NSF/MPS ADVISORY COMMITTEE

A WHITE PAPER ON

RECOMMENDED MPS RESPONSE TO THE HART-RUDMAN REPORT

"'Road Map for National Security: Imperative for Change"

May, 2002

Summary and Recommendations

The Hart-Rudman report, *"Road Map for National Security: Imperative for Change" (February 15, 2001),* contains an extensive analysis of the current capability of the United States to respond to threats to homeland security as well as the strength of the national scientific enterprise. The report made significant recommendations for improvements in these areas, including an enhanced role for the National Science Foundation in the stewardship of the national scientific research and education programs. The Advisory Committee of the NSF Mathematical and Physical Sciences Directorate reviewed the issues in the Hart-Rudman report focusing on *Improving Homeland Security* and *Recapitalizing America's Strength in Science and Education*. This white paper presents recommendations to the NSF/MPS Directorate, and is intended to be a catalyst for further planning.

The Advisory Committee makes the following recommendations:

1. The National Science Foundation, and in particular, the MPS Directorate, should expand its role as a steward of America's science research capability. NSF/MPS should continue to focus on its strength in basic research, while responding to issues of national priority, such as homeland security and science education.

2. The MPS Directorate should play a leadership role in convening a strategic meeting with other agencies to discuss domains of interest and to establish means of coordination of activities.

3. The MPS Directorate should create and maintain an inventory of the research activities and capabilities in the fields that it covers. The inventory would start with current and recent grant awardees, but subsequently should be expanded. Having such an inventory will enable an assessment of existing activities and their support.

4. The MPS Directorate should take actions that will support the formation and maintenance of an active, national community involved in carrying out research in areas relevant to homeland security. Actions could include workshops, communications at national meetings and solicitations for exploratory proposals.

5. The MPS Directorate should conduct a set of open workshops to define actions that will support the recapitalization of America's strength in science and education. A cross-directorate Steering Committee should be formed to plan these workshops. The result of these workshops should be a detailed implementation plan.

1. Introduction

The Hart-Rudman report, entitled ***Road Map for National Security: Imperative for Change***, was released on February 15, 2001. It contains a careful analysis of the current capability of the United States to respond to threats to the homeland security as well as the strength of the national scientific enterprise and the effectiveness of government agencies to deal with these issues. The overall conclusion was alarming. The report asserted that the United States is currently in a state of unreadiness and it will take substantial efforts by many parties to address these problems:

> *... significant changes must be made to the structures and processes of the U.S. national security apparatus. Our institutional base is in decline and must be rebuilt. Otherwise, the United States risks losing its global influence and critical leadership role.*

The Hart-Rudman report specifically predicted terrorist attacks on the American Homeland. The terrorist attacks of September 11, 2001 have magnified the importance of speedy, coordinated responses by a broad set of agencies and organizations. The report included the following recommendation on page 34:

> *...we recommend that OSTP [White House Office for Science and Technology Policy], in conjunction with the National Science Foundation - and with the counsel of the National Academies of Science - design a system for the ongoing basic inventory stewardship of the nation's capital knowledge assets. The job of inventory stewardship could be vouchsafed to the National Science Board, the governing body of the National Science Foundation, were it to be provided staff for this purpose.*

The Advisory Committee of the Mathematical and Physical Sciences Directorate discussed these issues at its meeting in November 2001, and formed a subcommittee to review the issues and recommend actions suitable for NSF/MPS consideration. This white paper represents the subcommittee’s report that has been reviewed and endorsed by the full Advisory Committee for submission to the MPS Directorate.

Improving the national capability to respond to threats to homeland security is especially challenging because such attacks, by their very nature, often come from unexpected sources that are difficult to anticipate. Countering these threats therefore requires the maintenance and expansion of a broad scientific research capability which can act proactively and which can be rapidly mobilized as necessary. Research projects supported by NSF, as illustrated in this report, can form the basis for defenses against these threats by virtue of their long-term nature and scientific quality.

The National Science Foundation is one of several institutions that will play a role in responding to the recommendations of Hart-Rudman dealing with the research enterprise. Others include the Department of Defense research agencies, the National Security Agency, NIH, DOE and NASA. It is imperative that these groups respond in a coordinated fashion, each having clearly defined responsibilities and having well-defined interfaces between the various agencies. In addition, better cooperation with industry can provide great benefit, particularly in accelerating the speed of transfer of innovation from laboratories to usable products.

The National Academies have recently established a committee of distinguished scientists and engineers to help the government to develop a science and technology program plan and research strategy for combating terrorism. NSF/MPS can provide important input to this study, and some of the recommendations resulting from this proposed response to the Hart-Rudman report may also assist the Academies' study.

<u>Recommendation 1</u>. The National Science Foundation, and in particular, the MPS Directorate, should expand its role as a steward of America's science research capability. NSF/MPS should continue to focus on its strength in basic research, while responding to issues of national priority, such as homeland security and science education.

Stewardship includes the following responsibilities:

- Maintain an inventory of the current capability and expertise of the national science enterprise.
- Identify deficiencies in this capability as well as new opportunities to be drawn to the attention of the scientific community.
- Invest appropriately in the core enterprise of basic research and science education, as well as in exploratory activities designed to open up new fields of activity.
- Provide means to assist responsible agencies to rapidly identify resources within the national scientific enterprise that may lead to solutions to critical problems.

As a component of its science stewardship, NSF/MPS must continue to accept responsibility for the development of an educated workforce. The shortage of talented Americans entering areas of scientific research also poses a critical problem that must be addressed. This shortage will require attention at all stages of the "pipeline". This includes finding ways to excite pre-college students and their teachers, to educate and motivate undergraduates, and to provide opportunities that provide incentives for students to pursue graduate studies and research careers. The development of ideas should continue to receive significant support. We also require better means to disseminate and share ideas and to focus them on urgent problems. We need two types of tools: some enabling broad use of results within the scientific and engineering communities; some supporting the stewardship roles described above.

We stress that it will require an increase in funding for NSF to take on the expanded responsibility of stewardship in addition to its present role of being a prime supporter for basic research in the United States. However it is our strong belief that NSF, in conjunction with other agencies, is ideally qualified to play a major role. In 2000, the MPS Advisory Committee drafted a document called "*RISE*" - *Reinvestment in Science and Engineering*. This document contains many examples of how research in basic science has contributed to advances in all aspects of our lives. The time is right to expand this collection substantially.

In Sections 2 and 3 we discuss the two areas from the Hart-Rudman report requiring focus from NSF: *Improving Homeland Security* and *Recapitalizing America's Strength in Science and Education.* We discuss both short-term actions and continuing, long-term activities. MPS currently has basic research programs that are directly relevant to our recommendations, and examples of these are outlined in Section 4. These activities have been on-going prior to the new focus on homeland security and illustrate the potential of basic research to contribute to the resolution of new problems that confront our nation. Members of the subcommittee are listed in the Appendix.

2. The Role of MPS in Homeland Security

Homeland security is a national priority, and it is the duty of scientists in the U.S. to assess how their research expertise and capabilities can contribute to this important mission. As one of the Nation's leading science agencies, it is important that the NSF assumes a key position in this effort, as recommended in the Hart-Rudman Report. Indeed, this is specifically included in the NSF charter:

> *"To promote the progress of science; to advance the national health, prosperity, and welfare; <u>and to secure the national defense</u>."*

Support for homeland security involves three types of activities:

1. <u>Anticipatory</u>: Potential future threats are recognized and research is carried out that will develop capabilities to counter these threats. Much of the current work on cryptography research is of this nature.
2. <u>Responsive</u>: An actual security attack occurs and a very rapid response is required. An example of this is the identification of a test to identify the presence of anthrax spores.
3. <u>Capability building</u>: The unpredictability of homeland security threats makes it essential to conduct broad research programs in selected areas that will strengthen our base capabilities, without focusing on any particular threat. For example, basic research on computerized face recognition provides a core capability that can enable automated identification of suspected terrorists from security cameras.

A substantial fraction of the research sponsored by NSF, especially within the MPS directorate, can contribute to issues of national security. One example of particular importance today is the development of chemical and optical sensors that has been sponsored by various MPS Divisions, along with the accompanying signal processing techniques. For example, the Division of Chemistry alone has approximately 70 active proposals at $9.5M/yr in the general area of sensors and detection, and it will soon evaluate proposals for an Environmental Molecular Sciences Institute.

The MPS Advisory Committee considers the following to be important guidelines in establishing the role of NSF/MPS in homeland security research:

- NSF/MPS should concentrate on basic scientific research that feeds into applications that other agencies or industrial sectors can use effectively. Through this unique role, the MPS contributions can be maximized consistent with its mission and capabilities.

- NSF/MPS should justify an augmentation of its research budget for directed areas of emphasis, while maintaining strong support for the core program of basic research and science education. This is particularly important since novel ideas that impact homeland security applications may well be generated from basic research in core areas, and these may not be currently anticipated.

- NSF/MPS should help establish communication channels amongst all scientists involved in work that may be related to homeland security, and outline methods for maintaining an inventory of applicable national research programs in MPS disciplines that can be shared rapidly with other agencies in response to various homeland security situations and requirements.

MPS can contribute significantly to homeland security issues in many ways. The Directorate, as part of a broad NSF effort, should work with mission-oriented agencies such as AFOSR, DOE, NRL, ARO, NASA and the Homeland Security Office to identify opportunities for research and development and setting priorities for programs that address the scientific and technical needs for homeland security. NSF can use its broad contacts with educators and researchers in colleges, universities and the national labs to put together teams to make rapid progress in designing these projects and bringing them to fruition. NSF should play a major role in planning longer-term science initiatives that will provide the infrastructure necessary to meet future homeland security needs. Some areas of focus could be:

- Security of information technology and communication systems;
- Security of energy sources and distribution systems;
- Security of transportation systems;
- Continuing development of basic science discoveries, infrastructure and human resources needed for both a strong economy and the flexibility to meet unforeseen threats.

Recommendation 2. The MPS Directorate should play a leadership role in convening a strategic meeting with other agencies to discuss domains of interest and to establish means of coordination of activities.

The MPS Directorate is also well positioned to bring together interdisciplinary science teams to attack problems that require input from many disciplines. These are capability-building activities, focusing on *prevention*, not just response, as described on Page 6 of the Hart-Rudman report.

In the nearer term, the Directorate should identify current research projects funded by NSF that are likely to have an impact on homeland security. For example, the development of advanced sensors and detectors across the spectrum are critical components of many research projects. Imaging techniques, sophisticated methods of data analysis and visualization can be readily adapted for security needs. The Directorate can help identify those projects and programs that seem most likely to have devices and procedures that might be put to use in homeland security. In addition, the Directorate can provide guidance to researchers who bring forward devices and procedures that might yield quick responses to immediate homeland security needs, for example for rapid detection of anthrax spores. The Foundation can then assist in speeding the conversion of laboratory devices to practical devices for the field by brokering agreements between researchers, mission-oriented agencies, and commercial firms.

Recommendation 3. The MPS Directorate should create and maintain an inventory of the research activities and capabilities in the fields that it covers. The inventory would start with current and recent grant awardees, but subsequently should be expanded. Having such an inventory will enable an assessment of existing activities and their support.

This inventory should be created in the form of a well-indexed and cross-referenced text database. This will permit the application of data mining and text-mining techniques that can generate detailed and aggregate understanding of the totality of covered research. The creation, maintenance and analysis of this database will require targeted investment by NSF.

Recommendation 4. The MPS Directorate should take actions that will support the formation and maintenance of an active, national community involved in carrying out research in areas relevant to homeland security. Actions could include workshops, communications at national meetings and solicitations for exploratory proposals.

More specifically, the Advisory Committee recommends consideration of the following actions.

1. Strategic coordination: Initiate strategic coordination meetings with federal agencies such as DoD, NSA, DOE, NIH, etc., and outline NSF's role in homeland security. Such coordinated efforts could fall within the on-going study project of the National Academies, or be in response to requirements of the Office of Homeland Security. This should include strategic coordination amongst chief scientists at the above-named federal agencies. NSF/MPS should propose coordination of specific aspects of the national effort such as the inventory of relevant research and the establishment of a communication channel amongst scientists to insure a cohesive national program. As this forms a new thrust for MPS, it is important that close communications and review of this process be maintained with the Office of the NSF Director, the NSB, and the NAS.

2. Inventory of relevant research and expertise: Carry out a detailed inventory of ongoing research activities in the MPS Divisions to identify those areas that may impact homeland security issues both in the short and long term. Such a list, a few examples of which are given in Section 4 of this paper, would illustrate MPS' potential contributions in the national effort and help demonstrate the importance of basic research that can feed into the homeland security applications.

3. Assessment of current projects: Assess whether research projects identified by the inventory are operating under constrained budgetary levels. Seek input from the PIs about how additional resources could be utilized to facilitate faster progress in the research if possible, enhance educational opportunities in these areas to train the work force relevant to these areas, and to generate results that can be driven promptly towards applications.

4. Facilitation of scientific and mathematical community involvement: Encourage the MPS community to apply for short-term exploratory research projects to examine potential areas that can lead to contributions to homeland security. A special announcement of opportunity should be prepared and rapidly disseminated to the MPS community. NSF has the SGER mechanism for making such awards, and the size and conditions for such awards should be reexamined in light of the urgency of engaging the broad MPS community in this effort.

5. Communications with the community: Disseminate the important message of homeland security research to the community via presentations at the various upcoming national disciplinary meetings. The MPS Directorate and Divisions have traditionally supported successful 'town meeting' presentations at various national meetings and this would be a timely opportunity for this effort. The message to the community must be carefully presented as a new area that may apply to some but not all NSF research work, and that it is being considered as an augmentation to the MPS portfolio rather than a redirection of resources.

6. Community workshop: Plan an MPS multidisciplinary workshop to encourage discussion and debate on the appropriate program for homeland security within MPS and define the longer-term road map for this effort. Such a workshop would serve to build strong associations amongst MPS disciplinary scientists and engage them in defining the program with a strong stake in its success.

7. MPS management: Determine the appropriate mechanism to coordinate and manage homeland security research within MPS. A coherent and cohesive management mechanism would help build a stronger program and provide more visibility to the effort. Program coordination can either reside in the MPS Director's Office or within the OMA. The research programs themselves would continue to reside in the relevant divisions and would be supervised by the program directors.

We emphasize that all of these efforts should support continued focus by NSF on science research and education. Deciding whether NSF itself, with appropriate budget increases, ought to fund mission-oriented research directly, is a serious policy issue. Our recommendation is that this funding be left primarily to other mission-oriented agencies.

Support for short-term research and planning activities in FY02, where the budget has been already established, would come from potential cooperative efforts with other federal agencies or from special appropriations to the NSF budget for the purpose of supporting research on topics related to homeland security. Some support could come from the normal budget allocation where feasible, but solicitations to the community for involvement in this research need to be commensurate with the identification of appropriate resources. Clearly, the planning and longer-term activities in homeland security research may be very important for the development of the FY03 NSF budget request.

Secrecy and classified information issues will arise in dealing with other agencies and may also be important in the application of basic research tools to homeland security as laboratory devices and procedures are converted to homeland security uses. The Directorate should explore ways of speeding the security clearance for those university researchers who need it and finding ways for researchers without such clearance to contribute appropriately to classified projects.

3. Recapitalizing America's Strengths in Science and Education

The events of September 11, 2001 shed a harsh light on the science research and education infrastructure in this country. On the one hand, our current technology and expertise allowed rapid responses to both physical and biological terrorism, and to build defenses and wage war with enormous technological superiority. On the other hand, there was a feeling that a more capable national structure should have been able to detect and forestall these attacks before they occurred.

Responding as recommended in the Hart-Rudman report requires a number of actions. We must

- Rebuild and re-equip facilities that restore the nation to the forefront of scientific research.
- Better educate students at all levels in science and mathematics.
- Maintain the pool of creative scientists and educators in science, mathematics and engineering.

- Rebuild the industrial-academic collaborations that gave us advances such as atomic energy, synthetic rubber and the ability to place men on the moon.

These activities cannot be addressed separately; each builds on and reinforces the other. Good education prepares students; modern facilities and enthusiastic science mentors attract them, train them and work with them to develop new ideas; and healthy industry puts them to productive work.

The Hart-Rudman report has recommended a renewed national commitment along the lines of the commitment made in the Sputnik era. That commitment includes the following:

1. "Doubling the U.S. government's investment in science and technology research and development by 2010" in programs that would "emphasize research over development";
2. Better coordination of research efforts by diverse funding agencies and by the national labs;
3. Improvement of science education nationally.

If successfully implemented, 2. would complement 1. by providing communication links that close the gap between scientific insights and successful applications. The report includes concrete suggestions for achieving 2. and3. but does not give a price tag.

Our specific recommendations for actions to reinvest in science and education are based on the three tenets of NSF: *people, ideas and tools.* Rebuilding excellence in each is a complex process that will require participation from and cooperation between many sectors and agencies of government, industry, academia and the broader society. Although the desired end goal of a scientifically educated and technologically strong nation is clear, the specific path that the nation must pursue, the likely time scale, and the requisite cost to achieve this goal are less clear. We recommend that MPS establish a Steering Committee to oversee the definition and implementation of a series of focused workshops to articulate the pathway to reestablish international prominence in science and math research and education. These workshops should be held within the next year to address the recapitalization of science research and education infrastructure. The expected outcomes of these workshops will be detailed plans that articulate both the short-term and longer-term actions and costs for revitalization of science research and education in this country.

<u>Recommendation 5</u>. **The MPS Directorate should conduct a set of open workshops to define actions that will support the recapitalization of America's strength in science and education. A cross-directorate Steering Committee should be formed to plan these workshops. The result of these workshops should be a detailed implementation plan.**

Two workshops on rebuilding infrastructure are recommended. The first will focus on science education and the science workforce; the second will revolve around science research and technology. The first would call on national leaders in education at all levels, from elementary school teachers to world-class scientists from academia and industry. Their mandate would be to

- *Evaluate* where we are now: what educational strategies currently employed are effective, what problems require solutions, how do we move beyond the best strategies we now have, and what are the anticipated needs in the science and math research and education workforce in the next two decades?
- *Define* specific programs to promote systemic change: we already *know* how to teach well; how do we implement what we know to better prepare the current and next generation of researchers and educators?

- *Develop* plans for reinvigorating the cadre of science and math researchers and educators needed: how do we attract the best students into science and math research and teaching, how do we train them, and crucial to long term success, how do we retain them in these professions?

The second workshop would bring together leading researchers from academia, industry and national laboratories to define a plan for recapitalizing science and math research in this nation through long-term support and development of its infrastructure. Drawing on the depth of experience and knowledge of these scientists on how first-rate science is accomplished now and how it is translated into useful technology, they will be asked to

- *Determine* areas of immediate and long-term need to better position the nation for the scientific and technological demands of the 21st century. What areas of science research and technology expertise need to be developed and/or strengthened, what state-of-the-art instrumentation and facilities are required, and what human resources must be developed to support these areas?

- *Define* recommended new areas of emphasis in national programs and increases in funding required to meet these needs. Where are the needs greatest, what are the most urgent priorities, and what are the systemic improvements that will bring long-term health to the nation's science and technology base?

- *Develop* a specific timeline for phased implementation of these programs and costs.

4. Current Relevant MPS Programs and Funded Research

The NSF MPS Directorate, through its Divisions of Astronomical Sciences, Chemistry, Material Sciences, Mathematical Sciences, and Physics, has been supporting basic research in many areas that have relevance to our Nation's homeland security and to the recapitalization of our Nation's strengths in science and education. We illustrate below some of the research and educational programs that are on going within the MPS portfolio of support. These provide concrete examples of programs and initiatives that have been supported under the core program of basic research prior to the recent attention towards homeland security and the call for added emphasis on science education as recommended by the Hart-Rudman report. The Hart-Rudman report recommended a doubling of the NSF budget, and such action would provide many more opportunities for expanded support of basic research and education in MPS disciplines. Such an increase in support would also be an important step in recapitalizing America's investment in basic research and science education.

4.1 Examples relevant to homeland security research:

- ***Molecular Detector***

At Northwestern University, the research team of Joseph Hupp, Son Binh Nguyen and Randall Snurr, has developed a thin-film material with nanometer-sized cavities that serves as a molecular gatekeeper. The material can be manipulated to allow the passage of certain molecules on the basis of size, shape and other properties. The scientists have also discovered a means of chemically transforming molecules within these cavities. These films could potentially be used to selectively capture and destroy harmful chemical species introduced into the environment.

- ***Biological and Chemical Sensor***

At the University of Kentucky, Sylvia Daunert has been developing genetically engineered bacteria to be used in optical sensing systems applied to problems in environmental analysis. The bacteria contain reporter genes that provide light emission of specific wavelength when exposed to the targeted analyte. An internal background correction system is developed that allows extension of the spectroscopic method to achieve low levels of detection. Arrangements of bacteria-based sensors are explored for multianalyte sensing in flow streams and in static solutions. Bacterial genes are modified such that they luminesce when exposed to trace levels of targeted compounds. These systems can be used to sense and warn of harmful systems in the environment.

- ***Nanoparticle Strategies for DNA Sequence Detection of Anthrax***

A research group at Northwestern University led by Chad Mirkin has used a materials-based strategy as a novel approach towards detecting specific DNA sequences. Because nanoparticles only assemble in the presence of a complementary DNA strand, the change in material properties induced by nanoparticle assembly can be used as an indicator of whether a particular sequence is present in a sample or not. Such signatures include the changing optical, mechanical, and electrical properties of DNA-functionalized nanoparticles; for example, on DNA-mediated assembly, gold nanoparticles will change from red to blue, and this change can be correlated to the presence of a DNA target. The researchers have applied this idea to the detection of DNA from biological warfare agents such as anthrax, and are extending it to clinical DNA detection. Currently, they are extending the nanoparticle assembly strategy to analyzing combinatorial DNA arrays (or "gene chips"), and have demonstrated that DNA-functionalized gold nanoparticles will assemble onto a sensor surface only in the presence of a complementary target. If a patterned sensor surface of multiple DNA strands is used, the technique can detect millions of different DNA sequences simultaneously. Nanoparticles make particularly good labels for sensors because a variety of analytical techniques can be used to detect them, including optical absorption, fluorescence, Raman scattering, atomic and magnetic force probes, and electrical conductivity.

- ***3-D Geometry Face Recognition***

Work by Shing-Tung Yau at Harvard University on automatic face recognition can advance the techniques in surveillance and identity authentification. Most of current research in this area focuses on image based techniques, such as eigenfaces, memory-based approaches. While these methods work well in some small domain mugshot face databases, the performance falls off sharply when applied to more general cases. For example, on frontal images taken the same day, typical first choice recognition performance is over 95% accurate, while for images taken one year later, the typical accuracy is approximately 50%. The reason is that the face is a 3D object whose 2D pictures show strong variance because of the pose, facial expression, cosmetics, etc. To get a reliable face recognition algorithm, one has to use geometric information to study the 3D face information. With today's advances in 3D modeling techniques, face recognition can be pushed to a higher level. This research is strongly interdisciplinary, requiring contributions from geometry, computer graphics and computer vision.

- ***Precise Location of Radio Signals***

Astronomers have developed accurate techniques to map the position of distant galaxies in order to image their structures and study their evolution. The most precise of these methods involves networking radio telescopes that are separated by long distances from each other – a technique called very long baseline interferometry. The technique has been recently applied by Alan Rogers at the Massachusetts Institute of Technology, Haystack Observatory, to the precise determination of the location of a cellular phone making an E-911 call. The radio signal from the phone is equivalent to that emitted by a quasar, and the cellular towers behave as the radio telescopes that receive the signal. Joint work by the MIT astronomers and industrial partners at TruePosition, Inc. in Pennsylvania has resulted in the development of a network system capable of locating emergency calls from cellular phones to within 80 meters. The technique has been tested successfully in heavily populated urban environments and shown to meet requirements established by the FCC. It can be usefully extended to homeland security applications in the future.

- ***Hardening of electronics***

The development of new radiation hard electronics is essential for robust control and communications in extreme radiation environments. The inner particle tracker and very high speed readout systems of the LHC and

Fermilab high energy physics detectors must operate reliably when they are located but a few centimeters from the primary high energy accelerator beam - an incredibly hostile environment. The physics community is working together with industry to solve this problem for many mega-Rad doses, pursuing paths from new materials such as diamond detectors, to new circuit designs with built in error correction and redundancy, to new microchip designs to reduce the effect of radiation damage on semiconductors (e.g., smaller gates). While this work will have profound effect on the science reach of high luminosity particle physics experiments, the greater impact will be on reliable, fault-free electronics for our battlefields of the future and for space applications.

4.2 Examples relevant to strengthened education:

- ***Grant Opportunities for Academic Liaison with Industry***

The Grant Opportunities for Academic Liaison with Industry (GOALI) program makes funds available to establish university/industry partnerships. It provides opportunities for faculty, postdoctoral fellows, and students to conduct research and gain experience in an industrial setting; industry scientists and engineers to bring industrial perspective and integrative skills to academe; and interdisciplinary university/ industry teams to conduct long-term projects. This program targets high-risk and high-gain research, with focus on fundamental topics that would not otherwise have been undertaken by industry; the development of innovative, collaborative university/industry educational programs; and the direct exchange of new knowledge between academe and industry. GOALI provides funding for individuals such as faculty, postdoctoral fellows, and students to develop creative modes of collaborative interaction with industry through individual or small-group research projects and industry-based fellowships for graduate students and postdoctoral fellows. All NSF Directorates participate in the GOALI program.

- ***Research Experiences for Undergraduates***

The Research Experiences for Undergraduates (REU) Program supports active research participation by undergraduate students in any of the research areas funded by NSF. REU projects involve students in meaningful ways in ongoing research programs or in research projects specially designed for the purpose. Two support mechanisms are offered: REU Supplements and REU Sites. REU Supplements may be included in proposals for new or renewal NSF grants or as supplements to ongoing NSF-funded projects. REU Sites are based on independent proposals to initiate and conduct undergraduate research participation projects for a number of students. REU Sites projects are often focused within a single discipline and/or single academic department; however, interdisciplinary or multiple-department proposals with a strong intellectual focus are also encouraged, as are proposals with international dimensions.

- ***Research Experiences for Teachers***

The Research Experiences for Teachers (RET) program facilitates the professional development of K-12 teachers by promoting collaborative relationships with research scientists, thus strengthening the partnership between universities and local school districts. The program allows scientists to connect personally with math and science teachers in their areas, and to reach students broadly. In this program, teachers are invited to spend internships with researchers in their laboratories during summer and the academic year in order to learn about on-going research and help translate the principles into lesson plans that they can take back to their students and fit within their class curricula. Close contacts are maintained between the scientists, the teachers and the students in follow-up activities in the schools, thus building long-term collaborative relationships. The RET program was initiated in the MPS Directorate in 1999 through a call from the MPS Assistant Director to the MPS science community for participation. The program was patterned after the Research Experiences for Undergraduates program, and is synergistic with it.

- ***Integrative Graduate Education and Research Traineeship***

The Integrative Graduate Education and Research Traineeship (IGERT) program was initiated in 1997. Its goal is to provide Ph.D. scientists and engineers with the multidisciplinary backgrounds and the technical, professional, and personal skills needed for the career demands of the future. The program is intended to catalyze a cultural change in graduate education, for students, faculty, and universities, by establishing new, innovative models for graduate education in a fertile environment for collaborative research that transcends traditional disciplinary boundaries. It is also intended to facilitate greater diversity in student participation and preparation and to contribute to the development of a diverse, globally-aware, science and engineering workforce. IGERT projects afford graduate students an in-depth education through course-work and research experience in emerging areas of science and engineering, areas that transcend traditional disciplinary boundaries and involve a diverse group of faculty members. The awards place a high priority on students' communication and teamwork skills, international awareness, experience with modern instrumentation, and responsible conduct of research. The IGERT projects also link graduate research with internships in industry, national laboratories and other non-academic settings in an effort to offer experiences relevant to both academic and nonacademic careers.

- ***Grants for Vertical Integration of Research and Education (VIGRE)***

VIGRE is an innovative effort by MPS, begun in 1998, to attack the "pipeline" problem by the integration of education and research. Support is provided to mathematical sciences departments that have a coherent plan for integration of an undergraduate research experience; a graduate traineeship program; a postdoctoral fellowship program; and undergraduate and graduate curriculum reviews. Some VIGRE projects also feature K-12 outreach activities.

APPENDIX

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