Network Infrastructure Systems/Services Function levels. Activities related to facilitation and collaboration define the Collaboratory’s interface with the user community. Activities related to the development, enhancement, operation, maintenance and scheduling of resources are critical to carrying out work central to the Collaboratory’s mission. Administrative and organizational support activities, such as developing a financial system that provides accurate information, budget development, establishing formal contractual arrangements with partners and service providers, and so on) are also critical, but might appropriately be responsibilities of the NEES Consortium. Clearly, these management and administrative activities must be fully integrated and coordinated.

To the extent possible, the membership of the Collaboratory should be as inclusive and open as possible. Any fees or other membership-related costs should modest. To avoid a “have/have not” division of the community, institutions providing resources (including, but not limited to, the shared-use equipment sites), sponsors, and other organizations with formal understandings with the Collaboratory might be called members of the “NEES Alliance” or “NEES Federation.” In this manner, individuals and organizations, with interests and commitments to further the goals of the NEES Collaboratory would be encouraged to participate.

4.8.3 Research agenda

During its 10 year scheduled period of operation, the NEES Collaboratory will support a wide variety of research and educational activities. At this stage, the Earthquake Engineering Research Institute, and the National Research Council are identifying (see Section 1.6) specific long-term needs related to earthquake loss reduction, procedures for prioritizing these needs and a detailed research plan for NEES.

As such, it is not possible to address the specific nature of the research programs to be undertaken. However, it is likely that these plans may include high-impact research efforts by single investigators, small
groups of investigators, and large coordinated ‘national challenge” initiatives related to:

- Improving the seismic design and performance of the Nation’s civil and mechanical systems.
- Providing critically missing, quantitative knowledge regarding the multitude of complex factors that affect physical behavior and seismic performance of the built environment,
- Developing and validating more complex and comprehensive analytical and computer numerical models capable of reliably simulating seismic performance of complete systems, including their foundations and nonstructural subsystems,
- Devising, evaluating and demonstrating the value of new concepts for reducing the damaging effects of earthquakes through the innovative use of new or improved materials, elements, systems and theories,
- Improving the constructability and durability of structures able to resist earthquake effects;
- Though partnerships with the earthquake engineering community, developing and validating methods for the design, analysis, evaluation and construction of structures and infrastructure systems such that they are able to perform consistent with targeted expectations,
- Devising and evaluating methods for monitoring and assessing earthquake and other forms of damage,
- Understand the relation of the ability of a structure to resist earthquakes to its vulnerability or resilience to other hazards, natural (e.g., wind storms, ground subsidence, soil failures, flooding, storm surge, etc.) or man-made (collisions with vehicles, explosions, inadequate construction, improper maintenance, etc.)
- Engaging students as well as broad segments of the entire earthquake engineering community in NEES, through meaningful opportunities to participate in research.
REFERENCES


RECOMMENDED STRATEGIES TO MAXIMIZE SHARED USE OF NEES EQUIPMENT AND COLLABORATIVE SITES

With the development of a limited number of NEES research equipment sites, there exists the danger of dividing the experimental earthquake engineering research community into NEES and non-NEES researchers and facilities. NEES as a national resource to earthquake engineering can only be successful when the broader earthquake engineering research community sees benefits from participating in NEES. NEES needs to develop into a collaborative, inclusive, shared use resource and not into an exclusive group of elite facilities. The earthquake engineering community needs to identify the research needs for NEES and direct the collaborative and shared use of NEES resources. The future NEES Consortium is expected to provide this link between NEES and the broader earthquake engineering research community. However, discussions on how this needs to happen and what is required to make NEES a success are essential now and can and should not wait until 2004 when the Consortium will be fully operational. Thus, to stimulate these important discussions, the break-out working group sessions of the NEES-2 workshop specifically addressed and recommended strategies to maximize the shared use of NEES research equipment and sites.

The following key items on how to make NEES a successful national collaborative shared use resource to the broader earthquake engineering research community are identified below:

1. The NEES Consortium needs to define clear rules and policies (cost, intellectual property, schedules, space, personnel, etc.).
2. Equipment sites under NEES should emphasize and be viewed as Collaborative Sites instead of NEES versus non-NEES sites.
3. Since the collaborative site host institutions will be responsible for the NEES research equipment, operation and safety, research partnerships with the host institution are encouraged.
4. There is a need for a full-time dedicated NEES project scientist at each collaborative site to facilitate shared use.
5. Special incentives need to be developed for laboratories and researchers not at dedicated NEES sites to participate in NEES.

6. Academic issues need to be resolved. For students, course reciprocity and special NEES fellowships should be considered. For faculty, sabbatical credits and intellectual property issues need to be resolved.

7. Special outreach efforts are required to make NEES an integral part of the broader earthquake engineering community.

8. The uniqueness of research equipment/facilities is judged to be more important than the geographic distribution.

9. Training processes need to be established (demonstration projects, user workshops, web-based training, user manuals, etc.) to develop NEES into a widely used national resource.

10. Industry participation in NEES needs to be developed and emphasized.

11. More focus should be provided for tele-participation rather than the much more difficult and problematic tele-operation.

12. Long term funding strategies for NEES collaborative research need to be developed.

13. The development of common tools (operation, visualization, simulation, etc.) needs to be emphasized.

14. A strong and empowered oversight committee is needed to develop and guide NEES.

These general recommendations should be considered in the formulation of NEES-2 projects to the extent by which the proposed project can facilitate some of the recommended strategies. Finally, active discussion of these issues and strategies needs to continue within the broader earthquake engineering research and user community prior to and as part of the formation of the NEES Consortium, to bring the NEES collaborative sites, the NEES systems integrator and the NEES user community together.

VISION

*Enabling the Nation’s future through discovery, learning and innovation.*

Realizing the promise of the 21st century depends in large measure on today’s investments in science, engineering and mathematics research and education. NSF investments – in people, in their ideas, and in the tools they use - will catalyze the strong progress in science and engineering needed to secure the Nation’s future.

MISSION

NSF’s mission, set out in the NSF Act of 1950 (Public Law 810507) is:

*To promote the progress of science; to advance the National health, prosperity, and welfare; to secure the National defense; and for other purposes.*

The Act authorizes and directs NSF to initiate and support:

- Basic scientific research and research fundamental to the engineering process,

- Programs to strengthen scientific and engineering research potential,

- Science and engineering education programs at all levels and in all fields of science and engineering, and

- An information base on science and engineering appropriate for development of national and international policy.
Resource Document 3 -- How we operate (from NSF Strategic Plan, 2001-2006)

HOW WE OPERATE

*We enable* people to perform by investing in their creative ideas, providing them with cutting-edge research and education tools, and supporting an infrastructure for education and learning.

*We partner* with a dynamic and diverse education and research community, working in a close trusting partnership while maintaining an independent perspective. We encourage partnerships among agencies, industry, academe, the states, and other nations when collaborative efforts further our goals.

*We integrate* and synergize the knowledge and skills of diverse disciplines and constituencies. We promote the mutual sharing of knowledge and resources. We integrate the processes of discovery, innovation and learning, and connect them to societal use.

*We embrace* competitiveness in all of our programs and activities. We optimize the efficiency and effectiveness of our investments through the use of the competitive merit review process and peer evaluation of programs and activities.

*We manage and communicate* in a professional and effective manner. We listen intently to our customers, valuing their ideas and opinions. We effectively build consensus for new ideas and directions. We clearly articulate and communicate our values, plans, and activities so that customers and constituencies know what to expect of us. We provide the very best service possible to our customers.

*We include* all citizens, groups and constituencies, and promote equal opportunity for all. We work to ensure that the scientific and engineering workforce is as extensive and diverse as possible in order to create a more inclusive and robust enterprise.
Resource Document 4 -- Our Attributes (From NSF Strategic Plan, 2001-2006)

**OUR ATTRIBUTES**

We continually refresh our plans and strategies to assure that the agency will be:

**Open** - NSF is committed to the sharing of information and a free marketplace of ideas. It demonstrates an openness and facility for relating to all key constituents within and outside the organization.

**Inclusive** – NSF takes a holistic view of opportunities and challenges, embracing diversity in all activities and at all levels.

**Inspiring** – Through leadership and creative flair, NSF inspires agency staff and the community it serves to strive for the greatest levels of accomplishment. The community seeks out NSF for its quality and reliable perspective, insights and offerings. NSF has earned an international reputation that makes the agency a benchmark for other science and engineering agencies throughout the world.

**Pace-setting** – In identifying and supporting ideas with the greatest creativity, embracing new thinking, and using information technologies in innovative ways, NSF helps chart new paths for the science and engineering community.

**Influential** – In both the global community and the corridors of science and technology policymakers, NSF is viewed as a creative catalyst – credible, relevant and timely – as well as an excellent, statesperson-like organization that brings together other high-level decision makers.

**Agile** – NSF quickly and effectively responds to changing needs and opportunities. It embraces change through effective systems-thinking and appropriate feedback mechanisms. NSF is a learning organization that is committed to self-improvement.

**Accountable** – NSF builds public trust by being professional, practical and orderly in its operating standards and how it manages its business. NSF and its staff are committed to excellence as a personal and an organizational standard.
Resource Document 5 -- NSF Merit Review Criteria

Criterion 1: What is the intellectual merit of the proposed activity?

How important is the proposed activity to advancing knowledge and understanding within its own field or across different fields? How well qualified is the proposer (individual or team) to conduct the project? (If appropriate, the reviewer will comment on the quality of prior work.) To what extent does the proposed activity suggest and explore creative and original concepts? How well conceived and organized is the proposed activity? Is there sufficient access to resources?

Criterion 2: What are the broader impacts of the proposed activity?

How well does the activity advance discovery and understanding while promoting teaching, training, and learning? How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)? To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships? Will the results be disseminated broadly to enhance scientific and technological understanding? What may be the benefits of the proposed activity to society?

PIs should address the following elements in their proposal to provide reviewers with the information necessary to respond fully to the above-described NSF merit review criteria. NSF staff will give these elements careful consideration in making funding decisions.

Integration of Research and Education

One of the principal strategies in support of NSF's goals is to foster integration of research and education through the programs, projects and activities it supports at academic and research institutions. These institutions provide abundant opportunities where individuals may concurrently assume responsibilities as researchers, educators, and students, and where all can engage in joint efforts that infuse education with the excitement of discovery and enrich research through the diversity of learning perspectives.

Integrating Diversity into NSF Programs, Projects, and Activities

Broadening opportunities and enabling the participation of all citizens -- women and men, underrepresented minorities, and persons with disabilities -- are essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.