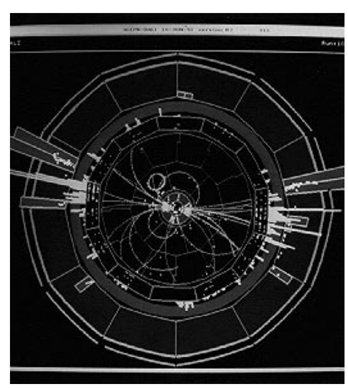
Overview and Findings 1

Over the past several decades, the federal government has supported a wide range of research projects in science and technology. Federal support has been crucial to many of the most important research and development (R&D) achievements in defense, space, energy, environmental, and other science and technology programs. Recently, however, federal budget deficits and concerns about the effectiveness of research efforts have intensified pressures on government R&D spending, making it difficult to sustain many ongoing efforts and limiting opportunities for new ventures. These pressures, coupled with the increasingly international character of science and technology R&D activities, have focused greater attention on bilateral and multilateral collaborative arrangements, particularly for large-scale, long-term projects in areas such as particle physics, energy and environmental science, and space.

The United States has pursued international collaborative projects in R&D to raise the likelihood of scientific success for particularly complex endeavors, to take greater advantage of international scientific expertise and facilities, to address science and technology issues that have global implications, to extend national scientific capabilities, and especially for very large science projects, to share costs and risks with other nations. International collaboration, however, poses special challenges, such as establishing R&D priorities within and across different scientific disciplines, developing funding and planning mechanisms that ensure the long-term stability of projects, and maintaining U.S. economic and national security interests.



This background paper, requested by the Chairman and Ranking Minority Member of the House Committee on Science,[1] examines the factors that may warrant or facilitate international collaboration in large science projects or, conversely, that may favor the United States pursuing projects independently. It identifies the challenges raised by international collaboration, such as reconciling collaboration with U.S. science goals, achieving equitable distribution of costs and benefits among nations, understanding the advantages and disadvantages of technology transfer, and dealing with increased project management complexity. In addition, the paper explores approaches that can promote the successful planning and execution of international projects.

Chapter 1 presents the principal findings of this background paper. Chapter 2 provides an overview of the broad trends in science and the rise of large projects. Chapter 3 examines U.S. science goals, the U.S. experience with collaborative projects in science, and their implications for future activities. The areas discussed include high-energy physics, fusion, space, neutron sources, and synchrotron radiation facilities. Chapter 4 explores the benefits and disadvantages of participating in international partnerships.

The issues addressed here are relevant to congressional authorization, appropriation, and oversight of ongoing and upcoming large science projects. These include the International Space Station and the International Thermonuclear Experimental Reactor (ITER), as well as U.S. participation in the Large Hadron Collider (LHC) project at the European Laboratory for Particle Physics (CERN).

Other important issues, however, are beyond the scope of this background paper. The overall process of priority setting and planning in federal research is not examined, nor are the relative benefits of big versus small science.[2] Also, the role of international collaboration as it relates to the area of defense R&D is not addressed.[3] In addition, the paper does not examine the broad commercial aspects of government-sponsored basic science research. Basic research can provide the underpinning for commercial innovation and technology development. The possible commercial implications of large science research projects (which are not limited to the consequences of basic research) will continue to be an important issue in structuring international partnerships, selecting projects for collaboration, and sharing their benefits and burdens (see chapter 2).

BACKGROUND

The Internationalization of Science and the Role of Big Science Projects

International collaboration in scientific research and the rise of large science projects are two significant outgrowths of the scientific revolution of the past century. This revolution has brought unprecedented increases in the speed of scientific and technical innovation. The sheer pace of this change has transformed the fabric of daily life, affecting the course of economic and social development as well as the relationship between society and the natural world. Along with an increased rate of scientific innovation and knowledge generation, there has also been (especially in the past 50 years) a marked expansion of the breadth, cre-

[1] Previously, the House Committee on Science, Space, and Technology.

[2] For a discussion of these issues see U.S. Congress, Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade*, OTA-SET-490 (Washington, DC: U.S. Government Printing Office, May 1991).

[3] Cooperation with its allies in the supply and joint production of defense technology has been an important element of U.S. national security policy over the past four decades. See U.S. Congress, Office of Technology Assessment, *Arming Our Allies: Cooperation and Competition in Defense Technology*, OTA-ISC-449 (Washington, DC: U.S. Government Printing Office, May 1990).

ativity, and sophistication of basic and applied research.[4] These qualitative changes have been accompanied by the growth of interdisciplinary research, which in turn has opened up new fields of inquiry. With the development and diffusion of powerful information and communications technologies,[5] the extraordinary pace of scientific discovery continues to accelerate. These new technologies have facilitated collaboration within and across scientific disciplines.

The expanding range of scientific and technological undertakings, and the development of new tools to expedite the exchange of information, have reinforced and augmented the international dimension of scientific research. This internationalization affects the nature of scientific inquiry, the transmission of information among scientists and programs, the development of interdisciplinary research, and the structure of transnational research initiatives. For example:

- The increased ability to coordinate research across international borders has stimulated ambitious research on global scientific questions such as climate change.
- The rapid global exchange of information has internationalized the results of almost all scientific research, even projects and investigations that are essentially national in character.
- The growth of cross-disciplinary research has been closely linked to greater interaction among researchers across international borders, stimulating the expansion of international scientific collaborations supported by a variety of national and international agencies and institutions.

The scale and scope of scientific research have expanded simultaneously with the growth of international activities. Although much research is still conducted on a small scale by individual investigators working in small laboratories, the past few decades have witnessed the development of very large science projects—called big science or megascience projects.

Defining "Big Science"

Although it is relatively easy to identify certain extremely large projects as megascience, it is more difficult to devise a generic definition of the term. Big science projects exist in a range of fields and share a number of common traits. Typically, and most simply, big science has meant "big money plus big machines." Megascience projects involve large, interdisciplinary teams of researchers, including both engineers and scientists. Such projects usually employ more complex and hierarchical management structures than smaller science projects. Big science ventures are almost always supported by governments. However, industry plays a more central role (as a contractor and recipient of federal funds) than it does in "small" science because of the need to build large, capital-intensive, high-technology facilities. Big science projects vary in scale and complexity, and reflect the different R&D goals and scientific capabilities of nations. They also vary in their commercialization potential and in the degree to which they address broad national or global needs. Some big science projects are based around a single facility, whereas others are distributed among several locations and institutions.[6]

[4] Although there is some overlap between basic and applied research, the following distinction can be offered: "Basic research pursues fundamental concepts and knowledge (theories, methods, and findings), while applied research focuses on the problems in utilizing these concepts and knowledge." Office of Technology Assessment, *Federally Funded Research*, see footnote 2.

[5] For example, the Internet—a set of interconnected computer networks that share a common set of communications protocols—links tens of millions of users worldwide via electronic mail and other communications services. Internet access is currently available in more than 160 countries, with connections being added almost daily.

[6] This aspect of project structure—single-site versus distributed projects—can profoundly alter the character of international collaboration and the benefits and challenges that underlie it. For example, the siting of international scientific facilities has been a contentious issue in some collaborations. See finding below.

TABLE 1-1: Total Estimated Costs of Selected Big Science Projects

Project	Year of completion [estimated]	Capital cost[a]	Participants
High-energy and nuclear physics			
Stanford Linear Collider	1987	$115 million	U.S.
Continuous Electron Beam Accelerator Facility	1995	$513 million	U.S.
Advanced Photon Source	1996	$812 million	U.S.
B-Factory	1998	$293 million	U.S.
Japanese Spring-8 Synchrotrons	1998	$1 billion	Japan
Relativistic Heavy Ion Collider	1999	$595 million	U.S.
Superconducting Super Collider	Canceled	$8 billion-$11 billion	U.S.
Proposed neutron spallation source[b]	2005-preliminary planning stage	~$1 billion (no definite estimate available)	U.S.
Large Hadron Collider (LHC)	2005	$2.3 billion[c]	Europe (CERN), U. S., Japan
Fusion			
Tokamak Physics Experiment	2001	$694 million	U.S.
International Thermonuclear Experimental Reactor (ITER)	2005	$8 billion-$10 billion[d]	U. S., Europe (Euratom) Japan, Russia

(continued on next page)

Although it downplays other factors, cost is probably the most important characteristic of big science projects. If project funding is used as the main criterion, a few very large projects clearly stand out as megaprojects. These include the space station (total estimated capital cost, $38 billion[7]), ITER (total estimated construction cost, $8 billion to $10 billion), CERN's Large Hadron Collider (current estimated cost, $2.3 billion[8]), and the proposed neutron spallation source[9] (estimates begin at $1 billion). All of these projects are in the billion-dollar (plus) class, and all—with the exception of the neutron spallation source—involve significant international collaboration. The failure to attract international support was a principal factor in the decision to terminate the multibillion dollar Superconducting Super Collider (see finding below). Table 1-1 shows estimated completion dates and costs for selected big science projects.

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[7] This figure is based on the following costs as reported by the National Aeronautics and Space Administration (NASA): pre-FY 1994 costs: $10.2 billion; shuttle launch costs (based on an average cost of about $500 million per flight): $14 billion. NASA reports $17.4 billion in construction costs from FY 94 through station completion. However, this figure includes $3.7 billion in operations and science costs, as identified by the General Accounting Office. This $3.7 billion has been excluded from OTA analysis. Source: NASA, Space Station Program Office, April 1995. NASA provided data to the House Committee on Science, Space, and Technology that account for the above costs, plus civil service and operations costs through the first 10 years of operations. These figures indicate that total costs for the station will be $72.3 billion. See Marcia Smith, *Space Stations* (Washington, DC: Library of Congress, Congressional Research Service, Apr. 6, 1995), p. 4; and U.S. General Accounting Office, "Space Station: Estimated Total U.S. Funding Requirements," GAO/NSIAD-95-163, June 1995, p. 4.

[8] The estimated cost for the LHC would be roughly twice as large ($4 billion to $5 billion) if it were developed on the same accounting basis as U.S. cost estimates. Also this figure does not include the detectors, which may total as much as $2 billion. CERN has asked the United States to contribute approximately $400 million to this project. This contribution could also include in-kind contributions such as equipment. The Department of Energy, however, will not be in a position to recommend any specific level of LHC funding until overall Department cost reduction goals through 2001 are developed. Harold Jaffe, Department of Energy, Office of High Energy and Nuclear Physics, personal communication, April 1995.

[9] The accelerator-based neutron spallation source has been proposed by the Clinton Administration as an alternative to the recently canceled nuclear reactor-based Advanced Neutron Source. The European Union is also in the preliminary planning stage for a spallation source, but no formal efforts have yet been made to explore the possibility of collaboration. See chapter 3.

TABLE 1-1: Total Estimated Costs of Selected Big Science Projects (Cont'd.)

Project	Year of completion (estimated)	Capital cost[a]	Participants
Space[e]			
Hubble Space Telescope	1990	$2.3 billion	U. S., Europe (ESA)
Compton Gamma Ray Observatory	1991	$957 million	U. S., Germany
Advanced X-Ray Astrophysics Facility	1998	$2.1 billion	U. S., Germany, Netherlands, U.K.
Cassini	1998	$1.9 billion	U. S., ESA, Italy
Earth Observing System	2000 (initial components)	$8 billion	U. S., ESA, Canada, Japan, France, Eumetsat
Space station	2002	$38 billion	U. S., Russia
Canadian Mobile Servicing System for the space station	1998-2002	$1 billion	Canada
Japanese Experimental Module for the space station	1998-2002	$3 billion	Japan
Proposed European Space Agency (ESA) module and equipment for the space station	1998-2002	$3 billion[f]	ESA
Ground-based astronomy and physics			
Gemini telescopes	1998-2000	$176 million[g]	U. S., U. K., Canada, Chile, Argentina, Brazil
Laser Interferometer Gravitational Wave Observatory	1999	$231 million	Us.

[a]Figures represent construction and development, exclusive of operational expenses, which can raise project costs considerably. Figures represent dollars as spent or projected, unadjusted for Inflation.

b The Neutron Spallation Source is being proposed to replace the canceled Advanced Neutron Source

[c]The estimated cost for the LHC would be roughly twice as large ($4 billion to $5 billion) if it were developed on the same accounting basis as U.S. cost estimates. Also this figure does not include the detectors, which may total as much as $2 billion. The proposed U.S. contribution to the project is $400 million U.S. scientists are already deeply involved in the design and construction of two LHC detectors.

[d]The U.S. share is currently 25 percent of the engineering design cost. Detailed cost estimates for ITER are not yet available. There has been no agreement among the parties about whether ITER will be built or what the U.S. share of construction costs would be.

[e]For U S space projects, figures reflect U.S. cost only.

[f]Unofficial ESA estimate.

[g]The U.S. share is $88 million.

SOURCE U S Congress, Office of Technology Assessment, 1995, based on figures from: William Boesman, Congressional Research Service, "Big Science and Technology Projects: Analysis of 30 Selected U.S. Government Projects," August 1994; Genevieve. Knezo, *Major Science and Technology Programs: Megaprojects and Presidential Initiatives, Trends Through FY 1996, Requested,* CRS Report for Congress (Washington, DC Congressional Research Service, Mar. 27, 1995); NASA Budget Operations Office; and Tormod Riste, *Synchrotron Radiation Sources and Neutron Beams* (Pans, France Organization for Economic Cooperation and Development, Megascience Forum, 1994).

Below the billion-dollar project level, it becomes more difficult to use funding to determine what constitutes megascience. A recent Congressional Research Service report on civilian big science and technology (S&T) projects identified 30 S&T development projects that cost more than $100 million in 1980 dollars.[10] Of these, 10 had

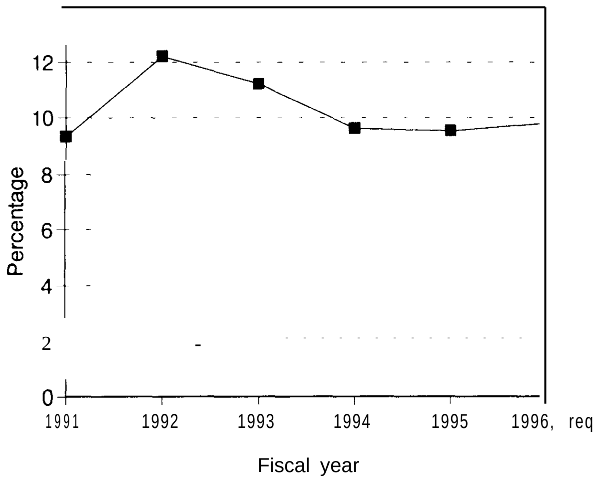
[10] William Boesman, *Big Science and Technology Projects: Analysis of 30 Selected U.S. Government Projects,* CRS Report for Congress, 94-687 SPR (Washington, DC: Congressional Research Service, Aug. 24, 1994).

been terminated,[11] leaving 20 projects completed or currently under way. Of these 20 projects, 16 were single-facility, basic science projects, accounting collectively for more than $50 billion of past, current, and proposed federal science spending (exclusive of operations costs). For the purposes of this report, the Office of Technology Assessment (OTA) has chosen to concentrate on the class of megaprojects that cost more than $100 million.

The budget impacts of these megaprojects have drawn considerable attention in the scientific community and Congress. In the United States, megaprojects account for about 10 percent of the federal (defense and nondefense) R&D budget[12] (see figure l-l). Although the growth of megaprojects appears to have leveled off somewhat, this trend could be reversed as several big science projects are brought up for congressional consideration over the next few years.[13] Thus, megaprojects merit attention not just because of their extraordinary size, but also because their large and potentially growing share of federal spending poses fundamental questions about the character of the nation's R&D portfolio.

In recent years, the high costs and scientific rationale of some megaprojects have been severely criticized, especially by those who regard small science as the foundation of the nation's R&Denterprise. In some cases, however, there can be a complementary relationship between small science and big science. For example, the National High Magnetic Field Laboratory and the Advanced Photon Source (an advanced x-ray synchrotrons facility) will essentially serve as platforms for small science, and thus reinforce the research support given to individual investigators across many disciplines.[14] Telescopes provide another example of large devices or facilities that serve individual investigators. But many other large projects do not directly complement small science activities. Priority setting is therefore becoming much more of an issue because all proposed megaprojects may not be supportable without affecting the underlying national science base.

FIGURE 1-1: Civilian and Defense Megaprojects as a Percentage of Total R&D, FY 1991-FY 1996, Requested



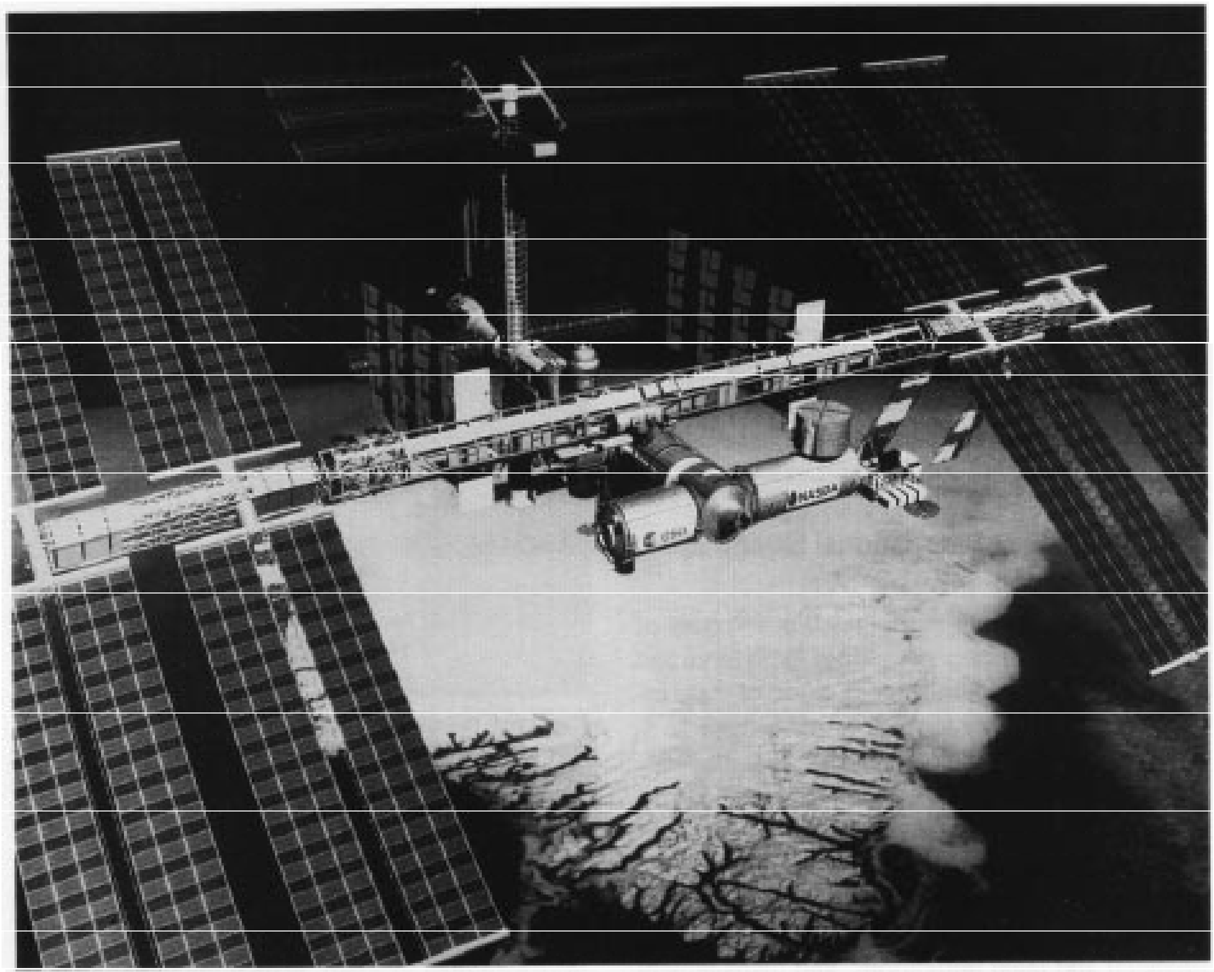
SOURCE: Genevieve J. Knezo, *Major Science and Technology Programs, Megaprojects and Presidential Initiatives, Trends Through FY 1996, Requested,* CRS Report for Congress (Washington, DC: Congressional Research Service, Mar 27, 1995), p. CRS-4

[11] An additional two programs (Advanced X-Ray Astrophysics Facility and Comet Rendezvous Asteroid Flyby Mission/Cassini) were partially terminated.

[12] This figure is based on a "basket" of large projects tracked by the Congressional Research Service. See Genevieve J. Knezo, *Major Science and Technology Programs: Megaprojects and Presidential Initiatives, Trends Through FY 1996, Requested,* CRS Report for Congress (Washington, DC: Congressional Research Service, Mar. 27, 1995).

[13] For example, carrying out the present development plan for a tokamak fusion reactor implies a doubling or even tripling of the annual magnetic fusion budget from its present level ($373 million in FY 1995). See chapter 3.

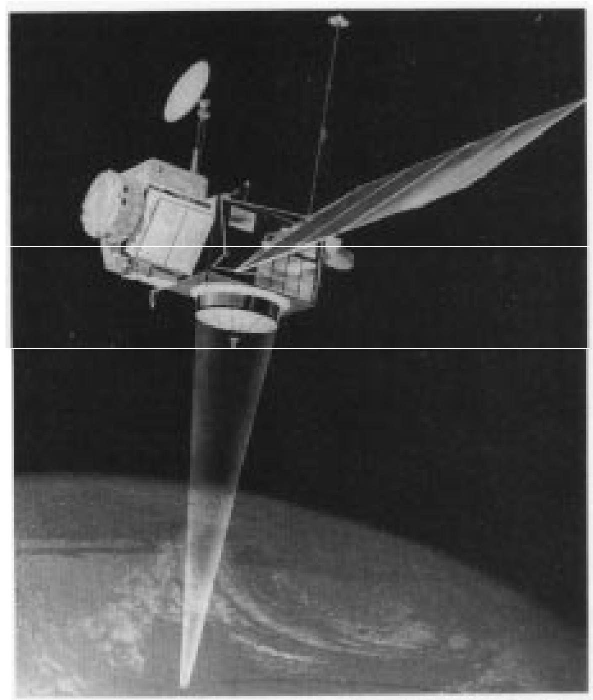
[14] These facilities will be used by researchers in a number of different fields, including materials science, condensed matter physics, chemistry, and molecular biology.



The International Space Station is depicted in its completed operational state, with elements from the United States, Europa, Canada, Japan, and Russia.

Why Are Big Science Projects So Big?

The development of large projects has been driven by several factors. In some fields of inquiry, scientific projects or undertakings must be large in scale in order to advance and demonstrate the underlying science or to achieve specific technical goals. For example, probing the high-energy domains that will provide new insights into the fundamental characteristics of matter, or demonstrating the feasibility of controlled nuclear fusion, will require apparatus (accelerators, detectors, reactors) of unusual size and sophistication. The International Space Station project—an effort to build and operate a permanently occupied Earth-orbiting facility-is, by its very nature, a complicated, immense undertaking. Other classes of problems, such as climate change, are truly global in nature. They require broad-based multinational, multidisciplinary initiatives to develop better scientific understanding of fundamental



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The Ocean Topography Experiment (TOPEX)/Poseidon is a cooperative project between the United States and France to develop and operate an advanced satellite system dedicated to observing the Earth's oceans.

physical processes and to ensure the international credibility of scientific results.[15]

Other motives, less directly related to basic research questions, also underlie the development of megaprojects. Large science projects are often viewed as symbols of national prestige. They may, in addition, serve as vehicles for building up domestic capabilities indifferent scientific and technical fields, and thus enhancing national economic productivity.[16] Political or foreign policy imperatives confronting governments can play an important role in launching large projects, as can the desire of research institutions to sustain or enlarge their portfolio of programs.

■ Experience in International Scientific Collaboration

The United States has participated in a variety of international science undertakings, both large and small, over the past few decades. Some of these international activities have developed from U.S. domestic projects. The United States has also participated in joint research organizations and projects, and is a contributing member in still other arrangements and organizations. This scientific collaboration can take many different forms involving varying degrees of research integration, financial and legal obligations, and management oversight, as described in box 1-1. Large projects have covered a broad spectrum of activity from pure fundamental research to near-commercial demonstrations (e.g., coal gasification).

For decades, the United States has enjoyed numerous successful small-scale scientific cooperative efforts, principally through bilateral agreements. Typically, these agreements involve the exchange of information ardor scientists and provide for access to facilities. There have also been a number of small- to medium-scale collaborative efforts involving the development of specialized instrumentation sponsored by the Department of Energy (DOE), the National Science Foundation, and the National Aeronautics and Space Administration (NASA) .17

Big science projects, however, present a different picture. Until recently, the United States has approached most megascience projects as primar-

[15]The worldwide global change research program, as presently conceived, could have a cumulative multinational cost approaching $l00 billion by the year 2020. See President's Council of Advisors on Science and Technology, *Megaprojects in the Sciences* (Washington, DC: Office of Science and Technology Policy, Executive Office of the President, December 1992).

[16]For example, the expertise gained from the development of superconducting magnet technology for particle accelerators and for magnetic fusion could ultimately be applied to such commercially important applications as magnetic resonance imaging, electric motors, advanced materials processing, and energy storage. U.S. Congress, Office of Technology Assessment *High-Temperature Superconductivity in Perspective,* OTA-E-440 (Washington, DC: U.S. Government Printing Office, April 1990).

[17]For example, DOE has been involved with a variety of multilateral cooperative activities under the auspices of the Internationd Energy Agency. See chapter 3 for a discussion of NASA's long history of collaborative activity.

ily domestic ventures. Most U.S. high-energy physics, space, and fusion facilities have been designed and funded as national projects, even though there has been growing collaboration in these fields at operational levels.[18] The U.S. experience in international collaboration in science and technology R&D—where research efforts are highly interdependent and jointly funded and conducted—is actually quite limited. The United States is only now starting to participate in the joint planning, construction, and operation of large facilities or platforms (e.g., ITER and the U.S.-Russian activities associated with the space station.)[19] These represent more integrated forms of collaboration than the compartmentalized approaches in which partners work independently on discrete elements of a project, as in the case of the European and Japanese components of the space station. The United States is still discovering what particular approaches to international collaboration can lead to stable, successful execution of long-term projects.

In contrast to the United States, other industrialized countries, especially the nations of Western Europe, have had more extensive experience with scientific collaborations in projects of all sizes. Europe's long history of collaboration has been motivated and facilitated by a variety of factors including close geographic proximity, demography, high levels of nonscientific interchange among partner countries, and joint competition with the United States. In addition, the treaty establishing the European Union calls for joint research activities and programs among member states. Yet, it must also be noted that European countries collaborate extensively in large measure because they effectively have little choice. The funding requirements and technical breadth of modern science R&D—especially megaprojects—often make it necessary for European countries to join forces across a broad spectrum of projects and disciplines. This trend has strengthened in recent years. In the eyes of some observers, European scientific collaboration has now become the norm, driven by European political integration and the need to pool scientific and financial resources.

Why Collaborate?

Given the breadth, ingenuity, and vitality of the modern scientific enterprise, policymakers in virtually all countries are confronted with difficult choices in establishing priorities for R&D. Included in this process of priority setting and project selection is determining whether large-scale international science undertakings complement national science goals and to what extent they should be supported. At a time when all governments are sensitive to the strategic economic advantages that can accrue from knowledge-based or technology-based industries, participation in international projects is evaluated closely. Although some countries may see distinct benefits associated with multinational partnerships, others may deem participation in particular projects inconsistent with the national interest. The latter may be particularly true if a nation is attempting

[18]Examples of national facilities are the Fermi National Accelerator Laboratory, the Stanford Linear Accelerator Center, the National High Magnetic Field Laboratory at Florida State University, and the Advanced Photon Source at Argonne National Laboratory. Each of these facilities have open access policies that encourage collaboration with foreign scientists.

[19] Although Canadian robotics have been on the space station's critical path from the beginning, the U.S. agreement with Canada provides for all Canadian hardware, drawing, and materials to be turned over to NASA in the event Canada withdraws from the program. This gives the agency ultimate control over the contribution and its underlying technology. The same provisions governed the development of Canada's robotic arm for the space shuttle.

BOX 1-1: Forms of International Collaboration

International scientific cooperation ranges from simple exchange of information and personnel in particular areas of research to joint planning, design, and construction of equipment or facilities. As cooperative arrangements become more complex in scale or scope, the need for more formalized organizational and managerial arrangements increases. The levels of program integration, information transfer, and financial and political commitment depend on the nature of the collaborative activity. Historically, many areas of international cooperation have proceeded on the basis of mutual trust. However, big science activities involving significant expenditure of human and financial resources require well-defined agreements that delineate specific project objectives and responsibilities.

International scientific collaborative activities can be classified into four broad categories:[1]

The **joint construction and operation** of large-scale experiments and facilities IS the most highly structured and Interdependent form of multilateral collaboration. It involves close partnership among project participants, with each country having a roughly equal voice in project planning, financing, and management. This type of cooperation sometimes involves the creation of elaborate institutional mechanisms to facilitate project decisionmaking and execution. Examples include the European Laboratory for Particle Physics (CERN), a 17-nation consortium that pursues research in high-energy physics; the International Thermonuclear Experimental Reactor (ITER) engineering design activity being pursued by the United States, Japan, Europe, and Russia; and the European Space Agency (ESA), a 14-member organization to pursue joint European activities in space.

Lead country collaborations are a less integrated mode of collaboration. Here, one country assumes the lead in pursuing a particular project while inviting other countries to make technical and financial contributions without taking on significant management responsibilities. The space station is one example of this type of collaboration. The National Aeronautics and Space Administration retains principal decisionmaking authority over its design and planning, while integrating specific technical modules or components from Russia, Japan, and Europe. Another example is the Hadron-Electron Ring Accelerator In this project, foreign countries are paying about 30 percent of the costs of operating this German national facility. Other illustrations of this type of cooperation include the international Ocean Drilling Program, initiated and led by the U.S. National Science Foundation; detector experiments at the Fermi National Accelerator Laboratory, to which Japan and Italy contributed key components; and the Japanese Planet-B mission to Mars, which involves five different countries.

to preserve or develop national expertise in a particular scientific or technological field.[20]

In the United States, the decision to collaborate rather than pursue research on a domestic basis has been determined by a set of factors specific to U.S. science goals and other interests. The goal of establishing and maintaining leadership in as many scientific fields as possible was especially important during the Cold War and dominated the U.S. approach to collaboration through the late 1970s. However, the development of scientific ambitions and expertise abroad, the constriction of U.S. government resources at home, and the end of the Cold War may require both a redefinition of U.S. leadership and a reformulation of the U.S. approach to international scientific collaboration. In addition, other goals—including economic competitiveness, foreign policy and na-

[20] As an illustration, the construction of Japan's Subaru telescope in Hawaii is linked to building up its domestic astronomy program and attracting young people to the field. For this reason, Japan chose not to join the multilateral Gemini collaboration. Other examples include various national efforts to develop sophisticated capabilities in launching and deploying satellites.

BOX1-1: Cont'd.

Distributed science projects, in which countries separately design, fund, and direct portions of a larger coordinated project, are another form of collaboration. Examples of distributed science projects include data gathering under the auspices of the worldwide Global Change Research Program; harmonization efforts for human genome research under the Human Genome Organization, sponsored by the United States and Europe; and the International Solar-Terrestrial Physics Programme involving Japan, Europe, the United States, and others.

The final category of international cooperation entails specific **user group projects,** in which individual researchers or governments use the experimental facilities or capabilities of other countries, but provide the necessary equipment or financing for specific experiments. The use of another country's space capabilities to launch satellites illustrates this type of cooperation. Building instrumentation that can be used at large neutron beam or synchrotrons radiation facilities is another example. When large facilities are involved, formal and informal arrangements have allowed scientists from one country "reciprocal" access to similar facilities in other countries.

Each of these collaborative forms permits, to differing degrees, the opportunity to reduce or share costs; to leverage intellectual resources and technical capabilities; and depending on the nature of the project, to address wider global concerns such as improved international stability.

[1]This Classification has been suggested by William A Blanpied and Jennifer S Bond, "Megaprojects in the Sciences," *Megascience and its Background,* OECD Megascience Forum (Paris, France: Organization for Economic Cooperation and Development, 1993), pp. 43-44.

tional security priorities, and environmental and social considerations—increasingly affect the U.S. attitude toward collaboration.[21]

Current and recent collaborations illustrate the difficulty in deciding whether to collaborate and the challenges in clearly defining U.S. goals. OTA's review of the U.S. experience in international cooperation in high-energy physics, fusion, and space has identified several advantages and disadvantages associated with collaborative ventures.

The scope and complexity of some scientific initiatives may by their very nature require a multinational collaborative effort to ensure that research objectives are successfully achieved.[22] Indeed, collaboration has long been used to enhance the scientific and engineering capabilities in R&D projects. The pooling of intellectual and technical resources from throughout the world has led to important experimental and theoretical advances in a variety of scientific fields. Moreover,

[21]See, for example, William J. Clinton and Albert Gore, Jr., *Science in the National Interest* (Washington, DC: Executive Office Of the president, August 1994), which sets forth broad science and technology policy goals of the Clinton Administration; and National Academy of Sciences, *Science, Technology, and the Federal Government: National Goals for a New Era* (Washington, DC: National Academy Press, June 1993), which suggests a framework for establishing science goals and priorities and rethinking the role of "scientific leadership." See also: Ralph Gomory and Hirsh Cohen, "Science: How Much Is Enough?" *Scientific American,* July 1993, p. 120; and Eugene B. Skolnikoff, *The Elusive Transformation: Science, Technology, and the Evolution of International Politics* (Princeton, NJ: Princeton University Press, 1993).

[22]For example, some scientific initiatives, such as climate change research, may require that research be carried out at several geographic locations around the world. For other initiatives that involve great technical complexity, such as the effort to harness fusion power, collaboration is viewed by many scientists as an important and even necessary vehicle for achieving project goals.

with the emergence of new centers of innovation abroad, the only way for the U.S. scientific community to extend its expertise in particular areas may be through collaboration.[23] As the scientific and technical competencies of other nations become comparable to or even surpass U.S. capabilities,[24] the United States may have to place a greater emphasis on having access to foreign facilities and participating in multilateral R&D projects if it is to remain competitive in different technical fields. In addition, the upgrading of U.S. scientific facilities may be necessary to encourage other countries to cooperate with the United States on both large and small projects.[25] These considerations underscore the need for reassessing the concept of leadership and how national scientific expertise can be most effectively advanced, as well as examining the nature of partnership and the various approaches to collaboration.

Another motivation for pursuing collaboration is economic. Concerns over the huge scale and large cost of some new projects have led scientists and policymakers in many countries to suggest sharing the burdens internationally. Collaboration is seen by some as particularly important to capital-intensive research endeavors that lack short- or medium-term commercial viability. This view has been presented to support international research projects such as ITER and the space station. Collaboration can reduce the net costs that individual nations must bear, though the aggregate cost of a multinational project may sometimes be greater than that of a project carried out by a single country. International projects may require the creation of elaborate management and logistical arrangements. For example, engineering design activities for the proposed ITER project are being carried out at three separate locations in the United States, Japan, and Germany. Also, in some cases, cost savings may not be as great as expected, because participation in international ventures still requires that investments be made in national programs. Without such investments, it may not be possible for individual countries to benefit fully from the advances coming from international projects.

Domestic and international political considerations can also be factors in pursuing collaboration. Projects are sometimes internationalized to raise their political profile and thereby ensure the continuity of funding. For instance, the formal involvement and integration of Russia in the planning and operation of the International Space Station project was to some degree motivated by the U.S. desire to support the Russian reform process and to promote Russian adherence to the Missile Technology Control Regime.[26] Political goals have also been an important aspect of European collaborative science projects.[27]

Other factors, related to changes in the nature of R&D itself, have induced both scientists and

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[23]For example, after the cancellation of the Superconducting Super Collider, a DOE advisory panel recommended that the United States formally join the Large Hadron Collider project at CERN to ensure that U.S. scientists remain at the forefront of accelerator design and physics investigation. See U.S. Department of Energy, Office of Energy Research, Division of High Energy Physics, *High Energy Physics Advisory Panel's Subpanel on Vision for the Future of High Energy Physics*, DOE/ER-0614P (Washington, DC: May 1994).

[24]See footnote 21.

[25]Many large U.S. science facilities operate at limited capacity because of funding constraints. In addition, there is a need for upgrading equipment and instrumentation. The fiscal year 1996 budget of the Clinton Administration proposes "adding $100 million above the 1995 level to significantly enhance the usage of major DOE-operated basic research facilities." This initiative will "facilitate a more efficient use of the facilities, boost the number of users by several thousand over 1995, and improve the quality of service." See *Budget of the United States Government, Fiscal Year 1996* (Washington, DC: U.S. Government Printing Office, 1995), p. 97.

[26]See U.S. Congress, Office of Technology Assessment, *U.S.-Russian Cooperation in Space*, OTA-ISS-618 (Washington, DC: U.S. Government Printing Office, April 1995).

[27]See Antonio Ruberti and Michel Andre, "The European Model of Research Cooperation," *Issues in Science and Technology*, spring 1995, pp. 17-21.

policymakers to give greater consideration to international cooperation. The global nature of some scientific areas, such as the environment, may necessitate a more international orientation for basic research. The widespread applicability of new technologies coupled with the globalization of business may also support a more explicit international approach to scientific innovation. Increasingly, R&D activities in the private sector involve strategic alliances among companies from many different countries.[28]

Challenges and Limitations of International Collaboration

While international collaboration may play an increasingly prominent role in R&D, there remains a variety of challenges and limitations. Collaboration raises fundamental questions about national goals and the U.S. role in scientific and technological innovation. Efforts to increase U.S. participation in international cooperative ventures potentially conflict with the U.S. desire to maintain scientific leadership, prestige, and project control.

A number of issues associated with project financing also can make it difficult to initiate, structure, and execute international projects. The difficulty in guaranteeing long-term financial commitment by all project partners introduces an element of instability to international undertakings. In discussions with OTA, European and Japanese government officials and scientists particularly questioned the reliability of the United States in maintaining the continuity and level of funding necessary for international R&D agreements. Distributing project costs and benefits in a more or less equitable manner among partners continues to complicate collaborations. Furthermore, some projects may be so expensive or involve such a high level of technical uncertainty that, even with multilateral burden sharing, the cost of U.S. or any other nation's participation could be prohibitively high. And this of course could make it difficult to generate the political support necessary to initiate and sustain such projects.

Another challenge to multinational projects is that the collaborative process itself may inhibit innovation by limiting competition among researchers. Due to the need to achieve technical consensus, collaboration that involves many partners might lead to projects that have somewhat conservative technical or scientific goals. ITER, for example, has been criticized by some observers for having a fairly conservative design because planners want to ensure that ignition of fusion fuel can actually be achieved. However, collaboration can also give rise to creative approaches or solutions because of the wider base of scientific talent that can be tapped. The success of the LHC project at CERN, for instance, is dependent on some extremely ambitious magnet and detector technologies. Moreover, it is possible to retain elements of competition within single large science projects—for example, when two or more research groups independently build and operate detectors while using the same particle accelerator. A key objective for all collaborative activities is to ensure that project objectives can be realized without suppressing innovative ideas or techniques.

Other challenges to international collaboration include the need for elaborate management and decisionmaking mechanisms and the possible loss of commercial advantage through the transfer of leading-edge national technologies. An additional issue involves striking an appropriate balance between the resources dedicated to collaboration and the need for maintaining a domestic education and R&D infrastructure to sustain and profit from a collaboration. Finally, for

[28]One example is the multi-billion dollar development effort of IBM, Toshiba, and Siemens to develop next-generation semiconductor memory technology. See "Computer Chip Project Brings Rivals Together, But the Cultures Clash," *Wall Street Journal*, May 3, 1994, p. A1.

some R&D projects, there may exist significant scientific and economic implications that could warrant the pursuit of purely national efforts.[29]

Policymakers within both the legislative and the executive branches have suggested various strategies to address the challenges of project selection and funding stability. Under one approach, countries would cooperate in prioritizing and selecting proposed big science projects from a variety of disciplines by placing these projects in a common "basket" where their relative costs and benefits could be traded off against each other. Others have suggested creating new international organizations to coordinate information, facilitate collaborations, or manage new international projects. Potential mechanisms for ensuring greater administrative and funding stability in multinational collaborations have also received the attention of policymakers and the scientific community. Proposals have been made that Congress adopt specific multiyear authorizations or appropriations for large projects to promote their long-term viability.

FINDINGS

The opportunities and challenges of international collaboration indicate a series of important issues to consider in structuring future large science undertakings. OTA's principal findings are presented below.

- **Big science projects cover an array of disciplines and vary considerably in form and purpose. Thus, funding and research prioritization decisions for big science projects are likely to be more effective and appropriate within their respective research fields, rather than among a group of unrelated costly projects.**

Large science projects are relatively few and highly diverse. They differ in scale, complexity, structure and the degree to which broad national or global needs are addressed. As a consequence of their differences, the scientific and social returns from big science projects tend to be incommensurate both within a particular project and among projects. For example, some projects involve the design and construction of a single large instrument such as an accelerator, while others like the Human Genome Project entail coordination of research activities that are widely dispersed. One project may have an explicit scientific rationale, while another may have broad economic, educational, or foreign policy objectives.

Although it may appear reasonable to lump big projects together for policy and budgetary reasons, in practice their disparate characteristics generally preclude concrete project-to-project comparisons. These characteristics of diversity and the difficulty in balancing costs and benefits among projects have important implications for policies addressing big science:

- Generic frameworks for setting priorities among large science projects on a national or international basis are probably not workable.
- The overall scientific merit as well as the associated costs and benefits of different projects are most effectively evaluated within the broader research and budgetary context of each specific scientific field.
- The appropriateness and extent of international collaboration in any large science project can be determined only on a case-specific basis.

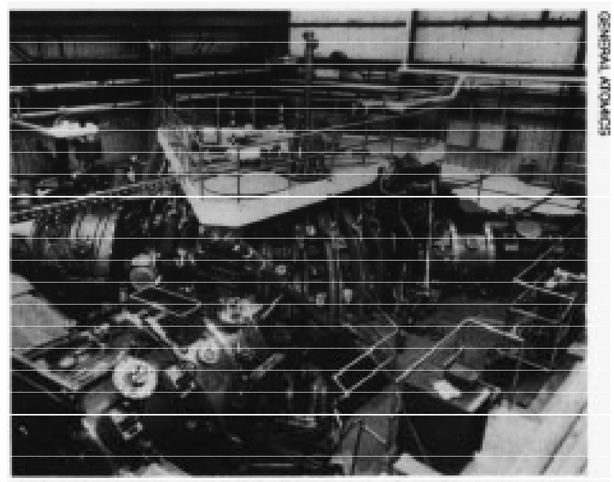
While big science projects continue to draw congressional attention, they are only one example of the major budget challenges facing federal R&D efforts overall. Priority setting occurs

[29]For example, synchrotron radiation facilities are heavily used by U.S. academia and private industry, and thus might be regarded as essential investments in national scientific infrastructure. In the area of applied research, the federal government has spent nearly $800 million over an eight-year period in supporting the SEMATECH consortium. This consortium of U.S. semiconductor producers and suppliers was created to bolster U.S. capabilities in semiconductor processing and manufacturing to ensure a viable microelectronics commercial and defense base. U.S. member companies matched the government contributions to the project.

throughout the federal government at many different levels. At the highest level, scientific priorities are compared to other conscience needs. Priorities are also determined within particular disciplines. .However, attempts at setting priorities across different scientific fields have suffered from a lack of consensus and have been largely unsuccessful. Because large projects are not readily comparable, and their political components make each unique,[30] any attempt to develop a priority-setting scheme for big projects is likely to encounter a variety of obstacles. Consequently, the largely ad hoc funding process for big projects will be diffi cult to change. Still, many observers believe that some mechanism of priority setting for large projects, whether domestic or international, is essential.[31]

These observations have particular relevance to the proposed basket approach, under which major science projects in different disciplines would be identified and placed in a common group or basket for nations to select or trade off one project against another. For example, if two or more big science projects were being built contemporaneously, there hypothetically could be some trading of costs and benefits between them. Under this scenario, one nation might agree to host a new high-energy physics facility, while another might host a fusion facility. In theory, this would provide a means for different countries to share both the burdens and the benefits of international science facilities. It could also be a vehicle for building political support for projects by demonstrating that foreign partners are willing to contribute to projects in other countries, as well as those that are based at home.

In practice, however, the basket approach has a variety of limitations. The timing and development of various projects usually differ significantly, and thus they cannot easily be lumped together. In addition, projects can encompass very different technologies, and consequently individual countries may be interested in participating or hosting particular projects and not participating in others. Big projects also have a variety of objectives. For example, while some large science projects may have very specific goals such as achieving controlled ignition of fusion fuel (ITER) or discovering anew class of fundamental particles (the LHC at CERN), others may have a broader set of purposes. As an illustration, neutron sources and synchrotron facilities essentially serve as platforms for small science undertakings. Although the costs of these platform facilities maybe considerable,[32] they could be regarded as long-term investments that provide the underlying infrastructure for decades of research in a variety of different disciplines (e.g., materials science, sol-



Under a bilateral agreement, the Japanese contributed to operations and upgrade of the Doublet III-D (0/1/-0) tokamak at General Atomics in San Diego in exchange for "hands-on" operating experience later transferable to their new JT-60 tokamak.

[30] For example, some programs and projects, particularly those that are capital-intensive, have developed strong industrial constituencies.

[31] For example, see William A. Blanpied and Jennifer S. Bond, "Megascience Projects: Challenges for the 21st Century," prepared for the International Workshop on Equipping Science for the 21st Century, Amsterdam, The Netherlands, April 1992. For a discussion of possible criteria that might be used in cross-discipline priority setting see Office of Technology Assessment, *Federally Funded Research,* footnote 2.

[32] For instance, the recently terminated Advanced Neutron Source had an estimated cost of $3.2 billion, and the nearly completed Advanced Photon Source will cost approximately $800 million (including both construction and related R&D costs).

id-state physics, chemistry, and structural biology). Having ready access to such facilities could have long-term implications for scientific and industrial competitiveness.

In general, the development of proposals for scientific projects is very much a "bottom-up" process. The scientific community plays a major role in setting the scientific agenda, and years are often required for specific and detailed research proposals to take shape.[33] Depending on how the basket idea is applied, it could undermine this bottom-up process. An ad hoc procedure of apportioning projects among different countries might come into conflict with a previously agreed on national R&D strategy, or might weaken a nation's effort to develop specific scientific or technical expertise. For these reasons, the basket approach is considered by some policymakers to be infeasible.[34]

At some level, though, there must be a linking of bottom-up planning and review procedures with top-down priority setting, and thus some multilateral decisionmaking framework for large projects will probably need to evolve (see finding below). In the near term, it is possible that an informal distribution of big projects to different regions of the world will still occur.

Since future large science projects are likely to be relatively few in number, approaching them on an individual basis should not be burdensome for policymakers or scientists. For the foreseeable future, megascience projects will probably best be realized when the most interested parties simply choose to collaborate.

- **Early and explicit consideration of international collaboration in the planning and authorization process for large projects would better identify opportunities for cooperation.**

There are clear reasons to consider international collaboration in any large, complex scientific undertaking. Among them are the potential for reducing costs, sharing risks, and enhancing scientific capabilities. Indeed, some scientifically worthy but expensive projects might not be pursued at all unless carried out on a collaborative basis. A more proactive approach to international cooperation would provide the United States with a broader set of scientific and budgetary options, and would ensure more effective and mutually advantageous collaborations in the future.

A variety of benefits could result if international collaboration for large science projects were considered as an option early in the planning process. Projects can benefit from formal cooperative arrangements even in their preliminary R&D stages. Such arrangements can foster "buy-in" to later technical choices and decisions by potential partners, and can result in a more efficient project development phase as well as a more thoroughly considered final proposal. An example of this approach is in the field of high-energy physics, where the development of the underlying accelerator physics and technology for the Next Linear Collider (NLC)[35] is being coordinated and reviewed by a collaborative working group representing laboratories in the United States, Europe, Japan, and the former Soviet Union.

[33] The U.S. government, for example, relies extensively on expert advisory panels to review scientific project proposals and to determine the long-term agenda of particular research fields. In Europe, the newly opened European Synchrotron Radiation Facility required almost two decades of discussion and planning before it was completed.

[34] In OTA discussions with European and Japanese science policy officials, the basket approach was dismissed as being impractical. However, under certain circumstances, it may be feasible to have a "small basket" for a specific field of research. For example, the effort to develop fusion power has a variety of different requirements including the construction of an engineering reactor such as ITER, an advanced physics machine such as the Tokamak Physics Experiment, and a materials irradiation facility. Nations participating in the international fusion effort could perhaps decide to share costs and distribute benefits by building each of these facilities in different countries.

[35] The NLC is an electron-positron collider now in the concept and early development stage. It is regarded as a complementary instrument to the Large Hadron Collider at CERN.

The United States has sometimes pursued international partnerships after facing budget constraints well into a project, as in the case of the Superconducting Super Collider (SSC), the space station, and the Earth Observing System (EOS).[36] In the case of the SSC, the United States sought foreign partners as a way of sharing costs well after key scientific and engineering decisions had been made and therefore had difficulty in securing commitments. In the case of the two space projects, the United States might have saved time and money, increased program technical sophistication, and avoided tensions with partners if it had planned more extensive and integrated collaborations from the beginning (see chapter 3). In other cases, scientists and project planners gave serious consideration to collaboration only after being directed to do so by Congress. For example, this occurred when Congress directed the National Science Foundation to pursue the Gemini telescope project on an international rather than a national basis.

One approach Congress might consider is to require agencies to provide justification for pursuing or not pursuing international collaboration if projects exceed a certain monetary threshold—for example, $100 million. The specific threshold value is less important than the exercise of exploring the possible scientific and fiscal benefits of internationalizing a proposed project or elements of a project. As an alternative, policymakers might compare the projected annual peak spending for a project to the annual appropriations for the relevant overall program. For example, the SSC needed a peak appropriation of nearly $1 billion on top of a base program in high-energy physics that was being funded at a level of $600 million. Thus, from this perspective, the SSC was a strong candidate for international collaboration.

As part of the procedure for funding new projects, agencies could be required to prepare an analysis that includes the following elements:

- an assessment of whether a proposed project is too costly or technically challenging for any one party;
- the international scientific context of the project: other countries' programs, capabilities, and goals;
- the nature of U.S. discussions with other countries about collaboration;
- prospective commitments of other countries (technical and financial) to the project or to competing projects;
- national security, commercial, legal, and technology-transfer implications of international collaboration; and
- justification for seeking or avoiding such collaboration.

Such a review process would force consideration of collaboration at the start of projects, thereby better ensuring that opportunities to collaborate are not missed and that inappropriate collaborations are screened out. It should be noted that under this framework, the decision to pursue a project on a national or international basis would still depend on the specific nature of the scientific undertaking.

In each case, policymakers need to ascertain whether the greatest scientific, budgetary, and commercial leverage can be achieved by entering into partnerships or by pursuing projects domestically. In some circumstances, collaborative arrangements can enhance U.S. scientific capabilities; in others, scientific and national objectives can be met better by pursuing projects on a domestic basis. Collaboration may not always be the most desirable or efficient means for achieving

[36] The space station program contained collaborative elements from the beginning, but until only recently all critical aspects of the project remained firmly under U.S. control. Although the Canadian robotics contribution has been on the project's "critical path" from the beginning, the U.S.-Canadian agreement assures ultimate project control for NASA in the case of Canadian withdrawal from the program. The EOS program originally envisioned foreign technical contributions that would complement data provided by planned U.S. instruments or which, in one case, would provide unique sensor capability. Subsequent budget reductions caused NASA to downsize the program, eliminate some U.S. instruments, and greatly expand its reliance on foreign instruments for certain data.

technical goals. Moreover, if particular projects can strengthen the national skill base, or provide opportunities to improve economic productivity, collaboration might not necessarily be in the national interest.

Furthermore, in some instances, it may be beneficial to construct multiple facilities. Having parallel facilities—whether within a country or in different countries—can broaden access to facilities or instrumentation and encourage more competition and innovation in particular disciplines. For example, the United States, Europe, and Japan are each sponsoring major new x-ray synchrotron radiation facilities (see chapter 3). Although each of the projects (varying from $800 million to $1 billion in their respective construction and development costs) has similar technical characteristics, they are not necessarily redundant because of the utility of synchrotron sources to a variety of scientific fields and industries.

- **Although the United States has generally met its fiscal and performance obligations under international arrangements for scientific cooperation, and often assumed a large share of funding responsibility for projects, concerns persist among potential partners about the reliability of U.S. commitments. Future partnerships may have to be more formally structured to address these concerns.**

Questions about the reliability of U.S. commitments to international scientific collaborations were frequently raised by U.S. and foreign government officials, and other interested observers in interviews with OTA. These concerns can be traced to a few international projects canceled in the early 1980s, U.S. design changes on the International Space Station, the cancellation of the SSC, and to funding uncertainties associated with the U.S. practice of making annual appropriations for major science projects. Differences in government structure and in approaches to science research planning, budgeting, and funding processes among the United States and its partners also contribute to the perception that the United States is less able to sustain its obligations.

Commonly cited as examples of shifting U.S. international commitments are two projects that were terminated after the United States had entered into international collaborative agreements—the Solvent Refined Coal II demonstration project canceled in 1981 (see box 1-2) and the U.S. spacecraft for the International Solar Polar Mission canceled in 1982 (see box 1-3).

Among the factors leading to the termination or rescoping of projects were changes in administrations and policies, and increasing budget pressures. These changes in U.S. priorities may not have surprised seasoned political observers, but foreign partners were in some cases dismayed by the abruptness in which the U.S. decided to withdraw from specific international endeavors. In particular, foreign scientists were largely unprepared for the sudden cancellation of the SSC and the redesigns of the space station.[37]

Although these project histories provide some basis for the widely expressed view that the United States has been an unreliable partner in science collaborations, changes in U.S. positions have generally occurred for identifiable reasons, and often involved extensive thought and debate. In some cases, projects have been terminated due to serious cost escalation or poor project management. Others have been canceled in the face of specific agency budget constraints. These decisions have tended to be exceptions to the U.S. record in international collaboration. In other instances, U.S. research agencies have given priority to support of international efforts over domestic projects in the face of unexpected budget cuts. For example, the U.S. Department of Energy

[37]See discussions of these projects in chapter 3 of this report.

BOX 1-2: The Solvent Refined Coal II (SRC-II) Demonstration Project

The SRC-II demonstration project was one of a number of aggressive efforts to develop commercial synthetic fuels begun in the energy crisis atmosphere of the 1970s. The SRC-II project was to be a $1.5 billion (1981 dollars) demonstration plant in Morgantown, West Virginia, that would convert 6,000 tons per day of high-sulfur, high-ash bituminous coal into a light distillate through a direct coal liquefaction process.

The project was initially begun as a phased effort between the U.S. Department of Energy (DOE) and the Gulf Oil subsidiary, Pittsburgh and Midway Coal Mining Company. The project had been jointly initiated by Congress and DOE under the Federal Non-Nuclear Energy Research and Development Act of 1974.

According to some DOE fossil energy officials, the decision to pursue the SRC-II demonstration project as an international collaboration was made after DOE agreed to construct both the SRC-II liquid fuel demonstration plant in West Virginia and the related SRC-I solid fuel demonstration plant in Kentucky. DOE had originally planned to select one of the plants for construction after completion of the design phase. To help offset the costs of budding the two plants, DOE solicited participation from the Japanese and Germans who had earlier expressed interest in the direct coal liquefaction technology.

In July 1980, an agreement was signed among the governments of the United States, West Germany, and Japan to sponsor the project, A joint venture was formed with Gulf and with Japanese and German industrial firms to carry out the project. Under the agreements, DOE was to contribute about 50 percent of the total cost, Japan and Germany were to provide about 25 percent each, and corporate participants were to provide $100 million in cash and in kind,

In 1981, the Reagan Administration sought to terminate funding for SRC-II and a number of other energy demonstration and commercialization efforts, The objections were both economic and political, By 1981, oil prices were trending downward and the crisis atmosphere had abated, Concerns over federal spending were leading to increased pressure for cutting back programs of all kinds, As a policy matter, the Reagan Administration felt that such demonstration and commercialization efforts were not appropriate for funding directly through the government but rather should be done by the private sector or the Synthetic Fuels Corporation, The project was eventually terminated by a joint decision of DOE, West Germany, and Japan in June 1981, The remaining unobligated funds were transferred to energy conservation activities.

Although U.S. and German government officials were somewhat indifferent to the fate of SRC-II, Japanese government officials were dismayed by its demise, according to OTA interviews, The careers of Japanese government employees who had been instrumental in Japan's participation in SRC-II were said to have been adversely affected as a result. Still other sources suggested that Japanese participation in SRC-II had been a quid pro quo for granting them access to the General Atomics DIII-D fusion tokamak technology and had been an attempt to insulate the troubled synthetic fuels project from political attack.

interestingly, the cancellation of SRC-II, just one of many early synthetic fuels ventures abandoned amid falling oil prices, has not been of high concern in the area of fossil fuels research, but has attained the status of legend among high-energy physicists, fusion researchers, and space scientists, Despite the rather clear rationale for its termination, foreign policymakers frequently cite the SRC-II endeavor as an example of the United States failing to honor its International obligations.

SOURCES: J Freel et al , "Synfuels Processing The SRC-II Demonstration Project, " *Chemical Engineering Progress,* vol **77,** May **1981,** pp. 86-90; William C Boesman, Big *Science and Technology Projects: Analysis of 30 Selected U.S. Government Projects,* CRS Report to Congress, 94-687-SPR (Washington, DC: Congressional Research Service, Aug 24, 1994), pp. 24-25, and Off Ice of Technology Assessment, 1995

BOX 1-3: The International Solar Polar Mission (ISPM) or Ulysses

Between 1974 and 1979, the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) designed a highly collaborative two-satellite mission to study the poles of the Sun. In March 1979, NASA and ESA signed a Memorandum of Understanding (MOU) that planned for launch in 1983. Obtaining funding for the mission proved to be more difficult than designing the project, Although funding for the ESA satellite was not in doubt, the pressures of financing the completion of the space shuttle constrained NASA's ability to fund its $250-million ISPM budget. The ISPM received its first request of $13 million for fiscal year (FY) 1979, despite intense shuttle-related budgetary pressures. In FY 1980 and 1981, with pressures to complete the shuttle further constraining NASA's budget, ISPM survived two attempts by the House Committee on Appropriations to terminate it.

The final challenge to ISPM came in FY 1982, when the Administration cut NASA's science budget from $757.7 million to $584.2 million. NASA could meet this cut only by terminating one of its three large, scientific, satellite development programs: Galileo, Hubble, or ISPM. NASA decided to cancel the U.S. spacecraft in the ISPM and to delay launch of the European satellite until 1986.

The Europeans reacted with surprise and indignation—both at having been given no prior notice of cancellation and at the idea that an international agreement could be canceled at all. At a heated meeting between ESA and NASA officials in Washington shortly thereafter, ESA noted that it had chosen ISPM above a number of purely European missions to foster transatlantic cooperation and argued that the United States had unilaterally breached the MOU. NASA noted that the MOU had a clause allowing either partner to withdraw from its obligations if it had funding difficulties, but ESA officials said they thought that NASA would invoke this provision only in an extreme case.

The Europeans mounted intense diplomatic pressure at the Office of Management and Budget (OMB), the Office of Science and Technology Policy, the Department of State, and NASA to save the mission, proposing that NASA fly a simpler spacecraft, costing $40 million instead of the original $100 million, based on what was being built in Europe for ESA. NASA supported the new plan, but was told by OMB that no additional funding would be made available and that, if NASA wanted to keep ISPM, it would have to find the resources in its existing budget. In September 1981, NASA informed ESA that funding would not be sought for the European alternative, although the Europeans were encouraged to continue with the mission using just one spacecraft.

magnetic fusion energy program has consistently supported ITER design activities.[38]

Further complicating international scientific collaborations are the differences between the parliamentary government systems of our partners, in which executive and legislative authorities are merged, and the separate executive and legislative branches associated with the U.S. system of checks and balances. Ministers of parliamentary governments can effectively make and uphold long-term commitments. Under the U.S. system, executive branch officials cannot offer guarantees to the same extent. Additional action by Congress, such as support of authorizations, appropriations, treaty ratifications, or resolutions of approval, would be needed for an equivalent indication of government support.

[38] For a recent history of the DOE fusion energy research programs, see U.S. Congress, Office of Technology Assessment, *The Fusion Energy Program: The Role of TPX and Alternate Concepts,* OTA-BP-ETI-141 (Washington, DC: U.S. Government Printing Office, February 1995), ch. 2. DOE's decision to give priority to maintaining ITER funding over the U.S. base program was supported in reviews by U.S. fusion scientists.

BOX 1-3 Cont'd.

Cancellation of the U.S. satellite degraded the mission's scientific potential, eliminating about half of the originally planned instruments, and 80 positions for U.S. and European scientists, Cancellation also meant that the $15 million spent by European scientists on experiments for the U.S. spacecraft would be wasted, In 1982, ESA decided to proceed with a one-spacecraft mission, renamed Ulysses. Ulysses was scheduled to be launched in May 1986 but was delayed for more than four years by the Challenger accident, It was finally placed in orbit around the Sun by the Shuttle Discovery in October 1990,

Europeans contend that the ISPM cancellation deeply weakened their confidence in the reliability of U.S. commitments, According to ESA officials who participated in the ISPM negotiations with the United States: "NO one can deny that the ISPM crisis had a profound and lasting effect on the attitude of ESA towards NASA and on international cooperation in general, " They contrast the attitudes of the two partners to the MOU, seen as binding by ESA but a "sort of—loose---gentlemen's agreement" for NASA that was irrelevant to its internal deliberations when NASA was faced with budgetary cuts in its annual reviews, In subsequent negotiations, the Europeans have sought deeper cooperation and consultation, They contend, however, that a basic problem remains, ISPM and the negotiations over the space station (which they also describe) "show how difficult it is to conduct m a cooperative framework a space project whose funding requires yearly authorizations without a long-term commitment, "[1]

U.S. analysts also lament the ISPM cancellation and the manner in which Europe was informed, However, they note that NASA did provide a nuclear power source (radioisotope thermal generator) for onboard electrical power, a space shuttle launch, and tracking and data support for the Ulysses mission, These elements translate to a U.S. financial commitment of over $500 million to the project. Moreover, as one analyst notes, ESA may have overestimated the legal status of an MOU and the strength of U.S. congressional commitment to the project from the beginning, Further, ESA has been adept at emphasizing the legacy of ISPM cancellation and using American contrition as a "bargaining chip" in subsequent negotiations,[2]

[1] Roger M. Bonnet and Vittorio Manno, *International Cooperation in Space: The Example of the European Space Agency* (Cambridge, MA: Harvard University Press, 1994), p. 118.

[2] Joan Johnson-Freese, *Changing Patterns of International Cooperation in Space* (Malabar, FL: Orbit Book Co.), 1990, P 44

Parliamentary systems, however, are not immune to changes in government and resultant shifts in policy, and under both systems, funds for research projects are subject to periodic legislative approval. But as noted later in this chapter, European and Japanese governments commonly approve multiyear scientific research programs. In contrast, the risks of periodic legislative reviews have been heightened in recent years for U.S. researchers. Specific authorizing bills for many large science research projects have not passed Congress; instead, many projects have relied on annual appropriations.

Changes in project scope and commitment, and the unpredictable nature of the U.S. budget process, continue to make foreign partners hesitant about collaborating with the United States. This is particularly true in areas where foreign programs are dependent on a U.S. program, as in human space flight operations. Since the Japanese, European, and to some extent, Russian human space flight programs are now focused around their contributions to the space station, cancellation or further major redesign could have highly disruptive consequences for these U.S. partners.[39] In contrast, in a coequal and phased collaboration such as ITER, concerns about U.S. reliability are less acute. Since ITER partners have fusion programs that are comparable in size and sophistication, a pullout by one partner or even cancellation of the entire project would likely have a less significant impact on the direction and viability of the partners' domestic fusion programs than cancellation of the space station would have on some foreign space programs.

Various mechanisms are available for addressing the concerns of potential partners about the reliability of U.S. international commitments and to meet the added challenges of multinational efforts. These include a shift in how the U.S. components of international projects are authorized and funded—from annual to multiyear approaches—and the use of explicit provisions in international agreements to enhance project stability. International scientific projects inherently bring a more complicated structure, with additional layers of decisionmaking and management, than purely domestic ventures. The success of international collaborations may require compromises and special institutional arrangements that accommodate the differences among parties in procedures and schedules for planning, approving, and funding large science projects.

There are established multiyear funding mechanisms in the U.S. budgetary, appropriations, and procurement processes that could be tapped for more predictable funding of international efforts if policymakers so choose. Among them are providing multiyear authorizations, multiyear appropriations, advance appropriations, and full funding of the total estimated project costs. For example, legislation has been introduced in the 104th Congress authorizing over $13.1 billion, in annual installments of about $2.1 billion over fiscal years 1996 to 2001, for construction of the space station.[40] This step is being taken primarily to increase the confidence of foreign partners in the U.S. commitment to the project.[41] Appropriations that remain available beyond one fiscal year are not uncommon for large defense and space construction and procurement programs. Congress can also provide specific contract authority to allow sponsoring agencies to enter into multiyear contracts to support project activities.

Although multiyear funding can provide a greater measure of assurance to foreign partners, it can raise difficult budget challenges and is not irrevocable. Upfront appropriations may limit the flexibility of both a particular project and of future federal budgets. It is important to remember that unexpended appropriations may be rescinded by Congress and subsequent Congresses are not required to appropriate funds to meet full authorized levels. Given recent experiences with some large science projects, management reforms to assure more accurate project cost estimates and improved project planning, may be necessary to boost congressional confidence in such multiyear commitments (see finding below).

Greater care in structuring the processes by which the United States enters into international partnerships and in the terms of those agreements can also enhance stability. Early consideration of the possibility for international collaboration on large science projects and continuing consultation with prospective partners could help avoid the problems encountered when partners were sought late in project design. In negotiating agreements, the partners can include provisions that detail re-

[39] In interviews with OTA, Japanese space officials indicated that cancellation of the space station could have "catastrophic" consequences for their space program.

[40] H.R. 1601, International Space Station Authorization Act of 1995, was introduced May 10, 1995. The cap of $2.1 billion per year is designed to impose spending discipline.

[41] Robert S. Walker, Chairman, House Committee on Science, comments at media briefing, Apr. 6, 1995.

sponsibilities in case a partner is forced to withdraw or cannot fulfill financial commitments. In projects where there are substantial uncertainties about technical feasibility and costs, a phased approach to project commitments can aid collaboration.[42] Encouraging opportunities for collaboration will have to be balanced against the need to ensure that U.S. agencies and Congress fully understand and support the financial and other commitments needed to carry the project to completion.

Some have suggested that the use of treaties might be effective in formalizing collaborative commitments in cases where projects are of strategic importance to the United States and its foreign partners. Since treaty commitments require the approval of the Senate, proponents of this approach reason that such agreements could effectively insulate key projects from changing budget priorities and improve the confidence of our partners. On closer examination, use of treaty arrangements for large international science projects is not attractive. Due to the inevitable changes associated with long-term scientific and technological undertakings, treaties are a rather inflexible and process-intensive vehicle for structuring scientific collaborations. No single U.S. science project has ever been subject to the treaty ratification process. Few, if any, collaborations are likely to require such a high level of government commitment or the associated institutional structures characteristic of treaties. Moreover, the existence of treaty obligations has not prevented Congress from refusing to fund the U.S. contributions under these arrangements, and there are generally few mechanisms available to enforce such requirements. Treaty obligations have in the past been used to sanction U.S. participation in multinational organizations such as the International Atomic Energy Agency (IAEA), which does facilitate some international research efforts in addition to its responsibilities for nuclear arms control. Treaty agreements among European nations form the basis for CERN, the European Space Agency (ESA), and collaborative research on fusion.[43]

Even if there is a deeply held belief that the United States can be unreliable, it seems not to have outweighed the benefits to other nations of including the United States in projects. There continues to be no shortage of international interest in having the United States as a partner in collaborative science projects. Among the current examples, all at various stages of planning, are: the LHC, the NLC, and ITER. In certain areas, such as space, countries such as Japan and Russia have tied their own national efforts directly to U.S. activities and goals. As new areas of scientific inquiry and new types of problems emerge (e.g., global climate change), the United States will no doubt continue to be regarded as an indispensable partner, if not the principal leader in addressing such issues.

- **To assure long-term political and funding support of large science projects, early and thorough project cost and performance analyses are essential. However, improvements in project planning and cost estimation alone will not be sufficient to ensure project stability or greater reliability on the part of the United States in fulfilling its international commitments.**

The withdrawal of the United States from particular international and domestic projects has been precipitated by a variety of factors including: changing national goals and budgetary priorities, steep cost overruns following submission of unrealistic cost estimates to secure initial political approval of projects, inadequate project planning, and the difficulties of dealing with unforeseen

[42] Such a phased approach is being used in the ITER collaboration with separate agreements for conceptual design, engineering design activities, and construction and operations. The parties are now in the midst of the engineering design activities and will negotiate a new arrangement on whether and how to support construction and operation.

[43] In addition, the space station agreement was treated as an intergovernmental compact by European nations, as it was discussed and approved by the parliaments of all ESA member states.

technical challenges. All of these played a role in eroding support for megaprojects that initially had strong backing in both the legislative and executive branches.

Although more detailed engineering and cost estimation procedures could enhance the viability of large and complex scientific undertakings, such improvements still might not be enough to ensure the ultimate completion of projects. For example, in early 1995, after almost a decade of rigorous planning and review costing nearly $100 million, the Advanced Neutron Source was terminated before entering the construction phase, principally because of its high cost of $2.9 billion (see chapter 3). In other cases, projects entailing particularly risky technological aspects could encounter cost escalations, despite the thoroughness of the planning and management procedures.

Nevertheless, extensive and careful preliminary work on the technical and economic feasibility of a project is essential to sustained commitment and success. As an illustration, the original EOS plans were restructured and rescoped due to questions about the initial design concept and overall project implementation (see table 1-2). The first EOS plan was criticized for its cost, the long period of time before the system could provide policy-relevant data, and its dependence on just two platforms to carry the program's instruments. Difficulties also plagued the SSC project and eroded congressional support. Changes in magnet design led to increased project costs, which in turn raised questions about SSC management and performance.[44] The United States sought foreign partners as a way of sharing costs, but only after key engineering and siting decisions had been made. When the desired $2 billion in foreign commitments did not materialize, support for the project diminished further, which ultimately led to its termination in 1993.

TABLE 1-2: Earth Observing System Program History

Phase	Year
Mission planning	1982-1987
Announcement of opportunity	1988
Peer review process	
Letter review (academia/government)	
Panel review (academia/government)	
Prioritization panel (government)	1988-1989
Announcement of selection	1989
Definition phase	1989-1990
New start	1990
Execution phase	1990 on
Restructuring process	1991-1992
Restructuring confirmation	1992
Rescoping process	1992
National Space Policy Directive 7	1992
Rescoping confirmation	1993

SOURCE National Aeronautics and Space Administration, "EOS Program Chronology, " *1993 EOS Reference Handbook* (Washington, DC: 1993), p. 9

Changes in the way U.S. science projects are selected, funded, structured, and managed could aid the success of international collaborations. Given the role that unexpected cost escalations have played in the termination or redefinition of several big science projects, improvements in the planning and cost estimation of megaprojects

[44] Initially, the project was estimated to cost about $4.4 billion (in 1988 dollars without an allowance for contingencies); but by 1993, cost estimates had escalated to over $11 billion. At the time of termination, 15 miles (out of a total of 54) of tunnel had been dug. magnets had been tested, and $2.2 billion spent, mostly on salaries. Some observers argue that the management of the SSC was politicized and taken out of the hands of DOE technical managers who had a good record in overseeing the planning and execution of large projects. As a consequence, the various problems that developed over the course of the SSC endeavor might have been either avoided or addressed in a more effective manner.

would have several benefits.[45] More rigorous information about project costs and performance and about the potential for international collaboration could be useful in the authorization and appropriations processes and could lead to more stable project decisions. Better mechanisms for planning, engineering analysis, and cost estimation would permit policymakers to weigh more accurately the technical and financial tradeoffs of large scientific endeavors.[46] This is beneficial—and perhaps essential—regardless of whether other mechanisms, such as multiyear budgeting, are adopted to enhance project stability or to assure foreign partners.

Different modalities of funding may also be needed to address technical risks. If, for example, certain elements of a large project entail particularly high technical risks, a sequential development approach might be used to deal with such uncertainties. This could limit the cost of an undertaking by requiring that extensive prototyping or modeling be completed before commitment to the next phase of the full project can be made. For instance, if elaborate prototyping of magnets had been carried out before the entire project was approved, some of the cost overruns that plagued the SSC might have been avoided. Although a staged approach to large projects could provide a means for managing risk, such a strategy might require that project schedules be extended. In some cases, however, excessive conservatism could prevent promising or creative initiatives from ever being realized.

It may be desirable to make the initiation of large projects more difficult. However, the need for project stability may require the adoption of mechanisms that also make it more difficult to terminate such projects after they are approved. The challenge for policymakers is to develop a funding approach that ensures long-term commitment but simultaneously affords some elasticity in project design and execution.

- **Many nations have decisionmaking processes quite dissimilar to those in the United States. These may lead to greater stability, but less flexibility, in project decisions. There are signs, however, that increased budgetary pressures are also affecting the ability of other countries to sustain their international commitments.**

Other countries have elaborate planning and cost estimation procedures, as well as a phased approach to project implementation. The United States might draw on this experience in project planning and funding. In Japan, for example, the project planning process is a highly interactive, consensus-building exercise that evolves over a long period of time. The outgrowth of this consensus building has been commitment and stability. Carefully conceived project proposals with well-defined scientific and technical objectives and detailed cost breakdowns emanate from the bottom up. These proposals move through a hierarchy of administrative channels from the laboratory level through the bureau responsible for the laboratory, to the ministry in which the bureau is located,[47] and ultimately to the Ministry of Finance. Throughout the planning process, a tremendous amount of feedback is elicited. The larger the project, the more individuals are included in delibera-

[45]It should be noted that several projects ($500 million or less) have been completed on time and on budget. Examples of successfully completed domestic projects include the Continuous Electron Beam Accelerator Facility ($513 million), the Stanford Linear Collider ($115 million), and the Advanced Light Source ($100 million).

[46]For example, large projects like ITER require a clear strategy for funding and managing R&D and construction activities. Issues related to the site, host country regulations, contingency funding, and contract methods can directly affect cost estimates. Frequently, these factors are not well-defined during the conceptual and preliminary engineering stages when cost estimates are initially developed. Charles Baker, Leader, U.S. ITER Home Team Leader, personal communication, April 1995.

[47]For large science projects, the relevant ministries are the Science and Technology Agency and the Ministry of Education, Science, and Culture.

tions and the longer it takes for a consensus to be reached.

This process establishes accountability for overall project feasibility at the research level and also ensures administrative support until the project is completed.[48] In particular, the long planning process strengthens cost estimations. The high level of interaction among researchers and government administrators during the planning process reduces the possibility of "low-ball" estimates being made merely to secure funding.[49] These commitments are crucial to Japanese funding stability and stand in contrast to the funding and planning mechanisms of the United States. Project planning and funding by the Commission of the European Community and individual European countries is also quite interactive in nature. Proposed projects in Europe undergo a great deal of technical and financial scrutiny.

Furthermore, in Europe and Japan, scientific priorities are usually determined for fixed periods (five-year projects or programs are typical), thus insulating projects from year-to-year changes in the political and economic climate. Decisions to fund a project or program cannot be easily reversed or funding easily changed. Historically, projects have been funded with the clear intention of seeing them through to completion. In contrast, even long-term projects in the United States are subject to annual review and can be sharply reduced or terminated by Congress or a new administration.

Although multiyear budgets have been an integral part of project planning and have promoted project stability in Japan and Europe, this does not mean that long-term budgets are approved and appropriated at the same time. A staged approach is used to fund multiyear projects. The project budget is divided into segments, which are appropriated in given years. For very large projects such as fusion and space, obligations are made to fund a portion of the budget in each fiscal year.

However, whether these processes can withstand growing budgetary pressures is open to question. Europe and Japan are now experiencing some of the same budgetary constraints and political pressures that the United States has confronted in recent years. The Japanese Ministry of Education, Science, and Culture, which is the principal supporter of university research in Japan, has adopted a zero-growth budget for the next fiscal year. It is possible that in the future our overseas partners will have to adopt a more flexible decisionmaking process that is closer to the U.S. model. They may also experience the unexpected project changes that have been criticized in the U.S. system.

As an illustration, the prospective European commitment to the space station has changed markedly in the past few years and is still uncertain. Originally, ESA planned to participate in the station through the development of an attached pressurized laboratory facility and a Man-Tended Free Flyer (MTFF) that could dock with the station or operate independently. ESA also coupled its station-related activities to the development of its Hermes reusable spacecraft. This placed station participation within a larger plan to develop independent European human space capabilities. However, in the past few years, due in large part to funding pressures, both the MTFF and Hermes were canceled. Cancellation of these programs has produced sharp disagreements within ESA over how to allocate limited funds, how to structure European space station participation, and whether ESA should make additional contributions to the station program. As a result, plans to build a downsized version of the European at-

[48]For a detailed discussion of this process, see Kenneth Pechter, "Assessment of Japanese Attitudes Toward International Collaboration in Big Science," contractor report prepared for the Office of Technology Assessment, December 1994.

[49]There have been cases, though, where project cost projections in Japan proved to be unrealistic. For example, the H2 rocket launch vehicle program experienced a $700 million cost overrun because of needed engine design changes. An accelerator project at Japan's Institute of Radiological Sciences doubled in cost from $200 million to $400 million. Masakazu Murakami, Director, Policy Planning for International Programs, Science and Technology Agency, personal communication, November 1994.

tached pressurized laboratory—the sole remaining European commitment to the station—have yet to be approved.

It is important to note, that the European and Japanese approaches to project selection and planning, while more stable, might sometimes result in projects that have more conservative technical objectives than comparable U.S. projects. The additional levels of approval required to initiate a project in Europe or Japan could serve to minimize technical and financial risk or to narrow overall program goals. Historically, the sheer size and scope of U.S. research efforts have allowed a much broader portfolio of projects to be pursued, including those that are more speculative or risky in nature. This approach allowed the United States to achieve leadership positions in a variety of different disciplines.

However, as Europe and Japan have developed leading-edge scientific capabilities, their research projects have increasingly set aggressive scientific and technological goals. The magnet and detector technologies being developed for the LHC project at CERN are in some respects much more technically challenging than those planned for the SSC. The Joint European Torus (JET) was the first tokamak to produce significant quantities of fusion power using a deuterium-tritium fuel mix. Also, the Japanese decision to develop an indigenous rocket-launching capability has by its very nature required a technology development effort that involves considerable programmatic risk.

- **Developing approaches for allocating project costs and benefits in an equitable manner will continue to present challenges to all participants in international cooperative ventures. This especially will be the case in scientific collaborations involving technologies with potentially high industrial or commercial returns. The two issues that are likely to be a source of contention in almost all future negotiations are technology transfer and facility siting.**

The United States can study the experiences of international science organizations, such as CERN and ESA, that have established approaches for apportioning costs and benefits in collaborative efforts. However, the lessons learned by these organizations in bringing a number of smaller countries together for joint scientific and industrial development may prove of limited relevance to U.S. concerns and goals.

CERN and ESA policies on basic membership contributions and voting illustrate the difficulty of applying their procedures to U.S. participation in international science projects. CERN and ESA determine basic membership contributions as a share of each member's gross national product and assign each member country an equal vote in decisionmaking.[50] This method of allocating costs would be unrealistic for the United States, as it would result in a gross imbalance between the magnitude of U.S. contributions and its say in decisionmaking.

European science organizations have also developed industrial return policies to ensure that project contributions are channeled back to companies and research institutions in member countries. ESA, for example, has attempted to satisfy member demands for equity in contract apportionment by instituting a system of "equitable geographic return," whereby each country receives a percentage of project contracts proportionate to its funding contribution, both for mandatory and optional projects. ESA's system of fair return appeared to work well in the past when contracts were distributed over several years and over a series of projects. But political and budget pressures in member countries in recent years have led to demands for equitable returns on each project, re-

[50]At ESA, basic membership contributions are used to fund mandatory science programs. Member governments may contribute additional funds to finance optional programs outside the agency's mandatory science budget. In these optional programs, countries receive project contracts proportionate to their financial contribution.

ducing the organization's flexibility and possibly increasing costs.[51] CERN and the European Synchrotron Radiation Facility (ESRF) employ somewhat looser industrial return rules to ensure that prices of contracts come close to the lowest bid.

Rather than adopting such prearranged formulas for collaboration, it appears more consistent with U.S. national interest to continue to negotiate the allocation of costs and benefits on a case-by-case basis. The formula and procedures for distributing costs and benefits will depend on the origin and national sponsorship of each project, the science goals and priorities of the participants, and the resources each nation is willing to commit. These resources might involve not only funds, but also in-kind contributions such as expertise, instrumentation, or materials. Since the United States has joined few international scientific organizations or "umbrella" agreements in the past,[52] this approach may be the most practical path for U.S. policymakers to pursue.

Technology Transfer

Given increased domestic political pressures to link basic science research more closely to national economic development, and the increasing globalization of R&D, an international project's potential for technology transfer (from or to the United States) is likely to receive closer scrutiny in the future. Historically, U.S. policymakers have attempted to safeguard areas in which the United States has developed a clear lead or a significant commercial/industrial advantage (e.g., space technologies). Meanwhile, a more open approach has been pursued in areas where the United States is less dominant or where the industrial return is less certain (e.g., fusion research and some areas of high-energy physics). As the global community becomes increasingly integrated, scientific and technological knowledge will no doubt diffuse more rapidly. Over the past several decades, this process of knowledge diffusion has stimulated advances in many fields (e.g., biotechnology and computer and communications technology). Thus, preventing technological leakage to other countries or preserving U.S. dominance in particular fields will be an increasingly difficult task. In certain cases, the national interest may dictate that the United States closely control leading-edge technologies as part of a collaborative arrangement.

It should be noted, though, that multilateral collaborations may also be a source of new knowledge and technology, and thus participation in such ventures will likely have a number of benefits for the United States and other nations. In addition, the involvement of developing countries in collaborative projects can serve to improve international political stability as well as transfer vital skills and technologies to other parts of the world. Technology transfer should therefore not necessarily be viewed as being at odds with national goals.

Siting

Decisions over siting have also been a source of tension in international collaborations and could exacerbate competitive pressures in the future. The right to host an international science project has been a highly sought-after prize—a source of economic benefit and political and scientific

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[51] ESA increased its overall country-by-country fair return goal to 95 percent in 1993 and is trying to reach 96 percent by 1996, with a goal of 90 percent within each of its programs. See John Krige, "ESA and CERN as International Collaborative Science Organizations," contractor report prepared for the Office of Technology Assessment, December 1994.

[52] The most significant exception to this rule is U.S. participation in ITER, which is an equal partnership dedicated to a specific project, but is not an institution. The United States has signed international agreements to coordinate and participate in international Earth observation activities. However, these Earth observation agreements have been established between independent national programs rather than through a joint organization.

CERN

Aerial view of the European Laboratory forParticle Physics

prestige. One study found that between 40 and 70 percent of the funds used to operate large international facilities are spent in the host nation.[53] However, the types of economic benefits accruing to the host may be in areas of low technology (e.g., construction, materials, chemicals, and services) rather than high technology (project design and components). Still, local companies that provide technical support or equipment to facilities can enhance their underlying scientific or engineering expertise. A large facility can also attract new companies and thereby raise the skill base of a region's population.

In most cases, though, contracts for the most knowledge-intensive components of large projects are typically assigned to companies in many different countries. The distribution of key project components among international partners may diminish the economic return to the country hosting the project. Thus, it may be more advantageous for the United States in future projects to forego opportunities to host a facility, in exchange for the opportunity to develop technologies and expertise that will advance the leading sectors of U.S. science and industry.[54]

Moreover, development of the "information superhighway" will enable scientists all over the world to gain access to a project's data or even to operate an instrument remotely. Thus, access to the site itself may be less important in future years than it has been in the past.

Also, although siting a facility in a country may result in a net economic or technical benefit to that country, it may have drawbacks or cause domestic political concerns for the host nation. For example, hosting ITER may be attractive to the national science community and to industry, but the prospect of hosting a research facility that uses radioactive materials may arouse political opposition in the locality chosen as host.

Siting should therefore be considered in a comparative context. Although the siting decision is important, it is not necessarily in the U.S. interest to treat siting as a paramount issue. Policymakers should compare the economic, technical, and political advantages of hosting a project with the benefits offered by taking responsibility for other parts of the project, especially the development of high value-added knowledge-intensive components and processes. These opportunities suggest that U.S. policymakers adopt a broader perspective on siting issues.

- **U.S. science and technology goals and priorities may have to be reevaluated as international collaboration becomes a more integral component of R&D activities.**

[53] This analysis was based on the spending patterns of CERN, located on the Swiss-French border, the JET fusion experiment in England; and the ESRF and the Institute Laue-Langevin for neutron research, both in France. See "International Facilities Said To Boost National Economy," *Nature*, vol. 363, May 6, 1993.

[54] For example, even if ITER was built in Japan or Europe, U.S. industry could still participate in the design and construction of the reactor and support facilities, as well as reactor components such as superconducting magnets and associated computational and electronic systems.

The benefits and challenges presented by international collaboration raise basic questions about how U.S. scientific capabilities can be most effectively advanced.

The chief goal of U.S. R&D programs is to maintain or develop leading-edge capabilities across a broad spectrum of scientific fields. Other science goals are linked to economic competitiveness, foreign policy initiatives, and national security concerns. These goals influence decisions about whether to participate in international collaborative projects. Historically, the United States has collaborated only when its participation did not affect domestic science activities or when leadership could be maintained.

Some U.S. science goals are difficult to reconcile with international collaboration. Notably, the goal of U.S. leadership in science poses a potential conflict with the very nature of collaboration. This may be especially true if leadership is defined as "dominance" in any particular field. Thus, future U.S. participation in large-scale collaborative projects may necessitate a redefinition of what constitutes scientific leadership. For example, if leadership means the development of world-class capabilities in any particular scientific or technical field, then expanded international collaboration may not necessarily diminish—and may even enhance—underlying U.S. scientific prowess. Building up national scientific capabilities and joining international partnerships are not necessarily mutually exclusive strategies. In many cases, having access to scientific facilities in other countries or participating in the planning and operation of particular projects may strengthen and diversify the U.S. science base. Moreover, participation in collaborative endeavors can allow nations to avoid duplication of major facilities and thereby permit a broader array of R&D projects to be pursued. The ITER collaboration and the many cooperative ventures of NASA are good examples of this.

Furthermore, an emphasis on leadership can strain alliances with other nations because it appears to ignore the many achievements of the European and Japanese science communities, particularly in high-energy physics, space exploration, and fusion. As other nations continue to develop and refine their science programs and facilities, it will become increasingly difficult for the United States to exercise sole control over projects. Other nations will demand recognition of their achievements as well as a voice in key technical and administrative decisions.

The goal of promoting national economic competitiveness provides little guidance in deciding whether projects should be internationalized. Because pure science research is curiosity driven, it is often difficult to assess its short-term impact, even though over the long term, its benefits to society can be substantial.[55] Basic scientific discoveries in and of themselves usually possess little intrinsic value without further investments.[56] In those cases where commercial spinoffs are possible (e.g., advanced-materials development resulting from neutron-scattering research), economic competitiveness could play a role in shaping specific policies related to international collaboration. Whether large scientific projects can be used effectively to facilitate the development and deployment of new commercial technologies is an open question. As a general proposition, however, it is difficult to demonstrate that large science projects or specific aspects of large projects can be efficiently utilized for this purpose.

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[55]One study concluded that rates of return for R&D in particular industries and from university research can be 30 percent or more. See Edwin Mansfield, "Estimates of the Social Returns from Research and Development," *AAAS Science and Technology Policy Yearbook, 1991,* Margaret O. Meredith et al. (eds.) (Washington, DC: American Association for the Advancement of Science, 1991). Also see Edwin Mansfield, "Academic Research and Industrial Innovation," *Research Policy,* vol. 20, 1991, pp. 1-12.

[56]See Paul David et al., Center for Economic Policy Research, Stanford University, "The Economic Analysis of Payoffs from Basic Research—An Examination of the Case of Particle Physics Research," CEPR Publication No. 122, January 1988.

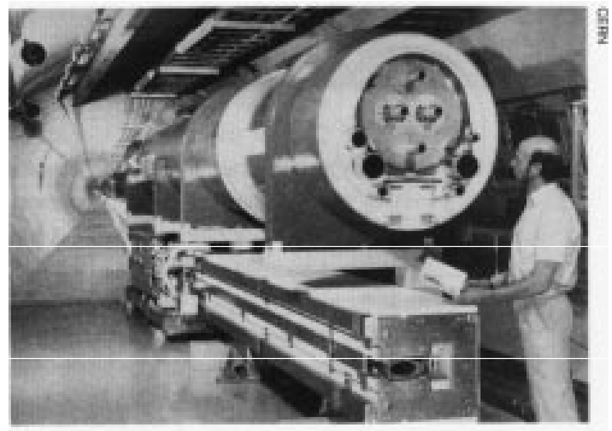
The support of foreign policy goals has also shaped decisions about whether to participate in collaborative science projects. As noted earlier, the United States uses scientific agreements to help forge and reinforce alliances and friendships. Most recently, the United **States** has used scientific agreements to support Russia's science base. In some instances, however, political goals can have a negative impact on scientfic research objectives and must be weighed against foreign policy benefits.

Overall, U.S. science goals provide little guidance to policymakers in developing a policy framework for future collaborations. In particular, the goal of leadership, as understood in the past, does not provide a clear basis for developing fundamental policies that address whether international collaboration should be pursued or what level of finding is appropriate. Reconciling U.S. goals with the benefits of collaboration will be a critical first step in this process.

- **More formal mechanisms for information exchange among science policymakers could enhance opportunities for effective international collaborations.**

An important need of decisionmakers is to have effective mechanisms for exchanging information about emerging scientific priorities and projects in various disciplines. OTA discussions with U.S., European, and Japanese science officials indicate that new intergovernmental mechanisms for information exchange could be beneficial.

There are advantages to having more formal information-sharing arrangements among governments. In some scientfic fields, several countries have facilities that are complementary or parallel to those found in the United States. Better usage of some national facilities and resources could be achieved by identifying how similar facilities around the world are utilized. Although there is growing demand for access to many domestic and foreign scientific facilities, they often operate for limited time periods because of funding constraints. In some fields, there is a need for greater intergovernmental coordination in both



Section of the CERN tunnel showing a model of the Large Hadron Collider on top of the Large Electron-Positron Collider

the use of existing facilities and the construction of new facilities. This could permit nations to consolidate and improve the efficiency of various R&D programs.

In some cases, essential U.S. scientific capabilities could be maintained or even extended in a particular field of inquiry by participating in existing ventures overseas (e.g., by joining the LHC project at CERN or the Institute Laue-Langevin European neutron facility). In specific fields of research, such as high-energy physics, U.S. and foreign programs might be designed to take advantage of existing infrastructure and expertise around the globe.

Since 1992, member countries of the Organization for Economic Cooperation and Development (OECD) have exchanged information and explored opportunities for international scientific cooperation under the auspices of the OECD Megascience Forum (see box 1-4). Before establishment of the Megascience Forum, science policymakers from different nations had limited opportunities to discuss R&D priorities as well as ideas and plans for future large projects. The Forum has sponsored both meetings for senior government officials and expert meetings where scientists and science policymakers can explore the needs of various scientific fields and proposals for new experiments or facilities. Although some major scientific fields such as high-energy phys-

BOX 1-4: The Organization for Economic Cooperation and Development (OECD) Megascience Forum

The OECD[1] Council created the Megascience Forum in June 1992 primarily as a means for information exchange and open discussion on existing and future large science projects and programs, and to facilitate international scientific cooperation among member governments. The Forum does not set priorities or conduct scientific research; it has no decisionmaking authority. Twenty-three out of the 25 OECD member countries participate in the Forum, which has a mandate of three years.

Several factors prompted the creation of the Megascience Forum. For countries with large research programs, much of the impetus came from the rising costs of big science projects and increasing budget constraints. For others, especially smaller countries, ensuring or expanding access to facilities and data was the primary concern. For all countries, the new opportunities for scientific cooperation presented by the end of the Cold War provided an additional impetus.

To facilitate discussion, the Forum has organized expert meetings in six specific scientific disciplines or broad research areas, excluding near-term commercial areas and national defense. Leading scientists in a particular field from all member and observer countries, and occasionally from other scientifically important countries (for example, China and India), are invited to attend, along with government policymakers. Discussions focus on identifying opportunities for international collaboration and mechanisms to ensure the success of cooperative projects. Meetings have been held on astronomy, deep drilling, global climate change research, oceanography, advanced neutron and synchrotrons radiation sources, and particle physics. The results of each meeting are conveyed to the Forum as a basis for further discussion. The Forum has approved publication of the results of the expert meetings and its own deliberations for all six research areas.

[1] OECD is an intergovernmental organization founded in 1960. Its primary aim is to promote economic promotes that stimulate growth, employment, and the expansion of world trade throughout the OECD area. The organization's 25 members are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States Iceland and Luxembourg do not participate in the Forum. Forum observer status has been granted to the European Union, Russia, Hungary, Poland, the Czech Republic, and Korea.

ics already have international scientific organizations in which ideas and plans for future experiments are discussed, the Megascience Forum is viewed by policymakers as being complementary to these organizations. The Forum is essentially designed to facilitate communication among governments.

OTA discovered a broad range of opinion regarding the usefulness of the OECD Megascience Forum. Whereas some participants found OECD's activities beneficial (e.g., the forums on astronomy, deep-sea drilling, and neutron sources were viewed by some government policy makers as quite useful), others, particularly scientists, have questioned its utility. Nevertheless, there has been foreign support for a U.S. proposal to establish a follow-on activity to the Forum that would continue to provide an intergovernmental venue for discussion and information exchange. In addition, proposals for the development of improved

BOX 1-4 Cor

With the Forum's three-year term due to expire in fall 1995, the United States proposed a follow-on activity Based on extensive discussions with OECD member government officials, the U.S. proposal was modified and formally adopted by the Forum at its January 1995 meeting. The proposal will be fine tuned and a specific workplan developed at the final meeting of the Forum in June 1995. The proposal and workplan will be submitted for the consideration of the Ministers of Science of the OECD countries at their meeting in September 1995.

Under terms of this proposal, a new organization, tentatively called the Group on Large Scientific Projects (GLSP), would provide a venue for government science policy officials to explore generic issues related to megascience projects and make recommendations to member governments. The new organization would also have the authority to establish ad hoc working groups in selected scientific disciplines where adequate mechanisms for intergovernmental discussion are lacking. The working groups would exchange information on each country's domestic research plans and projects, compare project priorities, and explore prospects for international cooperation. If the working group identifies opportunities for cooperation, interested governments could enter into discussions leading to the negotiation and implementation of an international project. The responsibility for negotiating final agreements and administering projects would reside with the participating governments rather than with OECD.

Senior science policy-level officials from OECD member governments will be delegates to GLSP. Delegates to the working group meetings will include senior government program officials and, at the discretion of each government, nongovernment scientists. Working groups would meet as frequently as required and would be authorized to invite nonmember countries to participate on a case-by-case basis.

SOURCES: Organization for Economic Cooperation and Development, *What Is the OECD Megascience Forum?* (Paris, France. 1995); "The Dawn of Global Scientific Co-operation, The *OECD Megascience Observer,* No. 187, April/May 1994; and Off Ice of Science and Technology Policy, "The OECD Megascience Forum: Past Activities and Proposed Future Plans, " reformational material, n.d.

coordination mechanisms among G-7[57] countries have recently been offered.[58]

Despite the acknowledged usefulness of information exchange, there is little support among U. S., European, and Japanese policymakers for the creation of international operational entities that would organize and supervise collaborations. Regardless of the consultation mechanisms created, the disparate characteristics of big science projects will still probably necessitate that each international endeavor be evaluated on a case-specific basis.

- **The different levels of scale and complexity of large collaborative projects require distinct management structures.**

Management frameworks for different projects must necessarily vary in structure because each cooperative enterprise involves different degrees of program integration, information transfer, and

[57] G-7 is the term applied to the group of large industrial economics (United States, Canada, Japan, France, Germany, United Kingdom, and Italy) that meet regularly to consider the state of the global economy.

[58] In order to have more focused discussions about large projects among key industrialized nations, U.S., German, and Japanese officials are exploring the possibility of creating formal consultation mechanisms at the G-7 level.

STEVE BROWN, U.S. NEWS & WORLD REPORT

The impetus for the ITER collaboration originated at the 1985 Geneva summit between President Reagan and Soviet General Secretary Gorbachev.

financial or political commitment. For example, distributed science activities such as data gathering on global climate conditions may have only informal or limited project coordination requirements.[59] Scientific facilities that offer particular services, such as neutron or synchrotrons sources, have a more developed, but rather straightforward, management organization.[60] Projects that involve the design and construction of large, sophisticated apparatus or instrumentation usually require more elaborate institutional mechanisms for overseeing project planning and execution.

In reviewing the experience of past and ongoing international projects, it becomes apparent that careful balance must be struck between the need for integrated project planning and oversight and the flexibility that is often necessary to successfully design project subsystems and components. For some types of projects it is fairly easy to develop modular designs that allow the different collaborators to each focus on very specific goals and essentially be concerned only with the interfaces between their subsystems and the overall system. The European and Japanese components of the International Space Station serve as an example of such a compartmentalized management approach. In other cases, however, a greater level of integration maybe required. The several hundred researchers who are now developing the technical specifications for the LHC particle detectors at CERN must work closely with LHC accelerator experts to ensure that the ultimate physics objectives of the project can be met. As a result of this requirement, specific management review processes have been created to guarantee that overall technical and financial targets of the LHC project are being achieved. The strong institutional structure provided by the CERN organization provides additional support to project planners and designers.

The ITER fusion project presents perhaps some of the most significant management challenges in terms of the way in which technical decisions are made, and how human or financial resources are deployed. At present, engineering design activities for the proposed ITER reactor are being carried out at three separate locations in the United States, Japan, and Germany.

At each site, a "joint central team" consisting of American, European, Russian, and Japanese researchers specifies R&D tasks that have to be completed. "Home teams" for each of the four partners provide additional technical support to the joint central teams, and coordinate the work of local researchers and contractors. Specific assignments and tasks are being defined as the overall design and engineering specifications of the fusion reactor are being developed. Responsibility for the overall reactor design and project management is in the hands of the ITER director based in San Diego, California, who reports to the ITER

[59] For example, data-collection and storage standards might have to be developed, and entities for data sharing and analysis might need to be organized.

[60] For instance, the European Synchrotrons Radiation Facility in France is a 12-nation private consortium that offers researchers access to high-intensity x-rays. This and similar facilities in the United States provide researchers in a variety of disciplines access to powerful experimental tools and thus are managed primarily as user-support organizations. Traditionally, such facilities have reciprocal access policies that allow scientists from different countries to take advantage of the unique capabilities of each installation.

council.[61] Because the reactor subsystems are integrally linked to each other, the ITER project does not especially lend itself to decentralization. Even after a reactor site is chosen, a geographically diffuse management operation will still be required to work with researchers and industrial contractors indifferent countries. This will necessitate a management structure that is capable of devolving responsibility, but also of developing strong oversight capabilities and effective communications channels. These requirements represent a formidable challenge. If ITER's management principle were to be characterized, it might be defined as "decentralization with coordination." The ITER experience will no doubt provide important lessons for other large-scale multinational projects that give each participating nation an equal role in project planning, financing, and decisionmaking.

A portion of the Advanced Photon Source storage ring shows the electromagnetic devices used to guide the 7 GeV position around the 0.7 mile circumference.

CONCLUSION

As budget pressures in all countries mount and as the complexity and scale of scientific projects increase, international scientific collaboration, whether on an institutional or an informal level, will become increasingly common. Policymakers will therefore be required to carefully assess R&D projects to determine whether it is critical to the national interest that they be conducted by the United States alone, or whether they can and should be internationalized.

Although large science projects continue to draw congressional attention, they represent only a subset of a larger domain of issues relating to national R&D goals and national well-being. In the current difficult fiscal climate, one can at best expect moderately increasing R&D budgets, especially for big science. Flat or declining budgets are more likely. Because of these pressures, some scientifically worthy but expensive projects might not be pursued at all unless carried out on a collaborative basis. Yet, despite the burden sharing that collaboration can provide, it still maybe difficult to generate the political support necessary to initiate and sustain large projects. This study identifies several major issues relevant to congressional consideration of U.S. participation in international collaborative science undertakings.

First, since large projects are not readily comparable, attempts to develop a priority-setting scheme for big projects are likely to encounter a variety of obstacles. The relatively small number of such projects should allow policymakers to rely on "bottom-up" scientific review processes to determine which projects should be pursued. The scientific community plays a major role in setting the scientific agenda, and years are often required for specific and detailed research proposals to take shape. Although there must inevitably be some linking of bottom-up planning and review with overall government R&D priority setting, selection and funding of large projects will most probably remain ad hoc. The development of

[61] The ITER Council has eight members, two from each of the four partners: the United States, the European Atomic Energy Community (Euratom),Japan, and the Russian Federation. Euratom is represented by officials from the European Commission, the executive Agency of the European Union.

intergovernmental mechanisms to identify scientifically worthy projects and to explore opportunities for collaboration could bring greater coherence to the process of project selection and siting. Proposals for the creation of improved coordination mechanisms are now under consideration by OECD countries.

Second, questions about U.S. reliability in international collaborations are somewhat overstated. The United States has generally fulfilled its international obligations, except in a few cases. Nevertheless, these few instances of U.S. withdrawal from international ventures and the uncertainties associated with the U.S. practice of making annual appropriations for major science projects have made foreign partners hesitant about collaborating with the United States. International collaboration can require special institutional arrangements or concessions that are not needed for domestic projects. Although multiyear funding mechanisms and improved project planning and cost estimation procedures can enhance project stability and provide additional assurance to U.S. partners, Congress can always reevaluate and even terminate projects (as can U.S. partners). The use of treaties to formalize U.S. commitments is too cumbersome a vehicle for structuring scientific projects, and will not necessarily guarantee funding stability. Despite these uncertainties, other countries continue to seek U.S. participation in a variety of scientific projects.

Third, active consideration of international cooperation before projects are authorized could provide the United States with a broader set of scientific and budgetary options. For big projects that exceed a certain monetary threshold (e.g., $100 million), or make up a large fraction of a program budget, Congress might consider requiring agencies to provide a formal justification for seeking or avoiding international collaboration. This strategy could ensure that important opportunities to collaborate are not missed and that inappropriate collaborations are screened out.

Finally, the opportunities and challenges of international partnerships raise fundamental questions about the concept of scientific leadership, of the nature of partnership, of what constitutes the national interest, and how scientific capabilities can be most effectively advanced. Traditional U.S. science goals potentially conflict with the requirements of collaboration or are too ambiguous to provide useful guidance for policymakers in deciding whether or how to collaborate. Congressional review of U.S. science goals and U.S. relations with the global scientific community in the post-Cold War era could provide guidance about where and how the nation should engage in future international partnerships.