Report of the Ad-Hoc Subcommittee on Funding and Governance of Future Major Multi-user Facilities

of the

National Science Foundation's Business and Operations Advisory Committee

Submitted to
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Contents

<u>Executive Summary</u>

The National Science Foundation's Ad-Hoc Subcommittee on *Funding and Governance of Future Major Multi-user Facilities* (FGFMMF) of the NSF Advisory Committee for Business and Operations met at NSF on October 20 - 22, 2010. At NSF's suggestion, and benefitting from NSF's meeting organization and suggested Agenda, the meeting was open to participants from the scientific research and research management communities plus other interested parties and had as its purpose to solicit and discuss input from these communities on the participation of NSF in large international scientific projects, especially those in which there is no dominant partner. A number of non-NSF representatives from other U.S. government science agencies and non-U.S. science ministries also attended and contributed to the discussions. The discussions were held at NSF in a town meeting format, structured only by a chosen sequence of discussion topics planned to best capture the views of the participants on the Charge topics. Afterwards, the Subcommittee, NSF and many participants expressed the view that it had largely achieved this purpose. The Agenda in Appendix B records the discussion topics addressed during the meeting.

Following the large meeting, the Subcommittee created the written report submitted here to capture their observations, commentary and recommendations. Formal submission of this report will be to the parent B&O Advisory Committee who will receive the report and decide whether or not to endorse and forward it to NSF management. The meeting was attended in person by 30 outside participants, plus many NSF staff members, as well as the Subcommittee itself. The Subcommittee received written input from 35 commentators. The Subcommittee was asked in the written Charge to advise NSF on two specific questions related to the FGFMMF process. These questions are contained in the full *Charge to the Subcommittee* included in this report as Appendix A and re-quoted in the next section of this report. A membership listing of the NSF-appointed Subcommittee, plus NSF officers that comprise the NSF Organizing Committee, is attached as Appendix C.

Deliberations of the Subcommittee on the discussions in the participants meeting and the written submissions, as well as subsequent interactions among the Subcommittee members, led to preparation of this report. The report includes specific and detailed responses to each of the two charge questions, organized by related topics in the main report text. A set of key conclusions and recommendations to NSF management follows the topical analysis sections. The Subcommittee recommendations are restated in this Executive Summary for convenience of the reader. For readers not familiar with the issues giving rise to these recommendations, it is important to read the full report text for issue context, background and historical lessons-learned. There are many specific issues and circumstances that contribute to the main Charge questions and all those discussed in the report text contributed to the conclusions we report. Many of our recommendations address current NSF policies but this is a necessary path for reaching the advocated changes.

By way of an overall summary of the Subcommittee's response to the Charge, we note that it became clear during our deliberations that no single 'optimal' approach to participation of U.S. scientists in large international projects is identifiable among the many cultures in the various research fields and among the national cultures of the partners assembled for large construction enterprises carried out by multiple sponsors. "One size does not fit all." We note, however, that we were able to identify some proven principles and specific actions that NSF could adopt to improve on practices now being followed that are *not* optimal for the successful evolution of future projects. Overall, the projects now underway are mostly proceeding successfully and the project managers have been steadily improving protocols and practices to eliminate project problems.

Likewise, NSF is continually improving its stewardship of MREFC projects and is supporting many best practices as it carries out projects already underway. But there is still room for improvement.

In this regard, the result of the Subcommittee's actions during and following the meeting with participants has been to identify some lessons-learned from successful NSF and other projects, as well as to note some counterproductive practices that can be improved upon by NSF going forward. We provide some recommendations here that we hope will help NSF in an effort to improve. Elaboration of the reasoning behind the recommendations given here is provided in the main text of the report and the Subcommittee's summary comments are stated along with our recommendations in the Key Comments and Recommendations section of this report.

Recommendations of the Subcommittee:

Recommendation 1: The Subcommittee recommends that the National Science Board, as the highest governance body of the NSF, be made an integral part of the NSF process for prioritizing, selecting and supporting large facility projects in the NSF portfolio, both domestic and international.

Recommendation 2: The Subcommittee recommends that NSF develop a cross-agency funding source, similar to the MREFC concept, to cover the very significant costs encountered in carrying out the Preliminary and Final Design phases of a contemplated MREFC class large facility project.

Recommendation 3: The Subcommittee recommends that NSF evolve towards a project planning system in which decommissioning and closing costs for large facilities, in which NSF is an operations partner, are considered along with project planning steps that NSF already considers for the construction and operations phases of such facilities

Recommendation 4: The Subcommittee recommends that NSF publicly release a qualified *Statement of Intent* to support the scientific goals, the anticipated project partnership and the technical development of large new international science projects after successful completion of the Conceptual Design, in order to facilitate the formation of the partnership, and provided the agency plans to continue with the next step leading to construction.

Recommendation 5: The Subcommittee recommends that early contact with government officials responsible for science policy, project priority and project funding, both domestic and international, be established by science agency program managers and project proponents as soon as a contemplated new facility project successfully passes the Conceptual Design review stage.

Recommendation 6: The Subcommittee recommends that NSF and other US agencies, in concert with international consortia as the need may arise, are urged to consider the sponsorship and funding of large, multi-disciplinary science campaigns over long periods of time. Such cross-discipline projects would be comparable to traditional MREFC projects in single fields of science.

The Subcommittee concurs unanimously in the contents of this report.

Subcommittee Charge

The FGFMMF Subcommittee was presented by NSF with a Charge document that contained two specific questions that the agency wished the Subcommittee to address. These questions comprise:

1) Are current NSF funding mechanisms - and the sequence of agency-specific approval activities for planning, construction, and operation - optimal for facilitating the participation of US scientists in large-scale international projects in which there is no single dominant entity?

    a. This should be considered within the context of identified future projects that may, or may not be built, and that would likely involve both other federal agencies, international partners, and perhaps private foundations, and NSF's need to preserve a vibrant base program of funding to individual researchers.

    b. For example, does the separate R&RA funding for planning, and prioritization for funding, hamper partnerships or create a disadvantage for US researchers or hamper the ability to establish, synchronize, and maintain funding partnerships during the early design and development phase? If so, what alternatives might be recommended?

2) What are lessons learned from governance of other large-scale international initiatives that should inform NSF in negotiating the business framework for future activities?

    a. The framework should protect NSF's interests, including its ability to oversee NSF-funded activity and take remedial action when necessary, while being equitable to other partners, and provide the greatest return to US science based on NSF investment.

    b. Citing examples from prior undertakings, what recommendations can the subcommittee offer, recognizing that international partners on a particular project may have much different processes for funding projects and dealing with cost over-runs, schedule delays, and so forth? (The subcommittee should account for NSF's unique policy of funding an awardee institution that is responsible for accomplishing the project - this may not correspond identically to the roles and responsibilities of prospective partners.)

The full Charge document supplied to the Subcommittee is attached as Appendix A.

Introduction

The trend of construction and operation of 'big science' facilities and enterprises in many scientific disciplines continues to emerge as an important enabling path for achieving transformational progress in their related research areas. This trend to larger and larger projects is, if anything, speeding up at the present time. By the term 'big science' we roughly mean single projects in a $100M and up cost of construction and with typical annual operating costs exceeding $10M. Historically, the two earliest scientific communities that have repeatedly initiated new projects in the big science category were: optical and radio telescopes; large accelerator facilities for the study of particle and nuclear physics. These two science communities, however, have pursued significantly different means of achieving sponsorship of the facilities that have been built and operated.

The optical telescope observing community has often solicited private donors who sponsored the construction of proposed new instruments and then financially supported telescope operations for astronomy. The sponsors also controlled the observing time allocated to astronomers using their facility, typically employing scientific advisory committees of respected scientific peers. Radio telescopes and large accelerator facilities constructed and operated for high energy and nuclear physics have usually been sponsored by governmental sources. Operations costs for radio telescopes have also been provided by government sources. For particle and nuclear facilities, the government sponsors also funded the experimental beam time plus other operating costs of research equipment and detectors such as electrical power, experiment-setup, rigging and surveying for approved scientific users. The particle beam users were typically selected by the facility management, advised by an outside program committee of expert peer scientists. These two models for operating big science facilities have been successful for more than 60 years and are still the most common modes of financial support in the two fields. The research facilities were, up to recent times, usually constructed and operated by a single country in the case of accelerators and radio telescopes and by relatively small private consortia in the case of optical telescopes.

In recent years, there have been developments in the advance of many additional fields of scientific investigation that are resulting in the contemplation and launch of big science facilities for a more widely diverse scientific community. In the case of *big optical telescopes*, these developments have challenged the capability of private donors to fund the next round of the largest instruments. In the case of the largest contemplated *accelerator facilities and radio telescope arrays*, their cost and scale has challenged the ability of single national governments to fund them. In other fields of science, the newly contemplated large facilities are already reaching the cost and complexity scale of the older big-science disciplines just noted. Examples of scientific fields in which NSF is actively contemplating big new facilities comprise biology, advanced computing, ecology, earth science, ocean science and others. To meet the emerging instrumentation needs of these science communities, governments are vigorously exploring multi-national consortia that can assemble the needed resources that any one government could not manage. Telescope project proponents are now actively seeking government partnership along with the private donor sponsors. In the case of NSF, this evolution of scale has confronted the agency with the additional issue of making large financial investments while still remaining a minority partner in the resulting facility. NSF has also encountered related difficulties in facing the issues of funding operations costs and carrying out the agency's governance and stewardship obligations.

Before moving on to a discussion of the forces and policy directions currently in play (the work of this Subcommittee being one aspect of this activity), we first note here that the identified issues are not without precedent, and in fact, have already been encountered in a number of cases, especially in the *largest accelerator facilities*. In several of these cases, viable solutions have been found to build and operate the needed facilities. Perhaps, the best known and most successful example is establishment of the Organisation Européenne pour la Recherche Nucléaire (CERN) in Geneva, Switzerland. This major, multi-program accelerator facility, first proposed in 1952 and formally initiated in 1954, is operated by a consortium of more than 20 national governments that contribute funding for the ongoing management of the laboratory and for the construction of new facilities from time to time as the scientific case for them evolves and is accepted by the CERN Council. Of course, as the laboratory has evolved, some of the older accelerators have been retired and decommissioned allowing new ones to be initiated.

Just last year, the Large Hadron Collider (LHC) at CERN began taking data for science. This project involved international cooperation and collaboration, not only by the multi-nation CERN membership, but by dozens of nations that collaborated to build the four giant instruments that detect the particle and heavy-ion collisions and translate the recorded data into scientific discoveries. NSF is a significant sponsor of these detector collaborations, but by no means a dominant one, hence its interest in the Subcommittee's responses to the two Charge questions. While the detector collaborations are a clear success story in international partnership, the inclusion of more expertise outside of CERN in the design and construction of the LHC itself could well have avoided some of the costly technical problems and delays experienced with the machine. The LHC, however, is now on its way to carrying out its mission to advance the study of particle and nuclear physics into energy and intensity regimes never before accessible. There is every prospect that this program will be as great a scientific success as envisioned at its instigation and, as has often been the case in particle and nuclear physics, uncover totally new and unexpected aspects of matter at its most elementary scale.

In addition to its accelerator mission, CERN has evolved other powerful in-house scientific communities and activities that do not use accelerators directly in their research. A foremost example is the theoretical particle physics community that embodies a very strong group at CERN. Another striking example is the great strength of the scientific computing enterprise at CERN and its contribution of many advances to large scale computing. In this area, perhaps the most famous example is the World Wide Web (WWW) that is now ubiquitous all over the world. The Web was invented by CERN scientist Tim Berners-Lee and its evolution made possible the continuing explosion of Internet activity. NSF has contributed support to some of these non-accelerator research programs as well.

A very inspiring example of a *large telescope* that was built and operated by an international government partnership (NASA, the European Space Agency plus seven industrial, non-profit and university partners) is the Hubble Space Telescope in near earth orbit. The NASA project was initiated by the petition of an ad-hoc committee of the U.S. National Academy of Science presented in a 1969 paper that advocated the scientific benefits and technical feasibility of a space-based telescope. The project was formally adopted as a project by NASA in 1971. As such, it was well beyond the cost scale that would be reachable by private funding. The telescope was launched into orbit in 1990 and celebrated its 20^{th} anniversary of scientific observations in 2010. The Hubble story is made even more fascinating by the fact that, following its launch and initial observations, it was discovered that the main mirror incorporated a mirror grinding fault that seriously compromised its optical performance. An extraordinary repair mission was completed in December 1993 that restored the full optical resolution of Hubble by installing a new correction mirror in the optical path that removed the distortion induced by the main mirror. Since then, Hubble has revolutionized important areas of astronomy and cosmology, producing a giant leap in our knowledge of how the universe began, evolved and will likely end. A truly remarkable story of science instrumentation built and operated at the largest scale of funding by international collaboration and a variety of partners.

There are other examples of successes in the creation and operation of scientific facilities on the scale of interest to the present investigation and Subcommittee report to the NSF. However, there are also painful failures that have transpired as well as difficult, project-threatening hurdles confronted in other facilities projects undertaken on the largest scales of size and cost that obtain in fundamental science research. It is clear that success in projects at these largest cost scales has certainly been achieved but is hardly assured.

Perhaps, the most dramatic and painful example of a very large and unsuccessful project in basic science research was the failure of the Superconducting Super Collider (SSC) project attempted by the U.S. Department of Energy (DOE) in the 1990s. The SSC was conceived by DOE as a scientifically superior, U.S. sponsored competitor to CERN's LHC project, a project already planned and moving to construction. The SSC was to be a purely national U.S. accelerator-collider project. In the case of the SSC, an 11 year process transpired from first conception of the accelerator-collider, through start of construction and on to ignominious cancellation by the U.S. Congress. The SSC project evolution led from a key scientific and facility planning workshop held in summer 1982 through the project cancellation vote by Congress in October 1993. Literally thousands of scientists suffered decade-long interruptions of their science careers during their most scientifically productive years. The U.S. spent an estimated two billion dollars on the project over this time and had nothing to show for its investment. Also, over the course of the project comprising conceptual design through termination, the construction cost estimate had grown from just over $2 billion in the first preliminary estimate to a pending, unofficial cost estimate over $13 billion. No one wants to repeat the mistakes made in the SSC program.

Project Mohole (1958-1966) was another example of a big science failure. In this case, the failure was attributed to the inability of its management to cope with the engineering complexity of the task. A consortium of scientists with backing from several oil companies proposed and initiated a project to drill through the "Mohorovicic discontinuity" (the boundary between the earth's crust and mantle) at a point in the ocean where the earth's crust was relatively thin. The program was subsequently supported by the NSF. It was finally cancelled after its estimated 'then year' cost to complete had increased from approximately $20M to over $130M and the schedule stretched from 5 to over 8 years. Lessons learned from Project Mohole led to the adoption by NSF of a phased development approach for large projects involving new or exploratory concepts (Charam, P., Fee, F.X., "GAO review of Project Mohole", GAO Review, Summer 1968.)

Given this quick, selective snapshot of the record on some of the biggest science facility projects recently undertaken around the world, it is clear that there are valuable lessons to be learned both in what to do and what *not* to do in organizing the international planning, construction and operation of scientific facilities at the largest cost scales. For NSF and the purposes of this Subcommittee study, the simple answer is likely to be "no" to the first Subcommittee Charge question, "*Are current NSF funding mechanisms - and the sequence of agency-specific approval activities for planning, construction, and operation - **optimal** for facilitating the participation of US scientists in large-scale international projects in which there is no single dominant entity?*" In fact, given the significant diversity among successful management models for facility conception, construction and operation, as well as the occasional failure of seemingly similar management models for these same roles, it may not be meaningful to identify *any* single approach as "optimal". Given the diverse scientific-culture histories of the NSF communities that are contemplating large international facilities, and the diversity of national government cultures that confront prospective international collaborating entities, the attempt to identify a "one size fits all" management approach may be unworkable. Instead, this Subcommittee has tried to identify *elements* of successful approaches for planning, construction and operation to take instruction from, as well as to identify lessons-learned from past problem areas in the largest projects.

Topics of Discussion by the Subcommittee in the Meeting with Participants

In this section, the report will identify and discuss the topics that were addressed during the two-day meeting with scientist researcher and science research administrator participants at NSF. The purpose of the meeting was to bring out the views of the scientific community involved with large multi-user facilities as they relate to the operational and governance issues that are germane to the Subcommittee Charge from NSF. The written discussion below is intended to identify important observations that appeared during the topical discussions, capture the insight that emerged during the Subcommittee's discussion, and present the Subcommittee's conclusions and recommendations that pertain to each topic considered. Our topical conclusions and recommendations are noted at the end of each topical or sub-topical discussion in the sections below. The Subcommittee's conclusions and recommendations that relate to the two NSF Charge questions are collected together in the key conclusions and recommendations section of this report.

In addition, we also note here, an observation by the Subcommittee that relates to the overall relationship of the Charge Question 1 ("*Are current NSF funding mechanisms - and the sequence of agency-specific approval activities for planning, construction, and operation - optimal for facilitating the participation of US scientists in large-scale international projects in which there is no single dominant entity*?") to the specific topical aspects discussed in detail in the following sections. We concluded after hearing from the meeting participants that there is no *uniquely optimal strategy* for facilitating the participation of U.S. scientists in the agency funding and approval activities employed for planning, construction and operation of large-scale international projects in which there is no single dominant entity. However, there are valuable principles and lessons-learned from earlier and ongoing projects, both successful and unsuccessful, that can provide valuable guidance for proceeding with future projects in this category. We try to identify these principles and lessons-learned in the topical sections below.

Topic 1. - Selection and Prioritization of Projects

Project Selection and prioritization

The processes of identifying, selecting, designing, developing, constructing, managing and sharing large facility infrastructures are complex and costly. The efficient and timely realization of all these processes is vital, not only in enabling a path for achieving transformational science, but also because the trend towards larger and larger projects is increasing over time. This topic of project selection and prioritization is closely interwoven with both of the NSF Charge questions and addresses both agency process and lessons learned aspects of them. A recommendation related to the role of the Science Board is offered. While there may be no single optimal strategy for agency prioritization and selection of large-facilities for funding, there are valuable lessons-learned in earlier projects, including issues associated with strategic planning within the agency, roadmap development to prioritize within and across-discipline projects, optimizing the timing of agency/partnership involvement, and the strategic use of pre-construction funding for the Conceptual Design (CD) and Preliminary Design (PD) phases that are critical elements to position a project for NSF prioritization and selection for construction.

The challenge of selecting and prioritizing large facilities to address scientific questions requires a strategic and balanced plan involving both top down and bottom-up approaches. NSF reacts to opportunities advocated by the research community. Priorities are generally set at the Directorate level within NSF but, as with all NSF endeavors, inquiry begins within the research community, after which the results are brought to the attention of the NSF directorate, divisional staff and program officers. Presently, NSF also utilizes Academies studies, community workshops, advisory committees and other methods to ensure a broad range of community input across disciplines.

Nurturing and maturation of a facility concept can take years to develop. In the early part of a project life-cycle, the "Horizon Stage", ideas and opportunities are identified by research communities with an eye toward a 10-20 year forward time-frame. The "Concept Stage" follows and starts when a candidate project is proposed for support for development. The output of this stage is a Conceptual Design Report (CDR) that characterizes the project's scientific value, scope, technology and other needed information at this early stage of development. The CDR is reviewed by an NSF-appointed committee of experts and this review must be successfully passed before the next stage of Preliminary Design (PD) can be initiated. Concept Projects then mature into more formal development projects with very significantly increased requirements for NSF funding support.

Prior to being presented to the Science Board, a new MREFC project must carry out the Preliminary Design and produce a PD Report. The PD Report receives an NSF sponsored review by a panel of experts that examine the technologies, cost and schedule estimates and the scope of the project at this stage. To proceed to Science Board review, the project must pass the PD review. This is the first point at which reliable cost and schedule estimates are available for an MREFC project. Final selection and prioritization by the NSB is linked to Congressional priorities and appropriation requests.

On at least an annual basis, the NSF Facility Plan identifies a small group of projects in advanced stages of development that the NSF's MREFC panel believes is ready to go to the National Science Board for approval. The Facility Plan presents the NSF's view. The NSB performs its own portfolio review, including assessment and prioritization among the projects presented by NSF.

Implicit in this process, but critical for its success at the MREFC level of project scope, is the evolving role of the Science Board in assessing and judging the international aspects of the contemplated new project, both its scientific role in the world outlook for evolution of the relevant area(s) of science and for the needed level of partner sponsorship to provide sufficient funding for construction and operation of the new facility. The new project should represent the potential for transformational science and be unique or highly competitive at the world level in the scientific areas it will address.

Subcommittee members and meeting participants heard from the NSF Deputy Director, Dr. Cora Marrett, about present policies regarding National Science Board's consideration of new facilities that are contemplated by NSF to advance agency-sponsored science programs. While support of unique, world class and transformational science facilities is one of NSF's core activities as expressed in the NSF Strategic Plan, it appeared to the Subcommittee that planning, selecting and operating the complete MREFC program over time suffers from a lack strategic oversight at the National Science Board level. NSF research priorities are established within the directorates. As Greg Boebinger, Director of the National High Magnetic Field Laboratory (MagLab), pointed out *"This can result in a 'stove-piping' problem in funding a broadly multidisciplinary facility"*. This "directorate-based" priority approach is also less than optimal in that it does not explicitly budget for the life-cycle costs of high-profile MREFC projects, ultimately resulting in undue pressure on budgets of other programs, especially at the division level.

Furthermore, while the process of prioritizing and progressing large facility projects through the construction phase assumes strong community input via the development of roadmaps, decadal surveys, etc., there appears to be a missing step between community input and how NSF addresses this input. William Smith, Association of Universities for Research and Astronomy observed, "*The present NSF Large Facilities Plan is mostly a tactical one. It describes in a rhetorical sense the possible projects on the horizon, but is aimed at making decisions only on an immediate one year basis in preparation for the next appropriations cycle. The budget projection for MREFC contains only the run-out funding curves for the existing projects……… NSF has now reached the point that large facilities are essential to the carrying out of the NSF mission. These are not just "fixed costs"…….they are becoming a core function of the NSF.*

As such, the NSF should develop a true strategic plan for large facilities. This plan should be accompanied by a budget projection that is submitted to the OMB and would include a more defined set of future projects and their timing. …..It is well recognized that a long range strategic plan does not constitute a commitment by the Congress or even the NSB, but it gives far more certainty to the community in planning for future large facilities.

The Subcommittee concluded from the discussion of these issues, that an early strategic involvement by the National Science Board in considering the agency's approach to selecting, prioritizing and time-phasing the entire NSF program of new large facilities is desirable and should be pursued by the NSF director with the Science Board.

<u>Comment 1:</u> Maintaining a balanced disciplinary portfolio of large facilities projects, limiting the number of approved projects to maintain that long-term balance, and phasing out lower priority or dated facilities and programs are essential aspects of the agency's long-term strategic plan. The Subcommittee believes that NSF can strengthen its ability to meet these goals by directly including the Science Board in the process of choosing and sequencing the approved list of large facility projects participated in by NSF. The Science Board can also help assure that effective planning for budgetary support of the NSF share of the operating costs for these future facilities has been carried out. Our understanding is that, under present policies, new facilities for the advancement of NSF sponsored science programs are considered by the Science Board on a case by case basis and are not considered in the context of the overall NSF scientific program. Because the Science Board is the highest governance entity in NSF, the Subcommittee strongly supports the principle of its involvement in setting the overall agency strategy for the approval and time sequencing of new facilities of the scale and type considered in this report. We were informed by NSF that it is the intention of the NSB to conduct a portfolio review, assessing and prioritizing future facility project proposals within the context of the overall NSF scientific program.

<u>Recommendation 1:</u> The Subcommittee recommends that the National Science Board, as the highest governance body of the NSF, be made an integral part of the NSF process for prioritizing, selecting and supporting large facility projects in the NSF portfolio, both domestic and international.

<u>Road Mapping and Long Term Planning</u>

On the larger scale of long-term strategic planning, roadmap development by many national agencies besides NSF has become a standard part of the process for prioritizing and funding of national research facilities. These roadmaps have become a highly useful tool for scientists and government officials as they are able to incorporate both scientific and non-scientific considerations, including areas such as education, workforce issues, national security and economic development.

Discipline-based roadmaps include the U.S. National Research Council's Decadal Surveys of Astronomy and Astrophysics, Scientific Ocean Drilling's Science Plan 2013-2023, the High Energy Physics Advisory Panel (HEPAP) Strategic Plan for the Next Ten Years, the Strategy for Particle Physics by the CERN Council, strategic plans for nuclear physics by DOE's Nuclear Science Advisory Committee (NSAC) and for the basic energy sciences by DOE's Basic Energy Sciences Advisory Committee (BESAC), as well as European roadmaps for nuclear physics by NUPECC, astronomy by ASTRONET and astroparticle physics by ASPERA. These roadmaps, and others like them, help mobilize scientific communities and identify broad-based integrated plans within particular disciplines for planning timescales of 10-20 years. For example, the Sixth Decadal Survey of Astronomy and Astrophysics proposes a broad-based, integrated plan for both space-based and ground-based astronomy and astrophysics for the decade 2012-2021; it also lays the foundation for advances in the decade 2022-2031. Similarly, the HEPAP report makes the overall recommendation that the US maintain a strong, integrated research program at the Energy, Intensity and Cosmic frontiers and then provides specific prioritizations within each frontier area.

Beyond the U.S. roadmapping efforts just noted, there are some significant issues that involve international ramifications of large project planning and roadmapping. While prioritization panels such as the Decadal Survey and PASAG include members from outside the US, their findings and recommendations do not formally recognize the findings of counterpart panels in Europe and elsewhere. Better international coordination of planning and roadmapping exercises would benefit global science initiatives and could contribute more effectively to global use of funding resources.

Stefan Michalowski, OECD/Global Science Forum, recommends the following steps be taken:

> *"1. The appropriate NSF office(s) should systematically keep track of roadmapping/prioritization processes that are being undertaken in various countries and regions. Under the right circumstances, NSF (and, possibly, other US agencies) could even be actively involved in these exercises.*
>
> 2. NSF could consider actively promoting the coordination and synchronization of long-term planning and roadmapping exercises in the various disciplines where large infrastructures play a major role."

Differing roadmap standards and criteria, however, need not be an impediment to prioritizing and selecting projects. The European Strategy Forum for Research Infrastructures (ESFRI), for example, identifies new Research Infrastructures (RI) of pan-European interest corresponding to the long-term needs of the European research communities and covering all scientific areas regardless of location. The ESFRI Roadmap then provides a reference for a growing number of European countries to prepare their own national roadmaps to define national budgets, facilitate political support and allow long-term financial commitment. ESFRI essentially acts as an incubator of pan-European research infrastructures. Similarly, a strategic and balanced NSF portfolio provides a reference for directorate and divisional level strategic plans and budgets.

Comment: Scientific roadmaps have been, and continue to be, very valuable tools within specific areas of science for identifying and prioritizing new science goals and characterizing the new facilities required to reach these goals. The focus of such planning roadmaps is typically a 10 – 20 year time frame. Such science planning roadmaps should continue to be supported and used by NSF. The roadmaps developed within particular scientific fields of science, however, provide relatively little value for prioritizing across the various fields of science. Such cross-field prioritizations have historically been done at the higher levels of government decision-making and this is likely to remain the decision process in the foreseeable future.

Long Term Planning and Facility Flexibility

Large facility projects can take 25 years or more to complete from the time of conception to the arrival of the first scientific results. During this period, new fields can emerge or take existing fields in new directions not originally anticipated. Scientific questions and priorities may change over this time period, a period in which large dollar investments have already been made. In addition, specialized facilities may not reveal the new discoveries that were foreseen at the outset of construction. Of course, there are many examples of significant scientific advances made with instruments not built for that specific purpose, like the discovery of the first exo-planet at the Observatoire de Haute-Provence by a Swiss team, and many others. There are also numerous examples of upgrading and retro-fitting instruments with new detectors to exploit the directions that the science of the facility is taking during the facility's productive lifetime. This scientific serendipity is often characterized as the discovery potential of the facility and becomes part of the case for construction. Given these risks, one critical question to be addressed during the selection and prioritization period is whether to build a *broad-based* or *special-purpose* facility. In other words, will the facility be a "discovery space for previously unknown phenomena?"

Most all facilities embody the capability to become "discovery space", even those built to meet a special purpose. It is very rare that a discovery is made that obviates the need for a particular, special-purpose, follow-up facility, given that such facilities proceed to exploit and expand the scope of the new science and, typically, later uncover even more previously unknown phenomena that lead to continuing discovery in this and related fields of science. However, this does not negate the need for flexibility in design to more effectively allow capability for serendipity and spontaneous discovery. Flexibility in terms of adding capacity or capability provides a mechanism to attract new partners, both early in the project design and in later stages of operation.

The National Ecological Observatory Network (NEON) program provides an example of a project that morphed during its conception from fixed bio-measurement towers to one that allows for quite rapid response to new environmental changes in the local biosphere. This added responsiveness comes in addition to maintaining the fixed, long-term program of ecological measurements in the fixed locations. NEON partitions the United States into 20 ecoclimatic domains (biomes), each with one fully instrumented, fixed tower based core site. Observations using instrumentation deployed on relocatable tower sites, airborne platforms, and mobile ground-based observing systems extend the reach of NEON measurements and increase the ability of the observatory to observe intensively managed ecosystems and abrupt ecological changes. Site design is expandable to allow the incorporation of new technology or new measurements not available or not practical in the initial implementation. While not originally planned as an international venture, some NEON sites are co-located with other international biological observing systems.

Comment: NSF's National Ecological Observatory Network (NEON) project provides useful practical experience in formulating and carrying out several of the principles that have emerged as desirable aspects of the next generation of large new scientific facilities. These principles include flexibility in utilizing infrastructure of the facility to respond to new scientific opportunities that emerge as the facility is operated, as well as the practical fostering of added international cooperation to expand the reach, scientific capabilities and the facility scope of an initial purely NSF project.

Topic 2. Funding Mechanisms and Pathways

Project Phases and Their Funding

Many participants reported that there needs to be a better "life-cycle" funding plan for projects in the NSF, whether the NSF is the sole funding agency or if it partners with other U.S. or foreign entities. This topic of funding mechanisms and pathways directly addresses the first of the two questions in the NSF Charge. It identifies a key issue relating to the current NSF policy for funding of the pre-construction phase of NSF projects and recommends two desirable policy changes. A specific and important theme among the meeting's contributors and participants was the need for a strategic and cross-agency coordinated approach for funding a project from the preliminary Conceptual Design and Preliminary Design phases through formal approval for construction funds. As it now stands, the formalization of funding protocols among partners appears to commence only with the start of construction.

The "life-cycle" of a project includes the provision of sufficient resources to develop planning and project development work beyond the Conceptual Design Report (CDR) stage. In particular, the Preliminary Design (PD) stage is crucial for developing reliable cost and schedule estimates prior to the point where the NSB approves construction. As a matter of current NSF policy, the PD Review must be successfully passed before a project can be submitted to the Science Board for their consideration. However, the NSF share of funding for the PD process is currently the responsibility of the NSF division(s) promoting the project and the cost burdens can be excessive for large NSF projects.

After a candidate project has passed the stage of conceptual preparation, substantial funds are needed to develop a robust cost/schedule/scope baseline plan through the PD process and Report. Without significantly enhanced levels of funding, robust development plans and reliable cost and schedule estimates are difficult or impossible to develop. Costs associated with the the PD phase, however, can easily constitute up to 15%, and could rise to 25% or more of the overall construction project. Historically, funding for planning, design and costing of a candidate facility has been managed with NSF division-level Research and Related Activities (R&RA) funding sources, the account that provides support for the ongoing grants-based research program of the division. In this R&RA model, however, the standards for readiness, although defined explicitly in the Facilities Manual, have varied significantly in their implementation, resulting in uneven development of proposed facility plans often at the expense of other division programs.

We heard that the cost risk of a project can be significantly limited to be <30% of initial estimates if 10-15% of the total cost is invested in pre-construction engineering and project planning (Werner Gruhl, NASA Comptroller (1991)). If less is invested, the costs can easily be up to double the initial estimates. The ongoing international ALMA Project in which NSF is a partner is an example as discussed by Ethan J. Schrier and John Weber in their paper "Lessons Learned from ALMA, September 2010" submitted to this Subcommittee following the meeting by participants. They conclude that: *"The total estimated cost for a 64-antenna array with 4 receiver bands in October 2002 was $565M. The cost at completion for a 50-antenna bilateral array (not including the ACA or operations budget) is now estimated to be (again in FY2002 dollars, not then year dollars) $785M. This is an overrun of 40% for a system with 28% fewer antennas. If funding was available for all 64 antennas the overrun would have been about 70% (not all costs are proportional to the number of antennas)."*

Currently there is no definite cross-agency mechanism in NSF for funding projects beyond the CDR. It was also pointed out by Beatrix Vierkorn-Rudolph, European Strategy Forum on Research

Infrastructure (ESFRI) that, once competent and experienced engineers have started on a project, one cannot expect them to leave the project for two (or more) years and expect to get them back. It is critical that the funding is continuous to minimize unnecessary and harmful fluctuations within the design team, as well as to enable an orderly ramp up and ramp down of design efforts.

William S. Smith, Association of Universities for Research in Astronomy, wrote: "*The MREFC process now well addressed the backlog and has brought great clarity to the ranking criteria. However, the NSF still lacks an effective mechanism for taking a project that has matured through a design phase, and nurturing it properly through the time period needed to achieve formal approval for construction. This is critical for many reasons.*

For example, in order to form effective partnerships at the international level, it is most effective for the NSF to directly engage its funding counterparts in other countries at an early stage. Yet lacking construction approval for a project, the NSF cannot unequivocally state the agency's commitment and is thus hampered in aggressively seeking a commitment from another partner. This could lead to a passive "who goes first" process.

AURA has recommended in the past the establishment of a pre-construction budget within the MREFC line that can sustain a project through the transition from design to full construction approval. This would establish a clearer intent to go forward with a project, even though it may not be fully approved by the NSB and the Congress, and could help in the process of engaging international partners."

Comment 2: The development of robust Preliminary and Final Designs with well-defined and accurate cost and schedule characterization is essential for the selection and prioritization of Large Facilities Projects. The PD and FD project phases require a sharp increase in needed funding levels to accomplish these vital project planning steps. In the context of a strategic, plan-balanced portfolio from the directorate level to the division level, the agency has been encouraged by many people over time to fund pre-construction engineering design work with MREFC-type cross-agency funds rather than with R&RA funds. The Subcommittee and the participants who discussed this issue support a cross-agency funding source for the PD and FD phases of a large facility project's evolution.

Recommendation 2: The Subcommittee recommends that NSF develop a cross-agency funding source, similar to the MREFC concept, to cover the very significant costs encountered in carrying out the Preliminary and Final Design phases of a contemplated MREFC class large facility project.

Operation of Facilities

Funding for the *operating* phase of facilities that the NSF has sponsored is subject to competition with other NSF activities in the particular division or program office involved. This is meant to invoke a natural method of prioritization within each program element. However, the MREFC method for funding construction has no limits in terms of scope. Some of the projects now being contemplated are so large that operating costs for the completed facility could become a major problem for that part of the division's research program. These operating costs should be addressed at the same time that the "life cycle" is planned. All the observations so far have been made in the context of a solely NSF sponsored facility. The complications and stresses for multi-partner and international facilities are strongly multiplied, especially where NSF is a minority partner in the contemplated operations funding plan.

We also heard that the MREFC process does not routinely address decommissioning an operating facility (or even serious consideration of such a plan). One prime example is the radio telescope at Arecibo http://www.naic.edu/ which is still scientifically productive. However, it costs about $10M/year to operate this facility (exclusive of the research support costs) and it is estimated that it would take more than $100M to decommission it, many times the annual operating cost. The large decommissioning cost, with no resources available for this purpose, prevents making a rational program decision about whether or not to continue operations.

Sidney Wolff, President of the Large Synoptic Survey Telescope Corporation (LSSTC), observed that "*It is extremely difficult given the U.S. annual budget system and long lead times required to insert a* [new scientific] *project in a timely and credible way.*" We also heard that it would be advantageous for the National Science Board to hear about big projects well before there has to be a decision to approve them for construction as the current system works.

Comment 3:
The Subcommittee urges NSF to expand their large facilities planning efforts to include steps that relate to the decommissioning and closure of facilities in which NSF is a partner in the facilities operations. The specific observations we make comprise:
1. Develop a planning process at the Division or Directorate level for the planning of life-cycle costs of all new and ongoing projects. The NSF Directorate should endorse these life-cycle plans to enable NSF to participate early and effectively with potential partners in project planning. A series of stages/milestones should be identified that specify the requirements and decisions needed in order to proceed forward to each successive milestone.
2. Develop a method of ensuring the support for the operations and maintenance (O&M) of all approved projects. Annual operating costs are easier to identify and quantify than the operating lifetime of the facility as this depends upon the evolution of the science program itself.
3. Set aside a small part of an appropriate NSF budget for decommissioning costs. A cross-agency funding source that could smooth out these considerable costs would be beneficial. The Subcommittee has been advised that such a decommissioning budgeting concept might conflict with federal budgeting practice but we believe that it should be explored by NSF.

Recommendation 3: The Subcommittee recommends that NSF evolve toward a project planning system in which decommissioning and closing costs for large facilities, in which NSF is an operations partner, are considered along with project planning steps that NSF already considers for the construction and operations phases of such facilities.

Topic 3. Planning and Implementing Partnerships

Partnerships for International Large Science Facility Projects
A very important aspect of answering the NSF Charge questions relating to the successful participation of U.S. scientists in large, multi-national collaborations, as well as related project governance issues with other international agency partners, is the timing and character of partnership initiation. We discuss this topic and offer two recommendations on this topic. During the meeting, the Subcommittee engaged in a wide ranging discussion with researcher/managers of

large optical telescopes, radio telescopes, high energy physics experiments, ocean drilling studies, seismic surveys and environmental monitoring projects, how actual international partnerships have been planned and carried out. While each of these projects confronts different challenges and constraints, some general conclusions emerged. We outline the challenges identified during the meeting with participants first, then turn to some successful ways identified for meeting these challenges.

With some exceptions, most newly contemplated major scientific research facilities are initiated by a group of scientists with common scientific objectives. While the science community, by its very nature, comfortably transcends national boundaries, differing national structures and policies make realizing international partnerships challenging. The reward for succeeding in such partnerships, of course, is the sharing of costs, risks, technical capabilities and, of especially great importance, broader access to intellectual participation. There need not be a lower limit on the scale of such projects, but this report focuses on the large international end of the spectrum.

To form effective international partnerships, it is important and necessary to move beyond the immediately affected scientist community and to mutually engage all important participants, including other research communities, scientific program officers and government officials at the cross discipline and policy levels. These contacts should be initiated at an *early stage of planning*. Given that agencies and governments are typically asked to provide funding across all the fields of science, early communication with and among government and agency officials is critical for the overall planning process, as well as for establishing successful funding of construction and operations phases for the resulting facilities. It is common, unfortunately, that these higher governmental levels of partnership involvement are frequently the last to hear of the new initiatives. In addition to communication issues, there are other significant challenges to the early establishment of partnerships.

To help ensure success, science projects of broad interest should initiate *international partnerships* at the conceptual stage of project initialization. The NSF and other U.S. funding agencies, in concert with non-U.S. agencies brought in early in the planning stage, could play an enabling role in establishing sponsorship and the policy basis for the potential new projects. NSF, by *instituting more proactive sponsorship policies*, would encourage U.S. participation in these partnerships, especially in the MREFC class of new facilities.

For example, it is extremely difficult to get international partners all to commit at the same time. In the case of NSF, until formal approval is obtained for the MREFC construction phase of the project, the agency has typically declined to fully commit to the partnership. This hesitancy, in turn, can be an impediment to obtaining commitments from other potential international partners resulting in a "you show me your money first" scenario. It is particularly important to avoid the situation where a national project seeks international partners only after the realization that anticipated costs exceed the funding ability of that country. This pernicious situation was experienced during the 1980s in the very large SSC Project, initially a solely U.S. sponsored accelerator/collider facility construction effort, it much later in the project's evolution sought participation by other countries when the total costs became much greater than the U.S. government felt it could shoulder.

An additional drawback to entering partnerships at later stages, as NSF's current approach constrains it to do, is that the partnership may have already established its guiding principles and operational protocols and may be reluctant to change for new members. Thus, without early commitment to an international project, NSF may be unable to guide decisions relating to project leadership, data management, technology implementation, etc.

NSF flexibility to work within the timeframes of other international partners is critical for success in consolidating tentative partnerships. Approaching the partnership in gradual stages, starting with a Statement of Intent (or Letter of Intent) stating the goals of the project, the anticipated project partnerships and later proceeding to a full funding commitment (assuming the necessary project development steps have been successfully met along the way) provides a mechanism to engage participants and new partners, as well as minimizing risk associated with a full construction project funding commitment early on. Utilizing non-binding letters or statements of intent early in a project life-cycle provides potential participants with a credible basis to articulate the scientific rationale, to build partnerships, build a strong business model, and determine programmatic impacts (what is the agency/partner gaining from this commitment as well as what would it not be doing if it commits to this project).

<u>Comment 4:</u> A flexible and graduated approach by NSF to entering partnerships, beginning with a letter or statement of intent, will facilitate international partnerships in pursuing the construction of large new facilities for science. This approach, as part of an overall agency strategic plan to prioritize and fund the life-cycle of each project, will signal NSF's positive intentions toward the project at an early stage, provide a credible basis for attracting new partners, permit NSF's involvement in establishing project management plans, and minimize NSF risk as conceptual level projects develop to fully approved partnerships and fully committed construction projects.

<u>Recommendation 4:</u> The Subcommittee recommends that NSF publicly release a qualified *Statement of Intent* to support the scientific goals, the anticipated project partnership and the technical development of large new international science projects after successful completion of the Conceptual Design, in order to facilitate the formation of the partnership, and provided the agency plans to continue with the next step leading to construction.

<u>Timing of Funding and Funding Modes</u>

A second significant hurdle in the planning of international projects can be the timing of national project approval and funding cycles. Some countries prioritize and fund projects on a multiple year basis. Proposals submitted out of phase may result in the delay of project approvals by several years. For large projects where planning can stretch over many years, synchronization of funding is typically a less serious problem.

A topic that generated significant discussion during the participants meeting was the issue of funding contributions during construction within international collaborations, specifically whether they were provided in cash or "contributions in kind". There was a clear divergence of opinion on the right mix of cash vs. in-kind contributions among the participants. (For a thoughtful discussion of cash vs. in-kind contributions to international partnerships, see the *OECD Global Science Forum report on Establishing Large International Research Infrastructures: Issues and Options*" submitted in written form to the Subcommittee.)

Countries naturally prefer in-kind contributions during construction to ensure that public money is spent at home to provide jobs locally and encourage industry. Where it is possible to parse the contributed hardware into manageable pieces that are within the capability of the partner countries, the in-kind contribution was typically 80%, where the remaining 20% was in the form of a cash contribution to a common fund. For large expenditures, not easily assumed by any one partner, (for example, the large superconducting magnets for collider experiments), the fractioning of the job among several countries and the in-kind supply of components has been typically fraught with problems and difficult to manage.

When adopted as necessary by an international project, the value of in-kind contributions can be determined at the outset of the project and progress in meeting deliveries can be tracked using suitable project management tools. Countries commit to their contributions by way of an agreement (typically, a Memorandum of Understanding), determine their own contingency plan and absorb any cost overruns. A strong project management team, of course, must control interfaces, assure appropriate quality standards are met and track fabrication and testing progress.

There is a perception that projects utilizing in-kind contributions will necessarily cost more. This need not be the case if strong project management is established from the beginning as part of the agreement among the partners. While the costs may not be greater, however, the time required to come to a suitable agreement among partners can indeed be longer. With experience, this process will become smoother. Some countries, particularly developing countries having little experience with international collaborations, have been reluctant to send sizable amounts of cash out of the country for scientific projects but will embrace an in-kind contribution. Such countries may also be particularly sensitive to the technical content of their contribution.

During the participant discussion, we heard that the Giant Magellan Telescope (GMT) plan requires that international partner contributions must be in cash for better management control of cost and schedule. This model seems to be working for GMT. It may not be possible to distribute contracts equitably to the partners, thus raising the issue of *juste retour*. This cash-only model may be particularly problematic for participation by developing countries.

Partnership Models

Partnerships formed to promote, organize, build and operate large new scientific facilities can fall into several distinguishable types. We note these first and then comment on the related issues that were discussed in the participants meeting.

True partnerships - True partnerships are those in which no country or region dominates and members share full participation in governance irrespective of the size of the contribution (symmetric partnerships). In principle this ideal promotes trust and respect among the partners, increasing the prospects for success. In this model, the partners have equal access to experimental data. Examples include the International Linear Collider (ILC), the International Thermonuclear Experimental Reactor (ITER), the Atacama Large Microwave Array (ALMA), the Square Kilometer Array (SKA) and the Auger Project.

Asymmetric partnerships – Accelerators for high energy physics are examples of asymmetric partnerships. The basic technical infrastructure, the accelerator, is built and maintained by the host country or region, in some cases with a few technologically advanced minority partners (CERN's Large Hadron Collider is a recent example). Collaborations of experimenters are invited to propose experiments to exploit the new accelerator facilities. When the successful proposals are approved for construction, the experiments are built and operated by large to very large collaborations of experimenters coming from academic and governmental institutions, usually located in several to many countries. Examples are CERN and Fermilab. This model is being increasingly followed by other scientific communities that use large, expensive accelerator and reactor facilities in their scientific programs. Examples are found in nuclear physics, synchrotron radiation experiments, neutron beam experiments and others. Another asymmetric partnership is the International Ocean Drilling Platform (IODP). The drilling platforms are regionally owned and operated but the science is carried out using fees from the partners. The cost of the largest and most expensive accelerator facility now under consideration, the International Linear Collider (ILC), has raised serious questions even for this maximally distributed partnership model. The ILC proponents are struggling to form a symmetric international partnership from the outset.

Shared access to national facilities is another approach. Sidney Wolff, President of LSSTC suggests that this model has been successful in the past and could be extended:
"Rather than forming an international partnership with shared governance and costs for every project for which there is international interest, would it sometimes be better to trade access to unique facilities or capabilities in other countries. This approach might simplify the management of individual projects and lower costs, since international projects can cost more than projects carried out by a single country."

An asymmetric partnership typically assumes that the host country does not have an otherwise special status or that it does not does not dominate the governance of the facility. At the same time that the host country is expected to accrue the benefit of jobs and local spending, the host has the obligation to provide an interface with local officials to ensure the ease of movement of people and material in and out of the country. For example, special arrangements may need to be made for customs waivers and entry visas. The partnership agreement must include provisions that ensure that the contribution of the host country is not dominated by pouring of concrete to the exclusion of technology based components. Distribution of costs for civil construction may be difficult to agree upon as some countries will not fund civil construction outside of their borders. These policies will probably change as the frequency and importance of international projects increases.

Apropos to the asymmetric type of partnership, some of the meeting participants felt that a single, dominant partner (>50% interest) was necessary for management efficiency and to avoid decision deadlock.

Corporate partnerships – Establishing a non-profit corporation is another partnership method that has long been used in the astronomy community and that is becoming increasingly exploited in other sciences. A typical current example is NSF's National Ecological Observatory Network (NEON) Project. The Giant Magellan Telescope (GMT) has a non-profit US based corporation formed through a legal partnership among the international participants. The Thirty Meter Telescope (TMT) has a similar partnership. Both of these international projects were (uniquely) enabled by private party funding and are well along. The two projects are now seeking NSF as a new partner to expand project funding. Since NSF was not involved from the conception stage, the agency has had little opportunity to influence planning that is considering a possible merger of the two projects.

<u>Lessons in forming partnerships</u>
Regardless of the form of the partnership, a survey of recent international projects yields some important lessons. Such partnerships are most likely to succeed if the partnership is formed at the concept stage. Ideally, the partnership comes together informally as a team to work out the project goals and prepare the conceptual design. This process builds an atmosphere of confidence and trust among the partners. While there will inevitably be different design approaches, any conflicts are most easily resolved early in an atmosphere where science rather than national interest will drive the

design process. An example of this approach may be found in the Pierre Auger Project described in an article submitted to the Subcommittee (The Pierre Auger Project – A Model for International Science). By 1993 it was clear to the cosmic ray research community that a very large aperture detector was needed to resolve some of the mysteries of the particles from space with the highest known energies. A workshop was held at Fermilab in 1995 where scientists and engineers from most of the eventual 17 partner countries met and together developed the design. The observatory described in the resulting design report was successfully built in Argentina and it is now taking data. Early in the design process, each country wanted something on which to paint their flag. As the team began to work closely together, however, such considerations were soon forgotten so that now it is difficult to find any subsystem that does not have components from several countries.

Examples of projects where partnerships were formed only after design efforts were well advanced are described elsewhere in this report along with problems these projects encountered.

<u>Comment:</u> International facility projects are most likely to succeed if the partnership is formed at the concept stage. As a team is formed to develop a common goals and design, trust builds up so that conflicts among the partners are more easily resolved. As a result the partnership is more cohesive and better prepared for the subsequent review and approval processes.

<u>Agreements and Written Documentation of the Partnership</u>

Capturing the terms of agreement (or the content of the often used Memorandum of Understanding) among intended partners is crucial to the success of a project. The Agreement or MOU must be developed and agreed to by the partners as one of the first acts of the incipient collaboration. The form of the agreement is particularly important when it is not legally binding on the partners, the usual protocol in the MOU format. We were informed by NSF that MOUs in which NSF participates are *never* legally binding, but rather are statements of intent. The Agreement or MOU should include sections on: organizational structure, governance, cost estimates (construction, operations and decommissioning), schedule, funding plan, as well as protocols for membership, withdrawal, ownership, intellectual property, data access and dispute resolution. The Agreement or MOU may need other special, project-specific sections containing policy on how access to the instrument (such as observing time, beam time, etc.) is allocated.

The Agreement should be linked with a Project Execution Plan (PEP) (NSF's terminology for this document) and a detailed work breakdown structure and project schedule as project planning proceeds. The details of the Agreement have to be hammered out and agreed to by the partners before the project can proceed to construction. The Agreement should be transparent and as simple as possible. If it is over-prescriptive, the Agreement may prove to be too inflexible as the project evolves. The higher the authority that signs the Agreement, the stronger the commitment is likely to be. Even though Agreements may contain a clear disclaimer that they are not legally binding, lawyers will raise objections so that only dogged persistence will allow the formal signing process to converge and complete.

The organizational structure, as detailed in a PEP, must have clear lines of responsibility and authority. While the management team should include persons with strong skills in cost and schedule, risk mitigation, quality assurance, systems engineering and safety, the key decision making should be in the hands of a scientist/manager with a passion for the science objectives of the project. Fortunately, the increasing number and size of international science projects has resulted in the expanding availability of such experienced scientist/managers.

Greg Boebinger, Director of the Pulsed High Magnetic Field Laboratory writes: *"I feel strongly that an optimized user facility requires directorship by scientists with international reputations for their own research. The organizational structure should place key decision making in the hands of these scientific leaders. The supporting business and management structure should serve the vision and strategic decision making of the scientific leaders and should (perhaps as a stretch goal!) strive to enable the scientific leaders to maintain some level of active research via collaborations and publications. Active participation in research is the single most important factor in learning about and attracting first-rate scientific talent to the facility, whether as new users or new hires. It is particularly important to ensure a scientific environment attentive to the many and detailed experimental capabilities necessary for scientific success."*

"The European Expert Group on Cost Control and Management Issues of Global Research Infrastructures" authored by the Group of Senior Officials, has prepared an excellent set of recommendations concerning the formulation of an agreement among partners in international collaborations and submitted them in written form to the Subcommittee.

<u>Partners From Developing Countries</u>
As high energy physics required ever more powerful machines and detectors, international collaborations evolved. Experience with these and other big science projects, however, has largely been limited to developed countries. Developing and undeveloped countries typically do not have this experience with its dependency on trust and goodwill. Moreover, these counties typically want their contribution to be in-kind and are reluctant to send cash for a common fund or operating costs, particularly if the infrastructure is in a richer country. The global science community feels an obligation to find ways to bring scientists in these countries into the collaborations. One possibility would be to grant special associate status for these countries with one of the major partners as a sponsor.

<u>Partnership Summary</u>
Summarizing the partnership outlook, we note that, with a few exceptions, international partnerships for large science projects have been remarkably successful, propelled by a passion for good science and by good will among the partners. Each experience with an ever increasing number of international partnerships has led to the refinement of the organizational models. Over the past two decades, governments have begun to appreciate the benefits of these partnerships and have become more flexible in agreements and in providing funding.

Europe, by necessity, has learned to work together on science projects of common interest, CERN being the earliest and best example. We should learn from their experience and the policies on cooperation that have evolved.

<u>Comment 5:</u> One key lesson from the historical record agreed upon by all participants in the Subcommittee's open meeting was that the partners in future contemplated projects of the sort considered by this Subcommittee (researchers, agency program managers and government officials responsible for approval of project funding) should establish close contact as soon as possible after a prospective project has passed the scientific priority setting process and is ready to be put forward as an approved and funded project. *International facility projects are most likely to succeed if the partnership is formed at the concept stage.* Given that governments are typically asked to provide funding across all the fields of science and that these fields have no practical mechanism for establishing relative priorities across disciplines, this close communication with government officials and ministers, who of necessity must prioritize across disciplines, is critical for the overall

planning process as well as for establishing successful funding of the construction and operations phases of the resulting facilities.

Recommendation 5: The Subcommittee recommends that early contact with government officials responsible for science policy, project priority and project funding, both domestic and international, be established by science agency program managers and project proponents as soon as a contemplated new facility project successfully passes the Conceptual Design review stage.

Topic 4. Infrastructure Management and Governance Models

Governance Issues

Governance has the same meaning for a scientific project or facility as it has for any other enterprise – it encompasses the rules and processes that are used by its stakeholders to control its development and management to accomplish a set of common goals. A variety of governance approaches have been used for the development and operation of scientific facilities, and proponents for some of the models that have been used put forward comments about them during the participant's meeting with the Subcommittee. This section provides a discussion of previously used governance models and addresses the 'lessons-learned' aspect of NSF Charge question 2.

The stakeholders in a scientific project or facility, especially the large, international facilities projects that are under consideration in this report, are a mixed set which at minimum include a scientific community and its sponsors but also can include additional segments of society. Scientific enterprises can and do have diverse sponsorship potentially including: different governments' funding agencies; different funding agencies within the government; and institutional, corporate and private donors. *Sponsorship complexity is a way of life in scientific governance, especially in the larger enterprises.* For example, in the U.S. alone there are a significant number of departments and agencies involved in the approval and support of large scientific facilities - NSF, DOE, NASA, DOD (with its various quasi-independent science and technology agencies), to name a few. Each has a mission to financially support or an interest in promoting science. All can, and do, participate as partners in shared projects.

Institutional sponsorship adds another level of complexity. Very large private donations and long term sponsorship are a tradition in the construction and operation of astronomical facilities. Major private and public education institutions ('research universities') are another traditional stakeholder with substantial financial, personnel, property and other investments.

International enterprises add an entirely new layer of complexity because of the existence of both national funding agency participation and super-national partners such as the EU and treaty-based organizations such as ESA and CERN. Although the Subcommittee did not hear much about this topic, public and private for-profit corporations can and have provided financial and other real sponsorship to big scientific enterprises.

It is obvious that sponsor-stakeholders become analogous to business partners and they can have different goals set by the nature of each partner. Science agencies have abstract missions while other partners can have more concrete goals and, in the case of public, private institutions and individual partners, *motives*. International partnerships, for example, must take into account the facts that (a) developed and developing nations have different views of the desired outcomes – a facility in Chile, for example, is primarily an economic development opportunity, and (b) even supposedly equal developed nations may retain overarching interests related to industrial policy, intellectual property or traditions. Most importantly, *each sponsor-stakeholder must behave in conformance with its own governance rules and processes.* The most primitive example of this fact is that each must obey the laws under which it exists – examples include financial, labor and tax laws which vary from nation-to-nation and are different for government agencies, institutional, corporate and private donors, and for profit and non-profit institutions. A more subtle example is that national funding agencies are bureaucratic stewards of public funds which ultimately answer to public interest through a governmental structure – the multiplicity of executive and legislative entities, committees and boards which govern US science funding is an example. Science bureaucrats interpret the intent of their agencies' mission and rules in unique ways and respond to the sense of the Executive Branch and the will of legislators. Personalities and politics are an enormous factor in the decisions that shape large scientific projects.

The science community that uses a project or facility is usually not explicitly represented as a stakeholder in the governance of most scientific projects or facilities. Their interests appear to be effectively but indirectly served in three, often overlapping, ways: by formal agreements that set up the details of the governance approach; through representatives of national funding agencies (responding to their bureaucratic imperatives); or by individual scientists who are selected or elected to serve in governance positions. Since many enterprises are conceptualized and promoted by scientists or groups of scientists, the moral influence of 'founders' is a powerful way in which specific segments of the community are represented. There appear to be few if any examples where the lack of direct representation by the specific user community is an issue.

The Subcommittee believes that the most effective governance arrangements are based on clear statements of goals, roles and responsibilities, simple governance structures, explicit decision making rules, and procedures for joining, leaving, apportioning costs and dealing with expected contingencies. These requirements for success effectively mirror the agreements (commonly expressed in Memoranda of Understanding) among the project partners as discussed in a previous section of this report.

If our first finding is that 'a variety of governance approaches have been used,' then our second is that the most successful of these have been built on clear foundational statements, structures and rules. This common sense statement can be very difficult to implement. The mixed set of stakeholders often requires foundational agreements that fall far short of contractual agreements. Non-controversial overarching goals can be stated but roles and responsibilities are sometimes only documented through a Memorandum of Understanding (MOU). The participants and stakeholders in these projects are usually aware of the desirability of clearer governance arrangements, but forced to use non-binding decision making processes and apportionment of obligations. Clear and strong governance arrangements have been established in some NSF and DOE funded projects as a result of requirements set by these agencies but the existence of a single agency financial stakeholder is not always enough. Reviewers of the cooperative agreement to operate the National Radio Astronomy Organization (NRAO) by Associated Universities Inc. (AUI) are always frustrated by the difficulty of separating the roles and responsibilities of the grantee (AUI) from the operating entity. Legal and treaty-dictated governance arrangements are much more transparent but developing and operating every international project or facility cannot and is not required to rise to this level in order to succeed. The resulting fuzzy governance arrangements in international projects can become a significant impediment to efficient execution - the antenna procurement incident in the Atacama Large Microwave Array (ALMA) is an example of the result of unenforceable decision-making processes.

Many scientific projects accrete stakeholders over time – the initial partners are joined later by funding agencies or other institutions that perceive a common purpose and want to benefit from spreading costs and responsibilities. Successful governance arrangements must make the process for accreting partners and absorbing them into the governance arrangements clear. *It seems to be a good practice to identify policies and procedures for joining an existing partnership part of the initial governance concept* - even if accretion is not part of the initial project or facility plan. Similarly, *it is prudent to identify policies and procedures for partially or completely dissolving an existing partnership as part of the initial governance concept.*

Projects with a very strong technical basis, or for which the scientific and financial stakes are very high, can succeed despite unclear governance arrangements. NSF is a financial stakeholder and is also an executing agent (i.e. a manager) for the Gemini Observatory. The European Southern Observatory, Associated Universities Incorporated and the National Astronomical Observatory of Japan partner in ALMA via demonstrably unenforceable governance arrangements, yet the project continues to move toward completion in the face of significant cost overruns and personnel turnover.

The Subcommittee and many participants in the open meeting agreed that setting up an independent, non-profit corporation to provide governance is a commonly successful approach for large, international science projects. Establishment of a non-profit corporation for the purpose of conceptualizing, developing and eventually operating a scientific project or facility provides an effective governance mechanism for this type of non-commercial entity. A corporate entity has standing with respect to government funding agencies, individual and corporate sponsors or donors, and most other institutions (universities, other public, private, for-profit and non-profit organizations.), In most cases, non-profit corporations have standing with respect to national and international law and individuals. More importantly, there is a long and effective tradition of non-profit corporations dealing with communities of interest, mixed stakeholders, governments and super-governmental entities. Once established, corporations can adopt a variety of internal governance structures, processes and rules which include provisions for enforcement, expansion and dissolution. Most of the models used for scientific enterprises follow a structure that mimics a business with a Board of Governors or Directors who exercise varying degrees of oversight on an executive agent or operating arm. Membership on the Board can be apportioned in a variety of ways – proportionate to financial or other investment, mixed with financial, user and other stakeholders sharing, or, like many private corporations, with representation from the executive agent, employees and even the public. The process for electing, selecting or designating Board members then becomes a way to regulate representation by mixed stakeholders. These processes do not have to be uniform.

The direct representation of governmental funding agencies on the Board of an enterprise receiving funding from that agency is usually not permitted – it can represent both a personal and an organizational conflict of interest. Exceptions can be made, of course, if participation is part of an individual's job or with appropriate waivers and authorizations from appropriate ethics officials. In NSF, we were informed by NSF, Boards that are constituted to conduct oversight or provide finance are exceptions. NSF representatives participate on both the Gemini and ALMA Boards and an analogous group of the IceCube funding agencies. The committee also notes that this board participation restriction does not impede the operation of many other public-private entities including the Corporation for Public Broadcasting and the various public-partnership activities of the National Institutes of Health.

The Subcommittee also identified two distinct non-profit corporation approaches to governance of large, international science projects. The first and most familiar approach is based on the association of more-or-less equal large institutions which develop and operate multiple facilities; examples include AURA, AUI and USRA. The second model, which is favored for mixed stakeholders, is the *one corporation, one facility approach*. The latter approach offers the maximum flexibility for setting up rules and processes to control development and management.

Governance can usefully be distinguished from management, which is more simply defined as the organizational entity carrying out the project – its approach, structure, processes and people – executing the development and operations of the enterprise.

Comment: The successful governance of large, international facility construction projects has not been reduced to a simple set of organizing protocols but has evolved in various ways to match the needs of the stakeholders. The governing entities are seldom based on legal contracts but mostly on non-binding Agreements or Memoranda of Understanding that rely on mutual trust and commonly agreed-upon goals among the stakeholders. The governance of the projects are increasingly implemented through non-profit corporations organized according to the needs of the partners, sponsors and users. This model is successful and its continued use is supported by the Subcommittee and the participants in the NSF large international facilities meeting.

Management Issues

The Subcommittee and most of the participants noted that successful projects are characterized by the emergence of strong and empowered managers who stay with the project from conception to completion of construction. Irrespective of the detailed governance model, most enterprises employ a Project Manager to control the project and lead its execution. Many projects now appoint a Project Director who sits above the project manager and directs his or her attention primarily to the sponsors and scientific community to be served. Not surprisingly, *skillful and dedicated people in the top executive positions are the most important ingredient in carrying out a successful facility construction project.* The Subcommittee expressed a strong preference for a project management approach in which the stakeholders give broad powers to a project director and project manager team to: make decisions; commit and expend resources; hire and fire staff; report on progress to the stakeholders; and generally lead the project. The stakeholders restrict their activities to oversight and advisory functions, as opposed to intercession in management. The primary method of overall project control is thus the power to select, retain and dismiss the project manager and/or the project director if there are two top project leaders.

The Subcommittee also believes that successful scientific enterprises are developed and operated using formal project management methods. The committee found that, almost uniformly, major science facilities are conceptualized, developed, constructed and operated using techniques and management practices that are familiar to (for example) the aerospace industry. The project development cycle, although its management may use different terminology, follows a *phased development plan with well defined milestones and stakeholder approvals.* Following a science community based *scientific need and scoping* activity, often pursued by means of community meetings and workshops, there is a *conceptual development phase* (phase A) in which the goals, scope and architecture of the emerging facility project are defined. This phase culminates in formal review(s) which, if successful, lead to a Statement of Intent from the main stakeholders to support the technical development of the project concept.

A technology development and Preliminary Design phase follows (phase B), culminating in a formal milestone called, in the NSF protocol, the Preliminary Design Review (PDR). At this point, several things obtain: (a) the expected scope and scientific performance requirements have been set (i.e. the scope of the project is defined); (b) engineering cost and schedule estimates have been completed and reviewed; (c) a technical baseline has been established and reviewed; and (d) stakeholders/sponsors commit to funding and supporting project continuation, subject to the next major milestone.

The next milestone comes at the end of a Final Design phase (phase C) at which point the actual design, and its predicted cost and schedule, are presented and the stakeholders/sponsors give an authorization to proceed into construction, testing and project completion. In NSF's MREFC protocol, R&RA funding continues to support the detailed design and engineering work of the Final Design. When the project moves into construction, funding is provided from MREFC funds. If the project is a facility, the construction phase ends when the facility begins scientific operations. There are cases in which the construction phase overlaps with a pre-operations phase of testing and commissioning but the funding sources for the two different activities are not mixed. The final phase comprises full operations, maintenance, upgrading or recapitalization of the facility. The committee noted that, in reality, there is another set of activities in which the facility is shut-down, decommissioned or otherwise ceases to operate. There are few (if any) scientific facilities that have fully characterized their closeout phase at the time of construction. This practice may have to be revisited as the cost scale of operating the facilities increases and the closeout costs rise in proportion.

Within phased development, many projects use familiar and formal approaches. Phases A, B and C are decomposed into work packages or *work breakdown structure* (WBS) (plus the associated WBS Dictionary) for project deliverables which comprise the basis for estimating cost and schedule for deliverables and for identifying the apportionment of roles and responsibilities. Each work package can be looked upon as a contract or contracts with defined specifications, a statement of work and fully characterized deliverables. A fully developed Project Schedule with precedence logic and tracking is also completed and readied for use during construction. In the case of NSF, we were informed that the agency does not require that the work comprising the A and B stages be supported by WBS formalism. Since much of the effort consists of labor budgeted as level-of-effort, NSF perceives little utility to the imposition of formal WBS tracking of these phases in most cases. Furthermore, phase A activity is usually funded through a grant with few reporting requirements. The *outputs* of Phases A, B, and C comprise the creation and successive refinement of a WBS for project construction.

The committee noted that the issue of different types of contributions to a project – direct financial support, contributions 'in-kind' of components or equipment, and personnel – is partially mitigated by decomposition into work packages. The valuation and governance apportionment issues arising from different contributions are not an issue for program management except with respect to technical and schedule non-performance by the responsible providers.

The coordination of the work packages is performed by a *system engineering* function which uses formal interface agreements, reviews and test and integration plans to control integration of the project deliverables into a coherent and documented system. System engineering is itself a WBS element. The overall control of the project is done by a project manager (or management team) which function is also a WBS element. Operations, maintenance, upgrading or recapitalization and monitoring of technical performance has, in some cases, also become a project WBS element to ensure that the project flows smoothly from development to operations, and the project director sometimes becomes the first facility director.

Many scientific development projects use *earned value management* (EVM) to report, track, and evaluate schedule progress and resource expenditures. EVM is a formal and disciplined approach that has a steep learning curve for initial application and imposes real overhead on a project. Despite this fact and that it may appear foreign to some scientific institutions and scientists, it appears to be in widespread and rapidly increasing use in contemporary projects. The full, formal application of EVM methodology, however, is limited to projects that are cash funded, i.e. where management controls all funding accounts. In the context of science projects by international partnerships, full EVM implementation may not be practical in the foreseeable future for all the international partners, although it could be applied to U.S. sub-projects when required by U.S. law. International partnerships depend largely on in-kind contributions. Few if any partners would allow a project manager access to their accounting systems, in order to ensure that the EVM system could be implemented across the entire project. A reasonably effective, though less rigorous alternative used in the ATLAS and Auger projects, was to construct a work breakdown structure and associated schedule that included deliverables (perhaps labor and certainly materials) and delivery schedules for all participating countries, evaluated in a common currency. (Suitable adjustments have to be made for how each country accounts for labor.) Progress and costs can then be tracked based on periodic reports from each country.

Comment: The use of formal project management tools and methods to plan, organize, cost estimate, schedule, assess progress and carry out large construction projects for new science facilities, including international partnerships where the use of these tools and methods are less familiar to some of the partners, is a very positive development for NSF and its partners, and these methods and practices should be fully implemented in all future projects on this scale (the use of Earned Value Management for MREFC projects is already Congressionally mandated). There is a good and growing record of effective management, cost and schedule performance when these project management methods are fully implemented in a project's evolution.

Topic 5. Other Topics

Some discussion topics arose spontaneously during the meeting with participants and were felt by the Subcommittee to be worth noting in this report. All of the issues are germane to NSF's participation in large international scientific facilities projects but may not fall strictly within the specific Charge to the Subcommittee. We note here the topics that most captured the attention of the participants and Subcommittee members.

Large Scale Cross-Discipline Science Projects:

An important issue raised in the 'Other Topics' category during the deliberations of the Subcommittee, with perhaps the broadest scope and novelty, was the need and opportunity for NSF to conceive of a new and different *kind* of large-scale research infrastructure. Such a new infrastructure construct would not be based on a set of physical research tools, such as an accelerator, a telescope or a tokamak for fusion research. The new kind of infrastructure would be of a more fluid nature, such as an ensemble of *coherent field-science campaigns* articulated around a main scientific theme. Such a theme would likely be multi-disciplinary in nature and would likely be deployed over an extended number of years. The new initiative might be devoted to a particularly complex and/or urgent scientific problem of broad relevance to society (Earthscope and ocean drilling campaigns, in some ways, embody this concept) but one can think of many other possibilities for productive scientific applications. Such projects would be comprehensive in their conception and each would involve significant numbers of disciplines from the scientific community. In order that these new initiatives be organized effectively and be carried out productively, it is likely that the project management principles, methods and skills already developed and used by NSF in the MREFC program should be incorporated in the project organization and would bring management value to the new kind of large initiatives.

Some important themes come to mind immediately, such as enhanced climate research, but ways to organize different and diverse scientific communities must also be funded by national agencies to help identify other novel themes. The NSF could encourage, sponsor and hold constitutive workshops for particular cross-disciplinary topics in order to help assemble white papers and decadal surveys delineating the needs and possibilities for significantly advancing the chosen topics and fields. This has been done successfully over the years (for example) in astrophysics.

These experimental/observational science campaigns, even if large-scale, may be of a somewhat moderate dimensions, taken one at a time, but when conceived as constituent parts of a more global initiative, and when compounded over a number of years, each could become a large-scale, multi-tool, multi-scale, multi-topic infrastructure that will be seriously considered by high-level scientific leaders and decision makers, as a result of its global scope and impact.

As an example, of particular concern today is the need for a more detailed and deeper understanding of fundamental processes underlying climate evolution. A concerted effort in this area of science should bring together most of the facets of the problem, in particular integrating input from pure and applied mathematics, basic science, hardware and software (algorithmic) innovation, as well as physics and engineering, chemistry and biology. A climate science initiative will also link to disciplines such as ecology and land use, geography and geology, incorporating as well, health sciences and socio-economics and the facets of human development most likely affected by climate change (see for example the NEON program). There are of course successful examples of such campaigns in the atmospheric and related sciences, different in their scope and scale, and at times involving large inter-agency national and international coordination; many such campaigns (and acronyms) could be noted here, such as BEACHON, GARP, HATS, ITOP, MIRAGE, UTLS.

If climate science is an obvious candidate for such a 'large instrument without walls', other fields will rise to the attention of decision makers (biology and health come to mind). Such projects will undoubtedly involve a variety of funding agencies, but NSF may well have a leading and coordinating role to play, given its mission for developing fundamental science of national importance. The international dimension of such large-scale campaigns/projects will be, in general, an integral component at some stages of each project, but this circumstance need not deter our national institutions (and NSF in particular) from exercising their leadership position and moving ahead in a rapid and determined fashion.

<u>Comment 6:</u> The new type of multi-science project infrastructure discussed by the Subcommittee is not novel in its aspect of organizing scientific effort across disciplines, but the large (and likely international) scale suggested here is a new level of application of the cross-discipline concept. We feel that NSF could usefully consider this kind of 'instrument without walls' as a potentially productive extension of the MREFC concept already being used to achieve transformational science results in single disciplines. In the new kind of project, the key transformational aspect for the science would be its potential for particularly productive advances resulting from the long-term and cross-disciplinary nature of the campaigns. These campaigns should involve a computational component both for modeling and data handling and they should contribute in direct ways to the

education of the future generations of scientists, engineers and decision makers in pressing problems of strategic importance and urgency for the nation.

Recommendation 6: NSF and other US agencies, in concert with international consortia as the need may arise, are urged to consider the sponsorship and funding of large, multi-disciplinary science campaigns over long periods of time. Such cross-discipline projects would be comparable to traditional MREFC projects in single fields of science.

Impact of ITAR Compliance on Large International Projects: The International Traffic in Arms Regulations (ITAR) rules require that items, services and information that appear on the US Munitions List (USML) may only be shared with "U.S. persons and organizations" without an authorization from the State Department. ITAR *does not* refer to classified information but rather to technologies that may be used in defense systems. The USML is maintained by the U.S. Department of State and changes can contain both specific items and categories of technologies. In particular, very broad categories of detectors, photonics devices and almost anything related to encryption and space technology can and does appear. "U.S. persons and organizations" mean U.S. citizens and permanent residents who do not work for foreign companies, governments or their agencies, the US government itself, and businesses or institutions that are incorporated under US law.

Compliance with ITAR regulations can range from a nuisance to a serious hazard to international science projects (but also to almost any science enterprise that uses foreign contractors for hardware and services and transfers specifications, technical data or analysis to them.) Companies, institutions and individuals have been fined and prosecuted for breaches and/or required to put expensive compliance measures in place. There is an exception for information related to general scientific or engineering principles taught in schools or information that is clearly in the public domain, but this is not a 'loophole' that exempts colleges, universities or professors. After some lively discussion during the participants meeting, the Subcommittee concluded that the topic was of high interest among the members of the science research and science administration communities. One specific action that could be helpful to NSF's large facilities community would be to include information and guidance on this topic in the NSF Large Facilities Manual and in any short "primer" that is developed or used by those contemplating engaging in the construction and operation of Large Facilities.

Comment: The provision of information and guidance about ITAR compliance to potential partners in large international facilities projects would be a useful aid to these partners. The NSF Large Facilities Manual is a natural repository for information that can be used by those contemplating engaging in the construction and operation of Large Facilities.

Open-Data Policy and Minority Partner Project Participation: When an open-data policy is in place, one may be led to ask "why pay when the data is made available for free in a reasonable amount of time (in general, of the order of one year)?" Direct knowledge of technological and thus strategic development as a project partner represents an important argument to participate in the funding of an instrument; however, it is not always sufficient to carry the day to get minority partners to participate in the funding of both the construction and the operations of a large instrument. The case of Gemini was discussed in this context with Dr. Jean-René Roy of NSF, noting the variable character of the budget, the necessity of a well-conceived, detailed agreement to envisage possible variation in the participation scenarios from the start, including the coming in and out of various countries as economic pressures are experienced over the years. It has also been observed that minority partner countries have motivations to participate in the new facilities as participants beyond rapid access to data. For example, in IODP, minority partners realize that participation is a good mechanism to train scientists, to engage their scientists internationally and to build scientific capacity/capability in new areas. To support and encourage the participation of minority partners in future projects of the scale considered in this report, we believe that the conditions for participation should have flexibility implemented from the start, both for partners leaving and new partners joining the project at different stages.

Comment: The continuation of partnership by minority partners in future NSF facilities projects has benefits for all parties and the NSF should encourage flexibility in protocols that will allow such participation to the maximum practical extent.

Key Conclusions and Recommendations

Following Subcommittee deliberations on scientific participant discussion and written contributions, discussions with NSF officers and Subcommittee discussion, the Funding and Governance of Future Major Multi-user Facilities Subcommittee has arrived at the following key conclusions and recommendations. The format is to include summary comments together with each recommendation in order to briefly relate the reasoning that motivates the associated recommendation. Background information and discussion of the issues for each numbered comment and recommendation are provided in the Topics of Discussion section. Comments that did not result in recommendations are provided in the topical text but are not repeated here.

Comment 1: Maintaining a balanced disciplinary portfolio of large facilities projects, limiting the number of approved projects to maintain that long-term balance, and phasing out lower priority or dated facilities and programs are essential aspects of the agency's long-term strategic plan. The Subcommittee believes that NSF can strengthen its ability to meet these goals by directly including the Science Board in the process of choosing and sequencing the approved list of large facility projects participated in by NSF. The Science Board can also help assure that effective planning for budgetary support of the NSF share of the operating costs for these future facilities has been carried out. Our understanding is that, under present policies, new facilities for the advancement of NSF sponsored science programs are considered by the Science Board on a case by case basis and are not considered in the context of the overall NSF scientific program. Because the Science Board is the highest governance entity in NSF, the Subcommittee strongly supports the principle of its involvement in setting the overall agency strategy for the approval and time sequencing of new facilities of the scale and type considered in this report. We were informed by NSF that it is the intention of the NSB to conduct a portfolio review, assessing and prioritizing future facility project proposals within the context of the overall NSF scientific program.

Recommendation 1: The Subcommittee recommends that the National Science Board, as the highest governance body of the NSF, be made an integral part of the NSF process for prioritizing, selecting and supporting large facility projects in the NSF portfolio, both domestic and international.

Comment 2: The development of robust Preliminary and Final Designs with well-defined and accurate cost and schedule characterization is essential for the selection and prioritization of Large Facilities Projects. The PD and FD project phases require a sharp increase in needed funding levels to accomplish these vital project planning steps. In the context of a strategic, plan-balanced portfolio from the directorate level to the division level, the agency has been encouraged by many people over time to fund pre-construction engineering design work with MREFC-type cross-agency funds rather than with R&RA funds. The Subcommittee and the participants who discussed this issue support a cross-agency funding source for the PD and FD phases of a large facility project's evolution.

Recommendation 2: The Subcommittee recommends that NSF develop a cross-agency funding source, similar to the MREFC concept, to cover the very significant costs encountered in carrying out the Preliminary and Final Design phases of a contemplated MREFC class large facility project.

Comment 3:
The Subcommittee urges NSF to expand their large facilities planning efforts to include steps that relate to the decommissioning and closure of facilities in which NSF is a partner in the facilities operations. The specific observations we make comprise:

1. Develop a planning process at the Division or Directorate level for the planning of life-cycle costs of all new and ongoing projects. The NSF Directorate should endorse these life-cycle plans in order that NSF be able to participate early and effectively with potential partners in project planning. A series of stages/milestones should be identified that specify the requirements and decisions needed in order to proceed forward to each successive milestone.
2. Develop a method of ensuring the support for the operations and maintenance (O&M) of all approved projects. Annual operating costs are easier to identify and quantify than the operating lifetime of the facility as this depends upon the evolution of the science program itself.
3. Set aside a small part of an appropriate NSF budget for decommissioning costs. A cross-agency funding source that could smooth out these considerable costs would be beneficial. The Subcommittee has been advised that such a decommissioning budgeting concept might conflict with federal budgeting practice but we believe that it should be explored by NSF.

<u>Recommendation 3:</u> The Subcommittee recommends that NSF evolve towards a project planning system in which decommissioning and closing costs for large facilities, in which NSF is an operations partner, are considered along with project planning steps that NSF already considers for the construction and operations phases of such facilities.

<u>Comment 4:</u> A flexible and graduated approach by NSF to entering partnerships, beginning with a letter or statement of intent, will facilitate international partnerships in pursuing the construction of large new facilities for science. This approach, as part of an overall agency strategic plan to prioritize and fund the life-cycle of each project, will signal NSF's positive intentions toward the project at an early stage, provide a credible basis for attracting new partners, permit NSF's involvement in establishing project management plans, and minimize NSF risk as conceptual level projects develop to fully approved partnerships and fully committed construction projects.

<u>Recommendation 4:</u> The Subcommittee recommends that NSF publicly release a qualified *Statement of Intent* to support the scientific goals, the anticipated project partnership and the technical development of large new international science projects after successful completion of the Conceptual Design in order to facilitate the formation of the partnership, and provided the agency plans to continue with the next step leading to construction.

<u>Comment 5:</u> One key lesson from the historical record agreed upon by all participants in the Subcommittee's open meeting was that the partners in future contemplated projects of the sort considered by this Subcommittee (researchers, agency program managers and government officials responsible for approval of project funding) should establish close contact as soon as possible after a prospective project has passed the scientific priority setting process and is ready to be put forward as an approved and funded project. *International facility projects are most likely to succeed if the partnership is formed at the concept stage.* Given that governments are typically asked to provide funding across all the fields of science and that these fields have no practical mechanism for establishing relative priorities across disciplines, this close communication with government officials and ministers, who of necessity must prioritize across disciplines, is critical for the overall planning process as well as for establishing successful funding of the construction and operations phases of the resulting facilities.

<u>Recommendation 5:</u> The Subcommittee recommends that early contact with government officials responsible for science policy, project priority and project funding, both domestic and international, be established by science agency program managers and project proponents as soon as a contemplated new facility project successfully passes the Conceptual Design review stage.

Comment 6: The new type of multi-science project infrastructure discussed by the Subcommittee is not novel in its aspect of organizing scientific effort across disciplines, but the large (and likely international) scale suggested here is a new level of application of the cross-discipline concept. We feel that NSF could usefully consider this kind of 'instrument without walls' as a potentially productive extension of the MREFC concept already being used to achieve transformational science results in single disciplines. In the new kind of project, the key transformational aspect for the science would be its potential for particularly productive advances resulting from the long-term and cross-disciplinary nature of the campaigns. These campaigns should involve a computational component both for modeling and data handling and they should contribute in direct ways to the education of the future generations of scientists, engineers and decision makers in pressing problems of strategic importance and urgency for the nation.

Recommendation 6: NSF and other US agencies, in concert with international consortia as the need may arise, are urged to consider the sponsorship and funding of large, multi-disciplinary science campaigns over long periods of time. Such cross-discipline projects would be comparable to traditional MREFC projects in single fields of science.

Appendix A

Ad Hoc Subcommittee on Funding and Governance of Future Major Multi-user Facilities Subcommittee Charge

The Business and Operations and Advisory Committee requests the ad hoc Subcommittee to advise it on two critical issues relating to funding and governance issues that are likely to arise as a result of NSF's participation in the planning, construction, and operation of future large scale scientific facilities. Specifically:

> 1) Are current NSF funding mechanisms for planning, construction, and operation optimal for facilitating the participation of US scientists in large-scale international projects in which there is no single dominant entity? For example, does the separate Research and Related Activities Account (R&RA) funding for planning, and prioritization for funding, hamper partnerships or create a disadvantage for US researchers? If so, what alternatives might be recommended?
>
> 2) What are lessons learned from governance of other large-scale international initiatives that could inform future Memoranda of Understanding (MoU's) to best protect NSF's interests while being equitable to other partners, and provide the greatest return to US science based on NSF investment? MoU's should recognize that international partners on a particular project may have much different processes for funding projects and dealing with cost over-runs, schedule delays, and so forth, and the MoU should create a business process that is equitable among all partners.

Background: The anticipated costs for planning, construction, and operation of future NSF facilities are likely to increase as a direct result of the progression in the scientific reach, scope, and complexity of next generation multi-user facilities. It is likely that funding for such initiatives, at all life-cycle stages, will come from multiple partners. It is also likely that NSF will be a minority partner - there may be no single dominant financing partner, and that multi-agency and international collaboration will be essential.

NSF's recent experience with large projects provides an opportunity to examine lessons learned and to provide a perspective on future opportunities. Also, the experience of other federal agencies, especially the DOE Office of Science, can inform NSF planning. Particularly relevant projects include the Large Hadron Collider (LHC), the Atacama Large Millimeter Array (ALMA), the International Ocean Drilling Partnership (IODP), and the International Thermonuclear Experimental Reactor (ITER).

Looking forward, NSF foresees a number of opportunities where it may engage as a partner, although it has made no commitments to do so. These may include: very large aperture telescopes such as the Thirty Meter Telescope (TMT) and Giant Magellan Telescope (GMT), the Large Synoptic Survey Telescope (LSST), the Square Kilometer Array (SKA), and the Deep Underground Science and Engineering Laboratory (DUSEL).

Activities of the subcommittee: The subcommittee is requested to provide a written report to the Business and Operations Advisory Committee recommending NSF actions in response to the two critical issues stated above. NSF will organize and convene a meeting, comprised of the subcommittee, NSF staff cognizant of the projects and issues concerning the subcommittee, representatives from other agencies or elsewhere within the US or foreign governments, and individuals with direct experience in the projects cited above or with comparable activities. These individuals with direct experience will have involvement in management of the facilities or business involvement within the host institutions or organizations providing the business and administrative framework for the facilities. The meeting will solicit discussion, presentations, and contributed materials by the participants. Following the meeting, the subcommittee will prepare its report.

Process: NSF will organize the activities of the subcommittee around a two and one-half day meeting, with open discussion between the subcommittee and other participants Oct. 20-21, followed by one-half day of discussion among the subcommittee and NSF, and initial report preparation, on Oct. 22. A broad range of participants from affected research communities, other federal agencies, and potential foreign funding partners will be invited to attend the first two days of the meeting to contribute to interactions with the subcommittee.

All invited participants, including the panel members, will be invited to submit written materials, in advance, that will be made available to everyone at least one week prior to the start of the meeting. Written inputs will be accepted from interested individuals unable to attend the two days of discussion. There will be no formal presentations during the meeting. The meeting format will be a moderated discussion, led by the subcommittee chair, to facilitate interaction between the subcommittee and the attendees.

The final half-day of the meeting will allow time for the subcommittee to write a summary of its conclusions and recommendations and to brief NSF staff. The subcommittee is asked to submit a more detailed written report to the NSF Business and Operations (B&O) Advisory Committee within several weeks following the meeting.

The subcommittee chair will provide a verbal presentation at a B&O Advisory Committee meeting subsequent to report submittal. The report will be publicly available on the B&O Advisory Committee web site following its acceptance by the B&O Advisory Committee.

NSF will provide travel expenses and per diem to the subcommittee members for the duration of the time members are on travel status in conjunction with this meeting. (Other invited participants not on the subcommittee that attend the first two days of meetings will be responsible for the own travel expenses.)

Specific Questions to the Subcommittee:

1) Are current NSF funding mechanisms - and the sequence of agency-specific approval activities for planning, construction, and operation - optimal for facilitating the participation of US scientists in large-scale international projects in which there is no single dominant entity?

a. This should be considered within the context of identified future projects that may, or may not be built, and that would likely involve both other federal agencies, international partners, and perhaps private foundations, and NSF's need to preserve a vibrant base program of funding to individual researchers.

b. For example, does the separate R&RA funding for planning, and prioritization for funding, hamper partnerships or create a disadvantage for US researchers or hamper the ability to establish, synchronize, and maintain funding partnerships during the early design and development phase? If so, what alternatives might be recommended?

2) What are lessons learned from governance of other large-scale international initiatives that should inform NSF in negotiating the business framework for future activities?

a. The framework should protect NSF's interests, including its ability to oversee NSF-funded activity and take remedial action when necessary, while being equitable to other partners, and provide the greatest return to US science based on NSF investment.

b. Citing examples from prior undertakings, what recommendations can the subcommittee offer, recognizing that international partners on a particular project may have much different processes for funding projects and dealing with cost over-runs, schedule delays, and so forth? (The subcommittee should account for NSF's unique policy of funding an awardee institution that is responsible for accomplishing the project - this may not correspond identically to the roles and responsibilities of prospective partners.)

Appendix B

Agenda for the Subcommittee Meeting with Participants

NATIONAL SCIENCE FOUNDATION
Sub-Committee of the Business & Operations Advisory Committee
Funding and Governance of Future Major Multi-User Facilities

20-22 October 2010

AGENDA

N.B.: all sessions of the meeting will be held in the auxiliary building **Stafford Place II** (4121 Wilson Boulevard) , **Room 555** [Stafford II is in front of the large shopping center]

However, first go to the NSF Security Office at the Reception Desk -- main NSF building/ corner of Stuart St & 9th St. You will be issued a personal badge. This badge is necessary to enter the NSF buildings and to access the conference room. The badge will be valid for the duration of the meeting. You will be asked to return the badge at your departure. If you have any issue, call Joan Miller at +1 703 292 4566. See instructions in separate document.

19 October

- Arrival of Subcommittee members and attendees

20 October

- 8h00 – 8h45 am: Subcommittee members and participants pick up their badges at the reception desk of the main NSF building ( ).

- Continental breakfast (Stafford II #555)

- 8h45 am: Opening Remarks (Mark Coles, NSF/BFA-LFO)
- 9h00 am: Welcome address (**Dr. Cora Marrett**, Deputy Director of the NSF)
- 9h15 am: Further preliminaries & Introduction (Tom Kirk, Chair)
- 9h30 am: Discussion Begins following participant self-introductions
- 10h30 am : Break
- 11h00 am**:** ***Discussion of the NSF and international partners processes for funding large facilities*** [appropriate documents will be provided]
- 12:15 pm: Lunch
- 1h30 pm: Discussion of Topic I

- 3h 15 pm: Break
- 3h45 pm: Discussion of Topic II
- 5h00 pm: Session adjournsS
- 7h00 pm: Dinner
  Reservation made at the Layalina Restaurant – Lebanese and Syrian Cuisine
  5216 Wilson Blvd
  Arlington, VA 22205
  Tel.: 703 525 1170

21 October

- 8h30 am: Continental breakfast

- 9h00 am: Discussion of Topic III
- 10h30 am: Break
- 11h00: Discussion of Topic IV
- Noon: lunch
- 1h30 pm: General discussion
- 3h30 pm: Break
- 4h00 pm: discussion of main findings
- 5h00 pm: Meeting adjourns

22 October (Subcommittee ONLY)

- 8h30 am: Continental breakfast

- 9h00 am: Subcommittee members draft main findings and recommendations
- 10h30 am: Break
- Noon: Meeting adjourned

{SOME OF THE) DISCUSSION TOPICS FOR ABOVE

1. Selection and prioritization of projects
2. Planning and implementing partnerships
3. Infrastructure management and governance models
4. Other issues/challenges to partnering

Appendix C

National Science Foundation
Ad-Hoc Subcommittee on Funding and Governance of
Future Major Multi-user Facilities

Subcommittee Membership

Dr. Howard Gordon – U.S. ATLAS Deputy Program Manager and Deputy Chair of the Brookhaven National Laboratory Physics Department, Brookhaven National Laboratory, Upton NY

Dr. Thomas R. Janecek – Program Director, Ocean Drilling Program, Division of Ocean Sciences, National Science Foundation, Arlington VA

Dr. Thomas B.W. Kirk (Subcommittee Chair) - Retired Associate Laboratory Director of High Energy and Nuclear Physics, Brookhaven National Laboratory, Upton NY and former Co-Chair of the NSF Business and Operations Advisory Committee

Dr. Paul Mantsch – Project Manager, Pierre Auger Observatory and Neutrino Detector subsystem manager, Long Baseline Neutrino Experiment, Fermi National Accelerator Laboratory, Batavia IL

Dr. Annick Pouquet – Director of the Geophysical Turbulence Program, National Center for Atmospheric Research, Boulder CO

Dr. Philip R. Schwartz - Distinguished Scientist, The Aerospace Corporation, Chantilly VA

NSF Organizing Committee Officers

Dr. Rodey Batiza - Section Head, Ocean Sciences Division, Arlington, VA

Dr. Mark W. Coles - Deputy Director for Large Facilities, Office of Budget, Finance and Award Management, Arlington, VA

Dr. Joseph L. Dehmer - Division Director, Physics Division, Arlington, VA

Dr. William L. Miller – Senior Analyst, Office of Budget, Finance and Award Management, Arlington, VA

Dr. Philip J. Puxley – Program Manager, Astronomical Sciences Division, Arlington, VA

Dr. Jean-Rene Roy – Large Facilities Officer, Office of Budget, Finance and Award Management, Arlington, VA