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Chairman Brooks, Ranking member Lipinski, and distinguished members of the Subcommittee, thank you for the opportunity to testify today. My name is Sol Gruner and I am the director and principal investigator of the Cornell High Energy Synchrotron Source/Cornell Electron Storage Ring (CHESS/CESR), a major multi-user NSF-supported facility. My testimony provides an overview of the facility from inception to the present day, with background pertaining to the changing relationship between the NSF and universities over stewardship of major interdisciplinary facilities. The challenges of this relationship will be described toward the end of my testimony.

1. Overview of the CHESS/CESR facility from inception to the present day

<u>Historical Overview</u>

Cornell University was an early leader in accelerator and synchrotron radiation research, having built the second cyclotron accelerator in the world in the 1930s and the world's first synchrotron radiation beamline in the early 1950s. In 1977, the NSF Physics Division awarded Cornell $22 million to build a colliding beam storage ring nearly a half mile in circumference in a pre-existing tunnel underneath the central Cornell campus. This machine, called the Cornell Electron Storage Ring (CESR), collided electron and positron beams for high-energy physics (HEP) studies. CESR was built in just 18 months, on budget, and was operational in 1979. Because storage rings also produce intense beams of x-rays through the synchrotron radiation process, the NSF Division of Materials Research (DMR) awarded Cornell the funds in 1978 to build the Cornell High Energy Synchrotron Source (CHESS) to utilize the x-ray beams produced by CESR. CHESS also became operational in 1979.

From the beginning, CESR was designed to be so flexible that advances in technology could easily be incorporated as they were developed. The HEP experiment at CESR was a collaboration between 22 universities and national laboratories. It was one of the most productive and longest running experiments in the history of high-energy physics, resulting in more than 500 publications in peer-reviewed journals. In 2008, after nearly 30 years of operation, the NSF Physics Division and Cornell scientists ended HEP data collection at CESR. At that time, DMR became the primary steward and funding source for both the CHESS x-ray user facility and the CESR machine needed to generate the x-rays (collectively, CHESS/CESR). The flexibility of CESR, however, makes it ideal for accelerator physics studies that cannot be performed anywhere else in the world. The NSF Physics Division (and, to a lesser extent, the Department of Energy) continues to support advanced accelerator physics research and development on CESR when the machine is not being used for x-ray production.

CHESS is a multidisciplinary user synchrotron radiation facility for research in physics, chemistry, biology and biomedical science, geology, engineering, and environmental and materials sciences, and objects of art and antiquity. CHESS serves experimental groups from universities, national laboratories, and industry from around the world with many unique, state-of-the-art capabilities. Each year, between 600 and 1000 research scientists, graduate, and undergraduate students use CHESS to develop experiments, receive advanced training, and collect data. Demand for CHESS beam time greatly exceeds capacity. At present, CHESS is able to serve only about one-third of the demand for time on its beamlines. Furthermore, the facility is highly productive: CHESS data results in about one publication for each day of user operations.

CHESS and CESR have both been upgraded multiple times to maintain world-class capabilities. In 1979, CHESS had three beamlines and five experimental stations. It expanded in the late 1980s and again in 2000. Over time, both CHESS and CESR have developed and implemented new technologies that have been adopted at other synchrotron radiation and electron storage facilities around the world. This process is on-going: Cornell is currently planning to upgrade CHESS with novel undulators that would provide much needed high-energy x-ray capabilities that are in very short supply in the United States.

Management

Cornell University has decades of experience using the Research Laboratory structure to operate large NSF-supported national facilities – including the Arecibo Radio telescope, CHESS/CESR, and the Cornell Nanofabrication Facility – flexibly and cost effectively. The Cornell Laboratory for Accelerator-based ScienceS and Education (CLASSE) is the umbrella Research Laboratory for CHESS/CESR. The Director of CLASSE reports to Cornell's Senior Vice-Provost for Research. A Directorate consisting of the directors for x-ray science, particle physics, accelerator science, technical operations, and administration makes CLASSE decisions.

Accelerator laboratories are complex enterprises, and rely on experts in radio-frequency engineering, accelerator physics, x-ray optics, high vacuum, cryogenics, and other technical disciplines to operate successfully. CLASSE maintains the necessary skill set to operate CHESS/CESR through a matrixed organization, whereby skills are shared and costs are allocated to projects by the amount of service provided. The advantage of this organization is that it reduces redundancy and lowers the operating costs of our research laboratory. CLASSE also draws upon the skills of about a dozen faculty members for whom the CLASSE facilities are their primary research tools, and several dozen additional faculty members who make extensive use of the facilities. These faculty members represent a university contribution to CHESS/CESR worth millions of dollars annually. Overall, CLASSE has an annual budget of about $35 million per year, not counting faculty costs. The NSF CHESS/CESR award – about $20 million in FY 2012 – makes up the majority of this budget with the rest paid for by a combination of other grants and Cornell University.

Competing CHESS/CESR renewals, typically every five years (see question 5 for elaboration) define the proposed program and the resulting detailed year-by-year preliminary budgets. Every six to twelve months, the NSF informs us of adjustments to the preliminary budget for the period, and Cornell's Office of Sponsored Programs submits a revised budget for the period. Every time a new budget is accepted, the NSF generates a notice of Grant Award to Cornell specifying the sum of allowed expenditures for each category for the budget period.

CLASSE has a Business Office to check expenditures against allowable expenses in each budget category. Cornell's Sponsored Financial Services Office handles the billing to the NSF. Cornell is reimbursed for its actual expenditures though weekly or bi-monthly requests for payment to NSF's Fastlane system for recent expenses. A few days after the request is made, the funds are deposited into Cornell's bank account.

CHESS/CESR is managed through a series of cooperative agreements and memoranda of understanding, partnerships, and line management arrangements that ensure accountability and open communication between all parties. The primary accelerator facility awards are managed under the terms of carefully negotiated Cooperative Agreements between the NSF and Cornell University. The Cooperative Agreements provides for the basic infrastructure of the accelerator facilities at Cornell. The major biomedical component of CHESS – the MacCHESS program – is a National Institutes of Health (NIH) Biomedical Biotechnology Research Center award, and managed under terms of that NIH grant. Specific experimental programs are managed through individual memoranda of understanding between CHESS/CESR and organizations such as the DOE-funded Energy Materials Center at Cornell, the Air Force Office of Scientific Research, the NSF-funded Materials Research Science and Engineering Center at Cornell, and the King Abdullah University of Science and Technology, which provide resources to CHESS/CESR through their grants. The terms of these individual agreements require these resources are owned by CHESS/CESR and are available to all CHESS/CESR users. More information on management is given in the answers to questions below.

2. Justification for the CHESS/CESR facility and return on the taxpayer investment
CHESS/CESR has a different character from light sources operated by the Department of Energy (DOE) that is immediately apparent to visitors familiar with both types of facilities. In addition to serving as a user facility, it has two unique and intertwined functions: it advances light source technology by training the young scientists who develop the new techniques and improved x-ray beams of the future. Both of these roles stem directly from the location of CHESS at a university, and they reflect the NSF's twin goals of innovation and education.

Student training is closely linked to innovation – our graduate students develop the new ideas from concept through implementation. As we like to say, they are in the control room and behind the shielding wall, meaning that they make the beams, and make them better. The mission of the DOE's large-scale user facilities is inconsistent with this type of access. However, it is essential to training the workforce, and innovators, of tomorrow. Moreover, it is the key to maintaining progress in the highly competitive synchrotron radiation field. In addition to receiving technological training, our students are immersed in frontier science, thereby equipping them for future leadership roles.

The importance of Cornell's synchrotron activities is demonstrated by our global impact. From the world's first synchrotron radiation beamline to CHESS/CESR today, Cornell has been a source of much of the accelerator and synchrotron radiation technology that enables modern synchrotron light source facilities. These facilities are recognized as necessary tools for much modern technology. For this reason, global capital investment in synchrotron light sources exceeds ten billion dollars, with global user communities numbering in the tens of thousands. The global competition for supremacy in the synchrotron light area is fierce because of the scientific and economic impact of this research, and as a result there is a global shortage of the requisite highly trained personnel. CHESS/CESR continues to be one of the world's major training grounds for these personnel, who develop new technology in the course of their training.

3. Steps to ensure best stewardship of taxpayer dollars and that money is spent appropriately and wisely
The CHESS/CESR cooperative agreement with the NSF details procedures to assure best stewardship practices. Required, regularly reported performance metrics for the CHESS/CESR facility operation ensure that American taxpayers continue to get high value for their investment. A list of recent NSF oversight and review of CHESS/CESR operations is included in **Box 1** and the answer to question 4.

BOX 1

- In 2010 the NSF performed a thorough Business Services review of the CHESS/CESR facility. An NSF team spent nearly a week at Cornell examining our financial, human resource, safety, accounting and other practices to assure that they were satisfactory.
- Cornell accounts are frequently subject to random audits by an independent firm chosen by the government. As one of the largest Cornell awards, CHESS/CESR is almost always chosen for audit.
- The NSF requires a detailed written annual report on the facility. The NSF also requires annual reporting of GPRA metrics of deliverables specified in the Cooperative Agreement, and projected budgets and financial reports.
- Milestones for the R&D programs set out in the original proposals and cooperative agreements ensure that they are performing at a high level.
- Matrix managed technical staff uses a commercial computer system to track and charge time to appropriate projects. The Cornell Administration units (e.g., Human Resources, Purchasing, Accounting, Office of Sponsored Programs) oversee and check financial and human resource transactions of the facility.
- The NSF performs a comprehensive annual external scientific review to assure that the facility is performing well.

BOX 2

Cornell's responsibilities, as summarized from the cooperative agreement

- Cornell assumes primary responsibility for planning, operation, safety and management of the facility, in accordance with the competing renewal proposal won for continued operation of the facility and the awarded budget.
- Maintenance, management, and operation of the facility equipment and human infrastructure.
- Operation of competitive, peer-reviewed proposal process for user access to the facility resources, and assistance to all users to help them succeed in their experiments.
- Upgrading of the facility, within budgetary constraints.
- Research and development of unique or desirable experimental capabilities, as specified in the renewal proposal.
- Continual assessment of national needs and adjustments to operations and the facility to meet these needs, and to remain at the forefront of synchrotron radiation-based research.
- Maintenance of an external advisory board, which also reviews all aspects of the facility, including the proposal process for access to the facility.
- Maintenance of a Committee of Users to advise on needs of the user community.
- Human resource development, including seeking a diversified staff, and involvement of students at all levels of the facility.
- Specific deliverables of x-ray beam time.
- Education in the broadest sense. This includes graduate student and post-doc trainees at the facility, as well as robust outreach program to the public to develop the national STEM workforce. The latter involves the public, K-12 students, and undergraduates at other institutions.

Joint Cornell/NSF roles, as summarized from the cooperative agreement

- Involvement in NSF-organized facility meetings and functions.
- Contribution to national scientific, engineering, and educational goals in synchrotron radiation research and capabilities.
- An annual site-visit review of all aspects of the facility.
- A periodic business service review.

4. Role of the Principal Investigator (PI)/Director and role of the NSF

The cooperative agreement signed between Cornell and the NSF specifies the respective roles and responsibilities of each party. Cornell has chosen me to be Principal Investigator and Director; in this role, I am responsible for ensuring that the facility meets the goals and obligations set out in the cooperative agreement. I also serve as the main interface to the NSF on this project. The work and roles in the cooperative agreement are briefly summarized in **Box 2**. These duties involve frequent communication and coordination, often several times per week, with our program officer at the NSF.

Broadly put, my role is to guide the facility, staff, and associated Cornell faculty to maximize the scientific and educational output of the facility, ensure that the facility is accessible to users, and to help users succeed in their science. I am charged with managing the facility responsibly, according to NSF and Cornell expectations. I also identify and foster the unique roles – education and innovation – of an NSF-stewarded facility. As mentioned above, the major distinction between CHESS/CESR and the synchrotron facilities in DOE laboratories is fulfillment of the NSF mission of education and training through the performance of research and development. Toward this end, Cornell expects me to facilitate involvement of the larger Cornell community to fulfill NSF and national goals.

5. Describe the life-cycle planning for the facility, including Cornell and NSF roles, and the competitive renewal process.

Each NSF-supported multi-user facility has distinct objectives. Some, like telescopes, serve well-defined disciplinary roles. Others, such as synchrotron x-ray sources, are interdisciplinary tools that provide capabilities that are otherwise unavailable, and that serve many users doing many different types of unrelated experiments. CHESS/CESR provides x-ray beams and capabilities to users from across the science and engineering disciplines, including physicists, chemists, materials scientists, biologists, biomedical scientists, environmental scientists, geological scientists, engineers, archaeologists, paleontologists, art historians, and cultural preservationists. A multidisciplinary multi-user facility reaches the end of its life cycle when it no longer serves a vibrant user community, usually because users have alternative means or places to acquire their data. In other words, users vote with their feet.

This is not the case with CHESS/CESR – as mentioned previously, the facility is greatly oversubscribed and can fulfill only about a third of the demand for its resources. In addition to the demand, CHESS/CESR serves an important national mission. As described above, CHESS/CESR is a unique national training ground for accelerator physicists and x-ray beam-line scientists. CHESS/CESR also enables the lengthy process of developing new synchrotron experiments and technologies. Furthermore, CESR – which also receives funding through the NSF's Division of Physics – is uniquely suited for accelerator physics studies and relies on the infrastructure currently provided by the CHESS/CESR facility. This combination of functions cannot be replicated elsewhere, except at great cost.

With respect to recompeting major facilities, the National Science Board stated in 2008, that "…after construction is completed and an appropriate time period is implemented to bring the facility to sustainable operations, full and open competition of the operations award will be required." The NSB was clearly referring to the free-standing facilities that comprise the great majority of the NSF major facilities portfolio. Recompetition for operations of CHESS/CESR must be considered in a different class, since the facility is physically embedded in the central Cornell campus and Cornell owns all the equipment. Instead, NSF requires an existential competitive renewal proposal every three to five years that is a much higher bar than recompeting the operation of a free standing facility. When facility operations are recompeted, the facility operators may change, but the facility and its staff remain. By contrast, if a university-owned facility such as CHESS/CESR fails to make a convincing case during a competitive renewal, the facility is terminated and the operators and the staff are dismissed. The threat of termination focuses the minds of all facility personnel on the compelling and important aspects of renewal.

During the recompetition process, reviewers are charged to evaluate uniqueness as well as the importance and quality of the proposed program. NSF reviewers have repeatedly and strongly endorsed the renewal of CHESS/CESR. Prior to signing the current cooperative agreement in 2010, the Mathematical and Physical Sciences Directorate additionally appointed a national panel of experts to evaluate whether the NSF should steward synchrotron light sources. The panel made a strong statement that the NSF has a unique role in the national framework of synchrotron sources and that it should steward light source facilities. The panel explicitly stated the national importance of the Cornell program. The NSF also performed reviews in 2010 and 2011, again charging the review panels to evaluate the uniqueness, importance, and effectiveness of the program. Both reviews strongly endorsed CHESS/CESR.

6. Describe the involvement of foreign entities, non-profit organizations, industry and other organizations with the facility.

NSF provides the primary support for CHESS/CESR. Additional support, amounting to about 10 percent of the overall costs, comes from the NIH for the MacCHESS program in structural biology. MacCHESS has been competitively renewed every three to five years since 1983, and the current award ends in mid-2013. CHESS also receives about $400,000 from a program at the NIH National Institute of General Medical Sciences to support macromolecular biology experiments.

As stipulated in the CHESS/CESR cooperative agreement, users gain access to the facility by competitive peer-reviewed proposal, without regard to their geographical location. Users wishing to obtain proprietary data must pay full cost recovery. In the last five years, CHESS has served users from 38 states, Washington D.C. and U.S. territories, as well as 24 foreign countries. We maintain a healthy reciprocity involved with foreign CHESS users – most of who are engaged in scientific collaborations with U.S. users, and many U.S. users utilize facilities in the foreign countries. In addition, users from 31 industrial organizations also used the facilities.

CHESS/CESR scientists are routinely involved in collaborations and exchanges, and serve as technical advisors for many counties, including Canada, Denmark, Japan, Taiwan, China, the United Kingdom, Saudi Arabia, Germany, and France. CHESS staff members routinely serve as technical advisors for almost all the DOE national synchrotron light, nuclear, and high-energy physics accelerator laboratories, as well as at many comparable international facilities.

Our scientists frequently collaborate with other national entities. Currently, we are working with the Air Force Laboratory at Wright Patterson Air Force base to build a special high-energy x-ray capability at Cornell to study the failure of aircraft alloys and materials. CHESS staff members played a leading role in designing the x-ray detectors operating at the x-ray free-electron laser in DOE's SLAC Accelerator Laboratory in California. CHESS/CESR staff members invented and developed the new helical undulator currently being installed on the Linac Coherent Light Source at SLAC. CHESS staff members are collaborating with DOE's Advanced Photon Source to test novel pixel-array detectors on their beamlines.

In addition to serving industrial users, CHESS/CESR staff members have been involved in sourcing technology to a number of independent companies. Many of the world's recent synchrotron light sources are powered by superconducting RF cavities developed for CESR and outsourced to industry. They are all tested at Cornell before being shipped to the end-user. A very large fraction of the world's protein structural data has been acquired on detectors sold by Area Detector Systems Corporation (ADSC) in Poway, California. This technology was first demonstrated at CHESS and transferred to ADSC. Advanced Design Consulting in Lansing, New York is major supplier of instrumentation to accelerators and synchrotron light sources. The company, started by a former CHESS employee, routinely uses CHESS as a test bed for new products developed by the company.

7. Describe major accomplishments of the facility?

CHESS and CESR have played key roles in the development of high-energy physics, particle accelerators, and x-ray sciences. At the same time, many of the hundreds of students and early career scientists who trained at CHESS and CESR have gone on to build and operate major research facilities around the world. Although CHESS and CESR have had profound impacts in many areas of sciences, due to the limited space available, we will mention only a few highlights in x-ray, particle, and accelerator sciences.

Many of the pioneering x-ray experiments done at CHESS opened up new areas of research and motivated and justified the development of third generation light sources. Examples include the discovery of resonant magnetic x-ray scattering by Dennis McWhan and Doon Gibbs, both of Brookhaven National Lab, scattering too weak to be seen by other means, and the first nanosecond time-resolved x-ray scattering and laser melting experiment by Ben Larson of the Oak Ridge National Lab and his coworkers.

Michael Rossmann of Purdue University, used CHESS to collect protein crystallography data while solving the structure of the human rhinovirus, the first large-scale macromolecular structure determination that proved to skeptical biologists that synchrotron facilities had revolutionary capabilities to solve their problems. That seminal work helped usher in the field of synchrotron structural biology, driving the burgeoning need in the 1990s that justified building new light source capabilities around the country. Our users have won many prizes. Fore example, the work by Ada Yonath of the Weitzmann Institute in Israel on ribosomes and the work by Rod MacKinnon of Rockefeller University on the potassium channel were both awarded Nobel Prizes in Chemistry within the last decade.

The work described above would not have been possible without a long string of developments in x-ray optics and technology. Major breakthroughs include the invention or discovery of:

- The idea for cryogenically cooled x-ray optics, which make brilliant third generation undulator beamlines possible;
- X-ray standing-wave techniques that find impurities in crystals, on atomically clean surfaces, and in thin films;
- Diamond-anvil specimen cell methods that let scientists study materials at high-pressure and high-temperatures;
- Tapered glass-capillary optics that focus x-ray beams to micron-scale;
- Nanofabricated confocal optics that create x-ray fluorescence analyzers with micron-scale depth resolution;
- High-pressure cryofreezing apparatus techniques that freeze small crystals without using cryoprotectants; and
- CCD and pixel-array area detectors, which have transformed x-ray data collection strategies.

In addition, CESR was the test bed for the prototype of the undulator used at the Advanced Photon Source at the Argonne National Laboratory. Building on this work, scientists have recently invented a new type of very inexpensive permanent magnet undulator that will power helically polarized x-ray beams at the x-ray free electron laser at the SLAC Accelerator Lab in Stanford, California.

Inventions and firsts in accelerator technologies at Cornell go back to the first characterization of the synchrotron-radiation spectrum. CESR is the first storage ring and collider exclusively powered by Superconducting Radio-Frequency (SRF) cavities. It was the test bed for the superconducting cavities that are the basis of the Thomas Jefferson National Accelerator Facility in Newport News, VA. It owns the record for the lowest vertical emittance in a positron storage ring and was the first storage ring to use superconducting wigglers to dominate emittance control and radiation damping. Cornell was the first organization to commercialize an SRF cryomodule by technology transfer to industry.

The technical accomplishments enabled a string of firsts in high-energy particle physics, including discoveries of B-meson decay channels; the discovery of the Ds, Y(1D), and 11 charmed baryons; the first observation of $J/\psi \rightarrow \gamma\gamma\gamma$ decays; and absolute measurements of D branching fractions.

Work at Cornell also led to the idea of energy recovery using superconducting RF cavities. This idea that has spawned a world-leading, decade-long research and development effort to design and prototype a high-energy Energy Recovery Linac (ERL) coherent x-ray source. This is a next generation light source, and a significant leap forward from current technology. Major accomplishments of the ERL research and development program include a laser-driven DC photocathode electron source with world record currents, and a prototype injector that can produce sufficiently small emittances to meet ERL design requirements.

8. What obstacles and challenges does the facility face?

Despite highly successful service to the nation, university-based interdisciplinary facilities face a daunting structural challenge because NSF's discipline-based organizational structure does not lend itself easily to support of truly interdisciplinary facilities. This challenge has national policy implications and would benefit from the attention of the Congress.

As the Subcommittee knows, the NSF is organized into Directorates such as the Directorate for Mathematical and Physical Sciences (MPS) and the Directorate for Biological Sciences (BIO). Each Directorate, in turn, consists of several Divisions. MPS, for example, includes divisions devoted to physics, chemistry, materials research, astronomy, and mathematics. NSF's major facilities are usually stewarded by a single division, which works well for facilities with users primarily from a single discipline. Thus, the astronomy division is a natural steward for telescopes.

The disciplinary model, however, is not well suited for facilities that serve broad interdisciplinary communities. **Figure 1** shows the NSF directorates that fund the principal investigators on CHESS proposals (see caption for details). As the figure illustrates, no single Directorate, much less a Division within a Directorate represents a majority. This should be the definition of a broadly successful interdisciplinary research facility. Moreover, many of the complex problems studied at CHESS do not divide neatly along simple disciplinary lines, which is one reason why so many "firsts" have resulted from work at the facility.

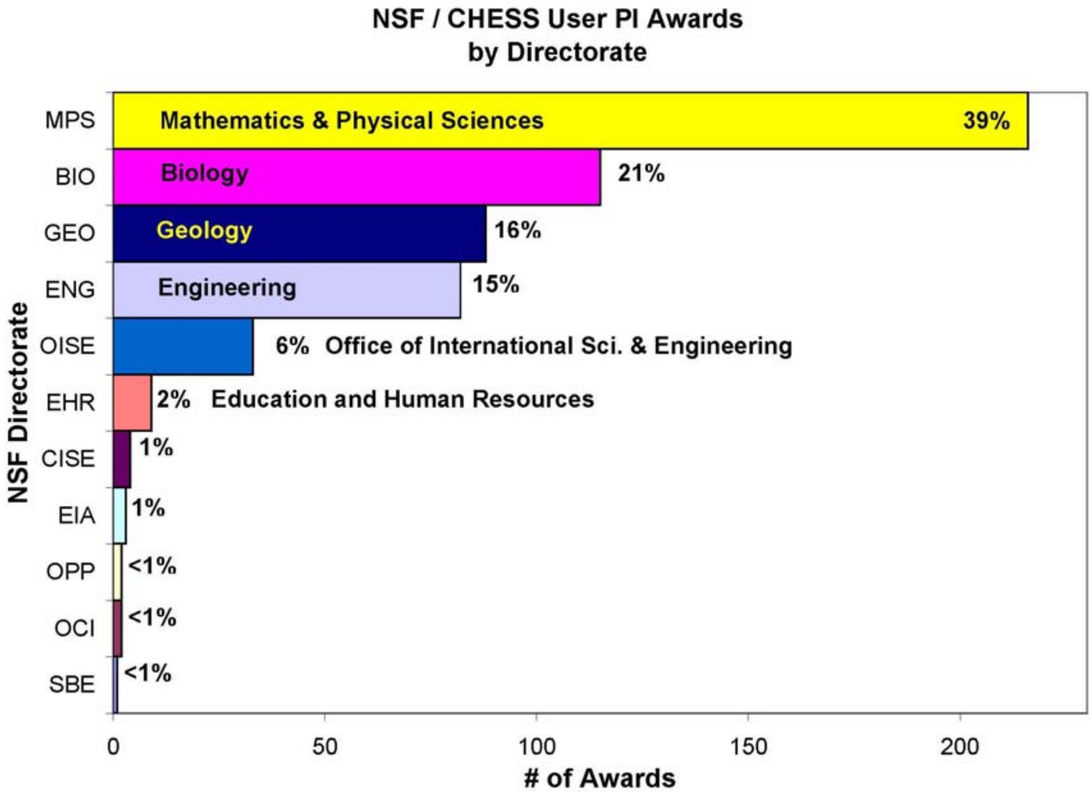

Figure 1. Distribution of NSF grants, by awarding Directorate, to principal investigators (PIs) who had active CHESS beam time proposals during 2003-2007. Many PIs of CHESS proposals are funded by other agencies and not the NSF, and are not represented here. If they were included the interdisciplinary spread would be even larger.

An excellent example is the work of Rod MacKinnon of Rockefeller University, who won the 2003 Nobel Prize in chemistry for research done primarily at CHESS. He determined the atomic structure of potassium ion channels, a class of proteins that are the essential engines that generate nerve impulses. Researchers had been trying to solve this problem for nearly a half century. Professor MacKinnon's research used a machine – CESR – built to do high-energy physics and a facility – CHESS – motivated by materials research. The critical data were taken using a novel detector, which we built utilizing techniques from astronomy and engineering. These data solved a seminal biological and biomedical problem that won a Nobel Prize in chemistry. What, then, is the relevant discipline: Physics? Materials? Astronomy? Engineering? Biology? Chemistry? A non-NSF focus, such as biomedicine? The answer, of course, is all of the above.

NSF's Divisions are under great pressure from their constituencies to use their resources to support their own discipline's grantees. The NSF is aware of this and recently launched the Integrated NSF Support Promoting Interdisciplinary Research and

Education (INSPIRE) program in an attempt to address the issue. The INSPIRE program, however, is aimed at research and education grants rather than facilities. Divisions know that supporting a major facility requires a large, long-term obligation, and are reluctant to provide support unless the science is "owned" by their discipline. Referring back to Figure 1, each NSF division notes that it is a minority player and concludes that the funding burden should lie elsewhere. The unintended result is that the discipline-based divisions are reluctant to support interdisciplinary facilities, even though their investigators rely on these facilities to do their work.

The NSF's discipline-based organizational structure also has consequences on the allocations between different types of awards in a division's portfolio. The Divisions are always under pressure to increase the number of awards they make. By definition, major facilities have large budget lines and are tempting targets for Division Directors seeking additional funding to increase the total number of awards they make. Unlike smaller awards, major facilities require initial investments of hundreds of millions of dollars and take many years to go from conception to full operation. The rate-limiting step is the time required to develop the highly trained and specialized human infrastructure to operate a facility. With even a short break in support, this human infrastructure disperses when the highly skilled staff – who are in great demand around the world – find other jobs. Such a team cannot be easily or quickly reassembled. Thus, major facility funding decisions must be considered in a long-term context, a task made especially difficult by the NSF's rotator system where the directors of divisions and directorates change every few years.

NSF has guidelines for the appropriate distribution of funds in divisional funding portfolios. Ten years ago, the National Science Board released a study (NSB 02-190) that considered the balance between the NSF investment in tools and facilities and other types of awards. The NSB found that 22 percent of portfolio going towards tools and facilities – the amount at the time of the study – was too low and advised increasing the level to 27 percent.

The NSF has not made much progress towards the NSB's recommendations, however, on the funding of facilities. As an example, the Division of Materials Research, which is one of the NSF's largest, devoted less than 20 percent of its base budget to tools and facilities in FY 2011. This is of special concern, because DMR's facility portfolio consisted primarily of major university-based interdisciplinary facilities. These included the Synchrotron Radiation Center, a low-energy x-ray facility at the University of Wisconsin for which funding was recently dropped; CHESS/CESR at Cornell; and the National High Field Magnet Lab in Tallahassee, Florida. DMR also provides support for smaller-scale facilities at universities, such as the National Nanotechnology Infrastructure Network. As noted above, the NSF's current discipline-based structure makes it more likely that multi-disciplinary university-based facilities will be the first casualties of a declining budget. Without some explicit direction from Congress, the nation is at risk of losing some of the key tools of innovation in the NSF's budget stovepipes.

In conclusion, I am most concerned for the future of NSF-supported interdisciplinary facilities at universities. As the Subcommittee knows, education is one of the most important parts of the NSF mission. As exemplified by CHESS/CESR, universities are ideally suited to incorporate student training into facility operation. At Cornell, we are quick to point out that CHESS/CESR is a proven incubator to develop the leaders of the future needed to sustain national synchrotron and accelerator, as well as other types of science. Moreover, universities deploy faculty and other resources to enhance the performance of the facility at no cost to the NSF. For decades, the NSF has stewarded facilities at universities that serve the nation by fostering innovation and educating young scientists. The NSF must decide how to reshape itself to support the multidisciplinary facilities of the future. Otherwise, it will remain static and lose those facilities, along with untold opportunity, innovation, and discovery. For the sake of the country's technical and economic strength and leadership, I urge you to make certain that the NSF chooses the path of adaptation and innovation.

Mr. Chairman, this concludes my written statement. Again, I thank you for the opportunity to testify at this important hearing. I would be pleased to answer any questions you or members of the Subcommittee may have.