Opportunities and Challenges of International Collaboration

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Previous chapters of this study have analyzed U.S. science goals in an international context and examined U.S. collaboration in several scientific disciplines. Although experience has demonstrated that collaboration offers distinct advantages, it can also have drawbacks. The decision about whether to collaborate depends on an assessment of the relative benefits and disadvantages of a particular undertaking. The present chapter identifies the main benefits from, and impediments to, collaboration. It offers policymakers a framework for analyzing the appropriateness of future collaborative opportunities.

BENEFITS OF COLLABORATION

Increased U.S. participation in international collaborative research and development (R&D) ventures could offer a variety of economic, technical, political, and institutional benefits. Although these benefits may not be realizable in every case, collaboration does offer a range of potential opportunities that may justify U.S. participation in future multilateral science efforts. These opportunities include:

- reducing net U.S. costs,
- enhancing scientific capabilities,
- enhancing the stability of science goals and funding,
- supporting U.S. foreign policy, and
- addressing global science and technology issues.

These different categories are analyzed below.

Reducing Net U.S. Costs

In government agencies and among science policy officials, saving money is consistently cited as a principal motive for undertak-

ing international collaboration in large science projects. Two financial trends have made international collaboration more attractive to both scientists and policymakers. First, the cost of big science has risen sharply, making it increasingly difficult for individual countries to undertake such projects alone. In the United States, megaprojects account for about 10 percent of the federal (defense and nondefense) R&D budget.[1]

Second, aggregate demands on national science and technology (S&T) budgets have also grown dramatically, outpacing government appropriations for basic science research. This has been the result of increases in the amount of R&D being conducted and in the cost of the projects (large or small) themselves. For example, since 1958, the average expenditures per U.S. scientific investigator, expressed in constant dollars, have tripled.[2] The ability of governments to meet these demands is being limited by the growing budget pressures of the 1990s. These factors have prompted policymakers to search for alternative, less expensive means of achieving S&T goals, particularly in large, high-cost projects.

One way to reduce the cost of achieving national science goals may be to undertake big science on an internationally collaborative basis. Although the international framework may raise total project costs, it is designed to lower the *net* cost to each country by distributing project tasks and expenses among a group of partners or by pooling international resources in a single project. In some cases, however, cost savings for individual countries 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 fully benefit from the advances coming from international projects.[3]

In addition to lowering project costs for individual countries, international partnerships on large science projects may also maximize the effectiveness of each dollar spent on research. By cooperating in big science endeavors, countries can coordinate construction and optimize the utilization of large, capital-intensive, special-purpose facilities. By avoiding duplication of these major facilities, nations can also free funds for other research or for nonscience uses.

International collaboration also provides a means by which countries can share the financial and technical risks of R&D projects. This is particularly important in big science projects, where the risks are often quite high. For example, the possibility of catastrophic failure of a space launch vehicle or its payload brings high levels of risk to space-related science. And although the claims of the National Aeronautics and Space Administration (NASA) that Russian participation in the space station will save the United States money have been discounted by General Accounting Office analysis,[4] it does appear that the addition of Russian equipment and the Russians' considerable expertise in long-duration human space flight will reduce the immense technical and

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[1] These figures are based on a selection 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,* CRS Report for Congress (Washington, DC: Congressional Research Service, Mar. 27, 1995).

[2] Increased R&D spending can be attributed to a growing number of qualified scientists (relative to the general population) able to perform research, pressure on individual investigators to produce more research, and the increasing complexity of equipment and facilities. 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, 1991), p. 199.

[3] It is important to note, however, that there have been no studies quantifying the net cost savings to individual countries from international collaboration or the value added by international collaboration of scientists. Moreover, as will be discussed below, international partnerships may increase *total* project costs.

[4] See U. S. General Accounting Office, *Space Station: Update on the Impact of the Expanded Russian Role* (Washington, DC: U.S. Government Printing Office, July 1994).

financial risks inherent in the U.S. program. According to NASA's space station business manager, the addition of Russian hardware has "reduced risk in many areas of the program."[5]

The financial savings offered by international collaboration enable countries to maintain the breadth of their national programs. For example, given NASA's substantial budget resources, the agency could, on its own, completely fund virtually any single one of the large international space research projects if they were carried out sequentially. However, doing so would severely limit the number of projects in which NASA is involved and would restrict the scope of U.S. scientific activities in space. By pursuing at least some projects collaboratively, NASA officials note that the agency has been able to spread its budget over a greater number of projects simultaneously, thereby diversifying its activities and increasing the net scientific yield of its budget. This has also enabled NASA to keep several research disciplines alive during times of budget stringency. For example, neither Cassini-Huygens (a mission of NASA and the European Space Agency (ESA) to Saturn) nor Topex-Poseidon (a U.S.-French oceanographic research satellite program) would have been possible without international participation. NASA alone could not have financed these missions simultaneously. Spacelab, the pressurized research module built for the space shuttle by ESA, has significantly increased the shuttle's research capacity. Given the severe funding pressures on the shuttle program, NASA probably would have been unable to fund Spacelab's full development cost.

Finally, some project managers voice the perception that Congress prefers that large science projects include international collaboration. For example, although NASA plans originally called for the United States to finance and build the core space station, agency executives also sought international collaboration from the beginning of the project, in part, to meet anticipated congressional requirements that some costs be shared with international partners. Planners of the Superconducting Super Collider (SSC) designed an exclusively national project. However, when cost overruns multiplied, the project was heavily criticized in Congress for failing to attract international support. Efforts to obtain foreign support failed in large part because they were undertaken too late.[6] In another case, Congress refused an initial National Science Foundation (NSF) proposal to fully fund the $176 million Gemini project to build two new eight-meter telescopes. Instead, Congress authorized only half of the amount requested and instructed NSF to internationalize the project and obtain the remaining funding from the partners. In this way, NSF successfully internationalized the venture from the beginning and the project is now proceeding on schedule. (See box 4-1.)

■ Enhancing Scientific Capabilities

Despite the importance of reducing net costs, the desire to save money generally does not by itself motivate international collaboration. Another important reason for pursuing international cooperative research is "to do the best science." Whereas policymakers may emphasize the financial advantages of partnerships, scientists and other advocates of increased international collaboration stress as their primary motive the immense technical advantages of working cooperatively. Enhancement of scientific capabilities ranks near the

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[5] Jeffrey M. Lenorovitz, "So Much Hardware, So Many Nations," *Aviation Week & Space Technology*, vol. 140, No. 14, Apr. 4, 1994, p. 43.

[6] For a discussion of these issues, see chapter 3. See also John M. Deutch, "A Supercollision of Interests," *Technology Review*, vol. 95, No. 8, November/December 1992, p. 66; and Bob Johnstone, "Superpowers Collide," *Far Eastern Economic Review*, vol. 155, No. 3, Jan. 23, 1992, p. 66.

BOX 4-1: Seeing the Stars: The Gemini Project

Ground-based telescopes are essential components of astronomical research. Over the past 30 years, large ground-based optical/infrared telescopes have played a key role in advancing scientific understanding of the cosmos. Further advances in the field of astronomy are expected with the construction of a new generation of even larger telescopes, including the University of California/Caltech twin 10-meter Keck telescopes, the European Southern Observatory's Very Large Telescope (VLT) project, and the Gemini Project,

The Gemini Project is a U, S.-led international partnership to build, design, and operate two 8-meter telescopes. One of the telescopes will be based at Mauna Kea, Hawaii, and the other on Cerro Pachon, in northern Chile, Initially, the project was envisioned as a purely U.S. effort. However, in 1991 Congress capped U.S. spending on the project at $88 million and directed that the U.S. contribution not exceed 50 percent of the project's total cost. As a result, Gemini was internationalized.

The United Kingdom, Canada, Chile, Argentina, and Brazil are project partners Under the terms of the partnership, outlined m the Gemini Agreement, the United States will provide half of the funding for the $176 million project, The United Kingdom will pay 25 percent of the project costs; Canada, 15 percent; and Chile, 5 percent. Argentina and Brazil will contribute 2,5 percent each. Estimated annual operating costs for both telescopes are $12 million, of which the United States will pay half.

The National Science Foundation acts as the executive agency for the partnership, and the Association of Universities for Research in Astronomy (AURA), Inc. manages the construction of the telescopes, AURA is a consortium of 20 universities, which also manages 3 major National Optical Astronomy Observatories facilities.

The Gemini telescopes are designed to operate in the optical and infrared ranges and provide complete coverage of both the Northern and Southern Hemispheres, with spatial resolution better than the Hubble Space Telescope. Construction of the Hawaii telescope began in October 1994, with "first light" expected in 1998. The second telescope will be constructed by 2000.

top of NASA's policies governing international collaboration,[7] and is an integral part of U.S. cooperative research programs in fusion.

In an ideal international project, researchers take advantage of each country's strengths to ensure that the project is on the cutting-edge of science, employs the very latest in technologies, and incorporates the broadest range of technical capabilities. Science policy analysts contend that the international situation has changed and that the United States is no longer dominant in many fields of science and technology. In this context, collaboration is often necessary to keep U.S. scientists abreast of cutting-edge work being conducted abroad. In some fields, U.S. scientists may remain at the cutting-edge only by conducting research internationally. As one observer has noted: "We *need* to collaborate if we are to compete, paradoxical as it may sound."[8]

In addition, the diversity of individuals and research styles encompassed by collaborative ventures may stimulate creativity and facilitate discovery. As noted by a Fusion Policy Advisory Committee report, in international collaborative work "the synergistic effects of sharing knowl-

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[7] See discussion of NASA guidelines in chapter 3. See also National Security Council, "National Space policy," National Space Policy Directive 1, Nov. *2, 1989.*

[8] Eugene B. Skolnikoff, personal communication, Apr. 18, 1995.

BOX 4-1 Cont'd.

The project was initially troubled by a number of factors, which illustrate some of the challenges of international collaboration. The most serious challenge was sustaining partner commitments. For example, Canada reduced its initial funding commitment from 25 percent to 15 percent. Further uncertainty over the Canadian budget caused delays in signing the agreement. Increased management complexity has affected the project, too. Project managers reported that formulating an acceptable collaborative agreement and standardizing different fiscal policies and accounting practices were difficult tasks. For example, different dates for fiscal years complicate budgeting. In addition, foreign laboratories employed accounting procedures that were inconsistent with U.S. government rules,

Disagreements also arose about the mirror technology. The astronomy community was divided over whether the mirrors should be ultra-low expansion glass menisci or borosilicate honeycombs. The borosilicate honeycomb mirror was developed by the University of Arizona's Steward Observatory Mirror Laboratory, as part of a 10-year, $24 million project, about 50 percent of which is publicly funded. In 1992, the decision was made to use the meniscus mirror, which will be made by Corning, Inc. The Gemini meniscus mirror is similar to those being produced by Corning for the Japanese Subaru telescope and by Scott Glaswerke (a German firm) for the VLT. The Corning mirror was chosen for its lesser cost and, because the same technology is being proven in these other large telescopes, lowering technical risk, Some astronomers voiced strong disagreement with the decision, based on technical grounds, but these objections were laid to rest after the Preliminary Design Review.

Despite the project's financial, administrative, and technical challenges, Gemini is a good example of the benefits of collaboration and how challenges can be overcome. In this project, partners are collaborating to construct cutting-edge facilities that no single partner was willing to build on its own. Even in the case of the United States—the project's largest contributor—the $88 million cap on spending would have been insufficient to build even one of the telescopes as a national facility. ' But as part of the international collaboration, U.S. astronomers will have access to two 8-meter telescopes that will help keep them competitive with European and Japanese investigators.

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[1] Economies of scale make it possible to build two telescopes for $176 million. Building just one telescope would cost $106 million

SOURCE: Leif J Robinson and Jack Murray, "The Gemini Project: Twins in Trouble?" Sky & *Telescope,* vol 85, No 5, May 1993, p 29; and National Science Foundation, personal communication, May 1995

edge and trained personnel" can be quite strong.[9] By facilitating the use of the most advanced technologies, promoting consideration of the fullest range of technical ideas, and creating new research dynamics, international projects can also reduce the risks inherent in R&D projects.

In addition to the technical benefits that accrue to the project as a whole, international collaboration can benefit U.S. national R&D programs. By participating in international partnerships, U.S. scientists can widen their sphere of access to research data from projects in which they play only a contributing role. By enhancing the capabilities of U.S. science, international cooperative research also attracts the brightest American and foreign students to careers in scientific research in the United States. Although many students eventually return to their native countries to build stronger (and competitive) research programs, the continuing attraction of foreign researchers en-

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[9] U.S. Department of Energy, Fusion Policy Advisory Committee, "Report of the Technical Panel on Magnetic Fusion of the Energy Research Advisory Board, Final Report," DOE 1S-0081, September 1990, p. 15.

ITER

The ITER San Diego Joint Work Site operations host political and scientific leaders in an unparalleled in international collaborative effort.

riches high-energy physics, fusion, and space-related science research in the United States.

Enhancing Stability of Science Goals and Funding

From the standpoint of scientists and partner nations, one of the most serious problems for U.S. science policy and research projects in recent years has been the uncertainty of long-term funding. All science projects-large and small, domestic and international---compete for funds in the annual congressional appropriations process. In the scientific community, this has produced uncertainty about the stability of project funding and the U.S. commitment to international collaboration. In addition, several large projects have experienced extensive mid-course revisions to meet reduced budget allocations (e.g., the space station, the Earth Observing System (EOS), and the fusion research program). A few projects already under way have been canceled (e.g., the International Solar Polar Mission and the SSC). These funding reductions and cancellations have resulted from a variety of causes, including inadequate project planning, unrealistically low initial cost estimates by scientists and project managers, unforeseen technical difficulties, severe budget pressures, and changes in administration policies.

However, researchers also express strong dissatisfaction about what they perceive as uncertain and shifting federal funding policies, as well as the need to rejustify finding for ongoing projects each year. This has been an especially difficult problem for megaprojects, which require long-term commitment to large outlays for capital and operational costs. In conversations with the Office of Technology Assessment (OTA), some U.S. scientists working on large, long-term projects have emphasized their desire to obtain-at best-full multiyear government funding. Short of this, they have asked that other mechanisms be sought to increase the certainty of continuing U.S. government support for science projects.

Some scientists have suggested that placing megascience projects in international collaborative contexts may provide the increased stability desired. Although this motivation is not often discussed explicitly, U.S. scientists who support increased international collaboration may be doing so at least partly because of their perception that Congress would be less likely to reduce funding for or cancel an international project than a purely domestic one. As noted in recent congressional testimony, “International projects offer many significant advantages, among which are. . . candidly . . . making it difficult to back out of a project once begun.”[10] This view is fueled both by perceptions of congressional priorities and by experience with past projects. Both scientists and science policy analysts have voiced tie strong perception that Congress maybe reluctant to reduce or discontinue funding for international projects if formal intergovernmental agreements have been

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[10] Statement of Norman R. Augustine, Chairman and Chief Executive Officer, Martin Marietta Corp., *Will Restructuring NASA Improve Its Performance?* hearing before the Subcommittee on Science, Technology and Space, Committee on Commerce, United States Senate, Nov. 16, 1993, Serial No. 103-4O6, p. 13; and U.S.-CREST,Center for Research and Education on Strategy and Technology, *Partners in Space---International Cooperation in Space: Strategies for* the New Century (Arlington, VA: May 1993), p. 24.

signed, because of the foreign policy implications of such modifications and impacts on other collaborations.[11]

There is evidence that in some cases international cooperation has been sought at least partially to bolster project stability. In an analysis of NASA's motivations for seeking international collaboration in the space station project, it was noted that "NASA is hoping to use the 'international commitment' aspect of the Space Station to protect it from devastating domestic budget cuts."[12] Although the commitments of Europe and Japan did not protect the program from major downsizings in the late 1980s and early 1990s, the recent addition of Russia may have saved the space station from cancellation. Before Russian involvement, the U.S.-ESA-Japan project had escaped termination in the House of Representatives by only one vote in 1993. However, in 1994, after Russia had been brought into the project—partly in support of high-priority foreign policy objectives—the House approved funding for the station by a much wider margin. Administration officials and House members attributed this wider margin of support in part to the station's increased importance for U.S. foreign policy goals.[13]

It should be noted that there is no evidence that a major science project has been pursued on an international collaborative basis *solely* to bolster its funding stability. However, the perception that inclusion of an international component enhances a large science project's political stability may contribute to the decision to seek such a collaboration.[14]

Supporting U.S. Foreign Policy

As discussed in chapter 3, the goals of U.S. foreign policy include enhancing national security, decreasing international tensions, strengthening U.S. alliances and friendships, and increasing cross-cultural understanding. U.S. cooperation with other countries in areas of mutual interest, including scientific research, has long been an important tool in support of these foreign policy objectives. Joint scientific research pays dividends not only in scientific discovery, but also in strengthening bonds of friendship with our allies and establishing levels of trust with our rivals.

The United States has been most active in cooperating with Canada, Western European allies, and Japan in a wide spectrum of scientific research. These ties helped build and maintain allied relationships during the Cold War. Collaboration occurred in areas of both civilian and defense-related research.

During this period, the United States conducted limited cooperative efforts with the Soviet Union in fields such as space exploration and fusion. This joint research helped decrease tensions and increase cross-cultural understanding during the Cold War. In fact, analysts have contended that the political significance of the best known collaboration, the Apollo-Soyuz Test Project, far exceeded

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[11] For example, commenting on possible cuts in the requested congressional appropriation for the Gemini telescope project for fiscal year 1993, Professor Bob Bless of the University of Wisconsin noted: "NSF has assured us that they consider the project to be very important, and the fact that it's an international effort gives it a high visibility." Jeffrey Mervis, "Gemini Telescope Project Shifts into High Gear," *Nature*, vol. 357, No. 6378, June 11, 1992, p. 430.

[12] Joan Johnson-Freese, *Changing Patterns of International Cooperation in Space* (Malabar, FL: Orbit Book Co., 1990), p. 91.

[13] According to Representative Dick Zimmer, who sponsored a measure to terminate station funding, the cooperation agreement with Russia "created considerably more support for the program on the Democratic . . . [and] Republican side." See Phil Kuntz and Jeffrey L. Katz, "Space Station Bounces Back with Strong House Vote," *Congressional Quarterly Weekly Report*, vol. 52, No. 26, July 2, 1994, p. 1803.

[14] OTA interviews with Japanese science officials indicated that such a perception does exist among scientists and policy planners in Japan.

the scientific and technical dividends that it produced. The symbolism of the two nations cooperating in a space linkup was a graphic illustration of the policy of detente, perhaps more powerful and important than the knowledge gained about space rendezvous operations.[15]

Since the end of the Cold War, joint undertakings have continued to be important to the maintenance of ties with longstanding U.S. allies. Perhaps more significantly, however, the United States has strengthened and expanded ties with its former Eastern bloc rivals. These new collaborations are important for establishing friendships with former enemies and enhancing U.S. national security. For former Soviet nations such as Russia, collaboration with U.S. scientists represents a way to sustain scientists, institutes, and research during a time of great economic stress, when previously lavish state support for the sciences has almost dried up. Collaborative work between Western and Eastern scientists also builds relationships of good will among individuals, institutes, and governments.

A longstanding example of this is the international fusion research program. Since the late 1950s, U.S., European, and Soviet fusion researchers have been engaged in productive scientific exchanges and cooperation under formal U.S.-Soviet agreements and under the auspices of the International Atomic Energy Agency. Soviet researchers developed the tokamak[16] confinement concept and shared their successful results with their peers in the United States and Europe. This information sharing quickly made the tokamak the leading magnetic confinement concept in all national programs.[17] The Russian Federation has succeeded the former Soviet Union as one of four partners in the International Thermonuclear Experimental Reactor (ITER). The ITER collaboration was launched by discussions between President Reagan and General Secretary Gorbachev at the 1985 Geneva summit.

Collaborative projects in support of science in the former Soviet Union are also important from the standpoint of U.S. national security. By engaging scientists and institutions formerly dedicated to military research in civilian projects with Western partners, the United States may support defense conversion and prevent scientists from selling their expertise to hostile countries. The United States has also used science collaboration as an incentive to former Soviet states to adhere to nonproliferation agreements. For example, the U.S. invitation to Russia to participate in the space station was conditioned on Russia's not violating the Missile Technology Control Regime by a proposed sale of cryogenic rocket engines to India.

Finally, U.S. science policy has also included collaboration with and training of scientists from developing countries, both during and after the end of the Cold War. As an illustration, large U.S. facilities, such as the Fermi National Accelerator Laboratory, have involved developing-country scientists in a variety of projects. More importantly, this scientific cooperation has reinforced U.S. foreign aid and development policies. In areas such as environmental monitoring, collaboration with scientists from the developing world has been essential to gathering data on global ecosystem behavior and establishing international policies to address global environmental problems.

Addressing Global Issues

The final motive for pursuing international partnerships derives from the changing nature of the world science agenda. In the past, the United

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[15] Johnson-Freese, see footnote 12, pp. 31-34; and U.S. Congress, Office of Technology Assessment, *International Cooperation and Competition in Civilian Space Activities*, OTA-ISC-239 (Washington, DC: U.S. Government Printing Office, July 1985), p. 377.

[16] "Tokamak" is a Russian acronym for TOroidal'naia KAMera s AKsial'nym magnitnym polem (toroidal chamber with axial magnetic field).

[17] For a description, see U.S. Congress, Office of Technology Assessment, *Starpower: The U.S. and the International Quest for Fusion Energy*, OTA-E-338 (Washington, DC: U.S. Government Printing Office, October 1987), p. 163.

States has focused most of its resources on noncollaborative national research programs, in part because the research issues confronting U.S. scientists were national in scale or did not necessitate the collaboration of other countries. However, the issues confronting U.S. scientists (in both large and small projects) are becoming increasingly global in nature. This is especially true in environmental research, where scientists are embarking on complex, long-term studies of the global ecosystem in connection with challenges presented by possible global climate change and ozone depletion.

Although some U.S. environmental R&D will continue to require only a domestic perspective, much new work will necessitate cooperation with many countries on land and sea, in the air, and in space. In many cases, ecological interdependence makes it impossible to study U.S. environmental problems in isolation from their global environmental context. The United States is taking a leading role in one of the most ambitious of these collaborations, the EOS, a multibillion dollar network of satellites to study Earth's ecosystems.

CHALLENGES OF COLLABORATION

Despite the many potential benefits deriving from collaborative research, there are also potential downsides associated with almost all of these opportunities. Such disincentives to collaboration can in some cases be quite serious. For example, although collaboration may reduce the net cost of research to each participating nation, it may increase total project costs.[18] In many cases, this cost escalation may not be a significant issue. However, in other circumstances, collaboration may result in the promotion of projects so financially disadvantageous that they would not be undertaken by individual countries acting alone.

There are additional deterrents to collaboration. Although international cooperation may enhance a project's scientific capabilities, it may also transfer critical knowledge and skills to other nations, thus enabling them to compete more effectively with the United States in both science and commerce. Moreover, although pursuing research through international collaboration could provide increased stability for large projects, this framework may also enforce an organizational and investigative rigidity that is harmful to overall research goals.

Finally, although scientific cooperation can in some cases support foreign policy, there is a risk that international scientific collaborations driven by foreign policy goals might act to the detriment of science. Politically motivated collaborations may be more likely to produce scientifically inappropriate or politically unstable projects. This has been one of the strongest criticisms of Russian participation in the space station, where analysts and policymakers have noted that the risks posed by that country's political instability may outweigh the benefits gained from its considerable technical expertise.[19] These potential downsides are listed in table 4-1.

They represent only a partial list of the disincentives to international cooperation in scientific research. Other factors that might preclude a nation from pursuing collaboration include:

- the loss of national leadership, prestige, and project control;
- the need for reliable mechanisms to guarantee long-term commitment to a project;
- the difficulty of distributing costs and benefits in an equitable manner;
- transfer of leading national technologies;
- sociocultural differences; and
- increased management complexity.

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[18] However, just as there have been no studies documenting *savings* from international collaboration, there is no research quantifying *increased costs* from cooperative ventures. Moreover, analysts have suggested that an accurate accounting of possible additional costs would have to discount for the value added by bringing together top scientists from different countries for work on the project.

[19] See, for example, Jeanne Ponessa, "Wariness Over Russia's Role," *Congressional Quarterly*, May 7, 1994, p. 1114.

TABLE 4-1: Opportunities and Potential Downsides to International Collaboration

Opportunity	Downside
Reduce net U.S. costs.	Increase total project costs.
Enhance U.S. scientific capabilities,	Enhance competitive capabilities of U.S. partners.
Enhance stability of science goals and funding.	Increase rigidity of goals and funding.
Maintain U.S. science leadership.	Dilute U.S. scientific leadership
Support U.S. foreign policy.	Distort or undermine science because of political goals.

SOURCE Office of Technology Assessment, 1995

Loss of National Leadership, Prestige, and Project Control

In the words of one observer: "Very large facilities are symbols of power. Consequently, individual countries will only agree to cooperate in constructing them if they have no other alternative."[20] Although this somewhat overstates the point and discounts other reasons for collaborative undertakings, large science projects are closely related to feelings of national leadership and prestige. While the desire to maintain U.S. scientific leadership can motivate collaboration in some cases, it is usually a much stronger disincentive to cooperate with other nations in large science ventures. The goal of establishing and maintaining leadership in scientific R&D is deeply embedded in the culture of U.S. science; it is reinforced by the system of financial and intellectual incentives that govern the activities of U.S. scientists and research institutions. Among the most important of these incentives are the criteria for awarding research grants and academic tenure, competitive salaries for top research scientists, and review criteria for publications.[21]

This culture can act as an obstacle to international collaboration. Since the highest rewards (e.g., the Nobel Prize) are generally based on individual achievement, many U.S. scientists prefer to conduct research independently. They are often very reluctant to participate in joint projects—domestically as well as internationally-in which rewards and recognition are shared. Even when budgets are severely constricted and research goals can be achieved at lower cost through international collaboration, U.S. scientists have sometimes pressed for strictly national research programs. For example, U.S. scientists, supported by NSF funds, are conducting gravitational wave experiments through the Laser Interferometer Gravitational Wave Observatory, completely independent of parallel research efforts in Europe. In addition, U.S. astronomers initially advocated that the two Gemini telescopes be strictly national projects. As noted above, foreign partners were sought only when Congress denied funding for strictly national telescopes and mandated international collaboration. Many attribute termination of the SSC—perhaps the most prominent failure of a big science project—partly to physicists pursuing a strictly national project too long, despite the financial advantages of building such an expensive project collaboratively. In this case, to researchers, the competition for scientific discovery outweighed the potential for saving public funds.

When U.S. scientists and institutions do participate in collaborations, the "culture of national leadership" may strongly influence the character of these cooperative ventures. Then too, the desire to maintain national leadership is often accompanied by the desire to maintain project control.

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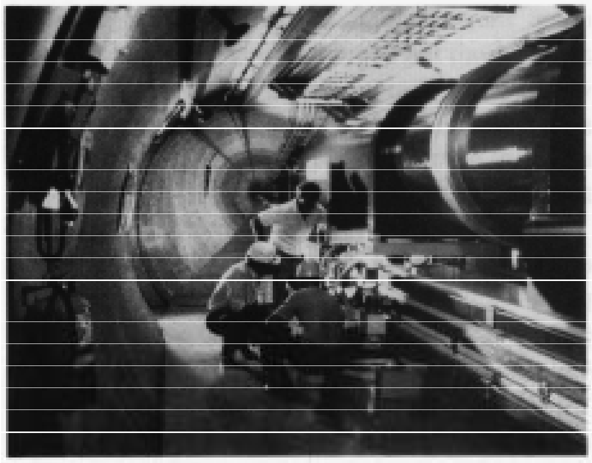
[20] Francoise Praderie, project Head, OECD Megascience Forum, *Megascience and Its Background* (Paris, France: Organization for Economic Cooperation and Development, 1993), p. 35.

[21] Although foreign scientists are governed by similar incentive systems that encourage individual achievement, they are subject to often stronger countervailing incentives (e.g., limitations on national funding abilities) to collaborate with other scientists both at home and abroad.

For example, NASA has been the U.S. agency most actively involved in international collaboration and has employed an explicit set of roles to govern its collaborative efforts. (See chapter 3, box 3-3.) At the heart of NASA's approach to collaboration is a preference for maintaining control over critical paths.[22] This policy was designed to ensure that the United States minimizes technical risk and maintains both leadership and project control in its collaborative space efforts.[23] However, this approach has also meant that most U.S. space partnerships have been compartmentalized, value-added projects, rather than integrated collaborative work.

This approach has worked relatively well at NASA, where the building of instruments for scientific activities in space is conducive to compartmentalization and where the United States continues to enjoy a very strong lead in scientific and technical capabilities, as well as higher levels of funding. However, it may not be easily applicable to other scientific areas, where the research enterprise is more integrated and where other nations have comparable scientific and technical capabilities.


CERN

Mock-up of the CERN tunnel that will be the home of the large Hadron Collider.

As their domestic science programs grow more sophisticated and competitive, potential partners in Western Europe and Japan are demanding more substantive involvement in collaborative research and a share of at least some leadership roles. In fact, Europe's two principal collaborative science organizations, the European Laboratory for Particle Physics (CERN) and ESA, were established explicitly to bridge the technical gap that emerged between Europe and the United States in the post-World War II era and to place Europe in a position to cooperate with the United States from a position of strength, as equal partners. In this, ESA and CERN have been largely successful. They have stopped the "brain drain" of European scientists to the United States, and they have developed high-energy physics facilities, telescopes, and space systems at least comparable and, in some cases, superior to those of the United States.[24]

Maintaining scientfic leadership and project control may also conflict with a primary motive for undertaking international collaboration-saving money. As other countries contribute a greater share of project funding, they will demand greater control. Even when the United States funds the bulk of a collaboration, partners are unlikely to cede complete discretion in project management. Writing about the lessons learned from the space station experience thus far, space policy analysts at NASA and the International Space University

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[22] NASA policies on cricical-path technologies are discussed in chapter 3. Prior to Russian participation in the Space Station, the Canadian robot arm for the space shuttle was the only exception to these policies. However, NASA maintained ultimate control overcritical pathways by stipulating in the contract for the robot arm that the Canadiand provide full access to all production plans and materials should they not fulfill the agreement.

[23] NASA has been able to establish collaborations under these guideline in part because the United States has usuallyprovided the bulk of project funds.

[24] John Krige< "ESA and CERN as International Collaborative Science Organizations,'' contractor report prepared for the Office of Technology Asscsstnent, January 1995, p. 1.

noted that although the space station partners agreed from the beginning that the United States would be the senior partner, "there was considerable discussion on the level of protection for the minority partners in the preservation of management roles."[25]

In contrast, the ITER project conceptual and engineering design phases have been true quadripartite collaborations from the beginning. Each partner has contributed one-quarter of the costs, and decisions have been reached through consensus. The project is overseen by the ITER Council, consisting of two representatives from each party. Engineering design activities are being coordinated by a multinational central team that has been tasking the respective national fusion programs to provide supporting R&D and technology development. Except for a relatively modest amount of funds transferred to support the Joint Central Team administration, the ITER parties have met their commitments through in-kind contributions of personnel, services, and equipment. That structure may have to evolve if and when the project moves into a construction phase to accommodate the management demands of overseeing and directing a large ($8 billion to $10 billion) construction project.

Nevertheless, U.S. goals can create a basic conflict with collaboration. This conflict is related less to money than to scientific leadership. To structure successful partnerships, the United States must provide adequate incentives for other parties to collaborate. Yet U.S. desires to maintain scientific leadership may undermine these efforts and provide a substantial disincentive to collaboration. As one European science official commented to OTA, "Why should I, as Europe, collaborate with the United States to maintain [U.S.] leadership?"[26]

The Need for Reliable Mechanisms To Guarantee Long-Term Project Commitment

One of the most often-cited impediments to future international collaborations has been the difficulty of guaranteeing long-term commitments on the part of all project partners. Countries are reluctant to agree to expensive, long-duration research projects unless they are confident that their partners' commitments are reliable. Once projects are under way, uncertain or changing commitments can complicate project planning, contracting, and budgeting. Questions about the commitment of a partner government can have a domino effect on the other partners, making it more difficult for them to raise money and sustain political commitment to the project at home. Lack of confidence in the reliability of partners also makes it difficult to establish the mutual trust necessary to do the best science in the most efficient manner.

Perceptions that it is an unreliable or unpredictable partner have been a particular problem for the United States. Yet these perceptions are based in part on recollections of only a few cases in which the United States has withdrawn from cooperative science projects. The cases usually cited by Western European and Japanese partners are the U.S. decision to withdraw from the Solvent Refined Coal Demonstration Plant-II (SRC-II) and the Solar Polar project. SRC-II was a joint project of the United States, Germany, and Japan to build a demonstration plant to produce liquid fuels from coal. (See chapter 1, box 1-2.) The project, established in 1980, was terminated by joint decision in 1981. The Solar Polar Project is described in box 1-3. Although these two cases occurred more than a decade ago, they are remembered and are cited frequently by our European and Japanese partners to

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[25] Lynn F.H. Cline and George Van Reeth, "Space Station—An International Venture," prepared for the Workshop on International Space Cooperation: Learning from the Past, Planning for the Future, November 1992, p. 5.

[26] OTA Workshop on International Collaboration in Large Science Projects, Sept. 13, 1994.

bolster claims that U.S. commitments are unstable.

An even more prominent issue among U.S. partners is the U.S. budget process, in which funding for all projects must be rejustified yearly. In virtually all of OTA's discussions with U.S. partners, foreign governments, and organizations, the annual uncertainty over U.S. appropriations was cited as among the most formidable challenges to prospective and ongoing collaborations.[27] It is important to note that differences in budget processes contribute to foreign perceptions that the U.S. process promotes instability. Our major partners have parliamentary systems in which the combination of legislative and executive authority gives majority political parties greater power to control the agenda and implement policy. For partners accustomed to this system, the U.S. budget process seems to lead to greater uncertainty.

The U.S. budget process frequently creates tensions for collaborations already under way. In the case of the space station, continuing struggles over funding have increased tensions between the United States and its partners. Even in less contentious cases where appropriations are virtually assured, U.S. partners report concern about what they perceive as an annual process that calls U.S. funding formally into question. Although international projects are rarely canceled in the yearly budget process, the cancellation of domestic science projects such as the SSC has contributed to uncertainty about the strength of funding for international projects as well.[28]

The annual budget process does allow flexibility in planning that European countries and Japan lack. Having made multiyear commitments to science projects, these countries often find it difficult to revise or terminate inefficient or nonperforming projects.[29] However, some partners see a contradiction between U.S. claims of world scientific leadership and its annual budget process.

In contrast to instabilities in the U.S. funding process, funding for science research in Europe—by country or in multilateral organizations—has generally been more stable. This increased stability cannot be attributed to different statutory procedures, such as multiyear appropriations for science projects. Like the United States, European countries generally appropriate science funds yearly, as part of the annual budget process. Instead, two other factors account for this increased stability. First, although these countries and organizations generally do not provide multiyear appropriations, their planning processes, both for research programs and individual large science projects, are more extensive, which results in more realistic funding estimates and research time lines. Once governments commit to a project—and this is generally a longer process

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[27] This perception is prominent in public discussion of international science projects as well. For example, commenting on the Gemini telescope project, Julie Lutz, Director of the National Science Foundation's astronomy division, said "[I]t is harder for the United States than for other countries to sustain a long-term scientific collaboration because the entire U.S. budget is reviewed annually by Congress." Mervis, see footnote 11, p. 430.

[28] In an analysis of 30 selected projects, several of which were canceled, the Congressional Research Service notes that "One . . . tentative conclusion is that significant technical, cost, political, foreign policy, and other events following an initial authorization and/or appropriation may overshadow initial congressional support." Sharp escalations in project cost or lower agency appropriations were an especially significant cause of project terminations. See William C. Boesman, *Big Science and Technology Projects: Analysis of 30 Selected U.S. Government Projects* (Washington, DC: Congressional Research Service, Aug. 24, 1994), p. 7.

[29] It should be noted that although individual countries lack flexibility, multinational European scientific organizations such as CERN, ESA, and ESO have in recent years shown flexibility in canceling, reducing funding for, and restructuring projects.

than in the United States—funding and participation are virtually guaranteed.[30] Second, almost all basic science research in Europe contains a significant international component. This applies not just to research conducted in multilateral organizations, but also to national research projects. Given their extensive interdependence in science research, stability of funding and adherence to international commitments are absolutely vital to the viability of European national research programs. The strength of international commitment in Europe has a nonscientific and historical component as well—the countries' relatively small size, close proximity, and closely interwoven economies. Moreover, the European Union treaty encourages joint research efforts among member states. The consequences of breaking an international commitment would likely be much more serious for a European country than they would be for the United States.

Similar factors apply in Japan. Projects receive approval only after undergoing a rigorous technical and financial evaluation that typically occurs over a three- to five-year period. Although Japan is generally slow to enter into commitments, once having agreed to a project, it adheres strongly to its commitments in part because of the desire to maintain and foster good international relations. However, participation in large international projects is usually not pursued by the Japanese unless there is a sound scientific or strategic motivation.[31]

Nevertheless, growing budget constraints within Europe may weaken multiyear funding arrangements or commitments to collaborative projects. Signs of strain are already showing within CERN, where Germany has lobbied successfully to reduce its yearly contribution and where the future of the Large Hadron Collider (LHC) was complicated by heated disputes over funding contributions. ESA itself has recently undergone dramatic budget reductions in its optional programs, necessitating project cancellations. Disagreements about funding priorities have delayed approval and resulted in a downsizing of the organization's plan to build a pressurized laboratory and other compenents for the space station.

However, despite the concern among partner nations that the United States can sometimes be an unreliable or unpredictable partner, some question whether the United States has actually paid a price for being perceived as unreliable. Although this perception has unquestionably complicated U.S. negotiations in prospective collaborations, OTA cannot identify a case in which efforts to collaborate or initiate a project have failed because of questions about U.S. reliability. In fact, concerns about U.S. reliability may be ameliorated by the disproportionately large share the United States has paid into some collaborations. Nevertheless, future partnerships may have to be more formally structured to address the concerns of potential U.S. partners.

Finally, reliability is not related solely to the ability to deliver promised funds. Reliability also has a technical aspect—the ability to deliver properly designed and tested project components in a timely manner. In a purely domestic project, oversight and project control may be much simpler than in an international venture, where multiple agencies and firms in various countries have technical responsibilities. If there are only a few items

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[30] European countries employ four- to five-year long-term planning processes for R&D decisions. Programs that have been approved at the cabinet level in these countries are reviewed on a two-year basis and generally can be canceled only if feasibility studies have not been conclusive or if the country is under economic constraints. Moreover, "[T]he most striking difference between the United States and other democratic countries is the action of Congress which can, more easily than anywhere else, shut down or create new programs without the agreement of the Administration/White House. In other countries, such behavior for major programs could lead to a political crisis." Center for Science, Trade and Technology Policy, George Mason University, "Large Science Project Priorities in Selected Countries," contractor report prepared for the Office of Technology Assessment, January 1995, p. 13.

[31] 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 Technoloy Assessment, December 1994.

on critical paths or if critical technologies are distributed among a smaller group of countries and firms, technical risks and concerns about the reliability of partners are reduced. However, the greater the number of partners that have responsibility over items on critical project paths, the more difficult it will be to ensure technical control. NASA's policies and preferences governing critical paths and project control are designed in part to meet these concerns.

Difficulty of Equitably Distributing Costs and Benefits

Apportionment of funding contributions and contracts can also impede cooperation. Successful collaboration requires convincing all international partners that project financing is structured fairly. Partners must also be satisfied with the policies that determine how and where money is spent. Distributing costs and benefits has been a continuing and difficult problem. The equitable allocation of costs and benefits has generally been a more serious problem for collaborative science organizations, with pooled funding and contracting operations, than for ad hoc collaborations in which there is often no exchange of funds or contracts.

The United States has collaborated more often using the latter arrangement and has placed heavy reliance on "clean interface" collaborations with no exchange of funds. This has reduced potential problems over the distribution of project costs and benefits. The Europeans, with their reliance on joint research organizations, have dealt with the problem more often and in greater depth. However, if the United States collaborates more actively in the future, it too will have to grapple with the issue of how to distribute project obligations and benefits. The United States may face this in awarding contracts and making the siting decision on the ITER project. The issue has also arisen at CERN over potential U.S. participation in the LHC project. CERN has informed the Department of Energy that U.S. physicists may be unable to conduct research on the Large Hadron Collider if the U.S. government does not contribute to the capital costs of building the LHC.[32] U.S. policymakers may therefore benefit from an assessment of the challenges that Europeans have encountered in this area.

In practice, it has been easier to formulate systems for determining each country's funding contribution than to apportion project contracts. ESA and CERN employ formulas based on the gross domestic product to determine each country's funding contribution. This system is designed to ensure proportionality: each country contributes funds relative to its resources. In ESA's case, the proportionality formula applies to the organization's "mandatory" science programs. ESA allows countries to contribute additional funds to "optional" projects in which they are especially interested.

Yet even in this area, there has been substantial difficulty in assessing and compensating for the costs and benefits that may accrue to a country hosting a science facility. Some organizations spread their facilities among participating countries. In areas of ad hoc collaboration, there may be informal agreements among governments about which country is next "in line" to host a major facility. The benefits of hosting a facility may also be factored into a country's funding contribution to a facility or organization. In the case of the European fusion community's Joint European Torus (JET), Great Britain agreed to pay an additional 10 percent as its share of project costs in exchange for hosting the facility. However, there was recently sharp disagreement at CERN between Germany and Great Britain, on the one hand, and France and Switzerland, on the other, over how much the latter two countries should

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[32] C. Llewellyn Smith, Director General of CERN, letter to U.S. Department of Energy Secretary Hazel O'Leary, Feb. 15, 1994.

contribute to the LHC in exchange for being its hosts. Final approval for building the LHC was held up while CERN members negotiated over this issue.[33]

Ensuring some balance in the procurement of goods and services has been even more difficult. There is a fundamental tension between each country's desire to receive financial returns commensurate with its contribution and the need for the project itself to contract work most efficiently and effectively. ESA, for example, has attempted to satisfy member demands for equity in contract apportionment by instituting a system of "fair return" (often referred to as *juste retour* or, in ESA's case, "equitable geographic return"), whereby each country receives a percentage of project contracts proportionate to its funding contribution, both for mandatory and optional projects. Observers report that this system worked relatively well in the past because ESA managers were allowed to meet the fair-return requirement by calculating contract distribution over several years and over a series of projects. ESA managers report that this gave them leeway to meet the distribution requirement and to place contracts where they were most technically and financially appropriate.

However, others argue that fair return discourages competitiveness and efficiency, and may prevent organizations from contracting with the best or most appropriate firms.[34] Recent experience at ESA may support this point. Although ESA's system of fair return appeared to work well in the past, political and budget pressures in member countries in recent years have led to demands for equitable returns on *each* project, reducing the organization's flexibility and possibly increasing costs.[35]

To avoid this problem, which can affect even the best functioning fair-return arrangements, CERN until recently had no requirement to distribute contracts among partners. CERN was mandated instead to place contracts where most appropriate—technically, logistically, and financially. However, the following factors have resulted in pressure on CERN to enact some variant of fair return as well: budgetary constraints among member countries of CERN; the fact that host-states France and Switzerland have consistently won almost 60 percent of CERN contracts; and the fact that about 8 percent of CERN's annual budget is spent outside its member states (more than 5 percent is spent in the United States). CERN now employs a relatively loose return coefficient of 80 percent and contracting rules that keep prices of fair-return contracts close to the lowest bid. These provisions allow much greater flexibility than ESA has for placing contracts where they are most technically and financially advantageous.[36]

Fair return is an issue of contention not only because each country seeks to recoup its immediate contribution to each project. Differences also arise over the distribution of contracts because of the possible commercial potential of the technologies involved in developing megascience projects. For example, contracts to develop superconducting magnets for a collider or for Earth-observing instruments on an orbiting vehicle may finance new technologies with commercial implications

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[33] In December 1994, the CERN Council approved the construction of a $2.3 billion Large Hadron Collider to be built in two stages. France and Switzerland, who will host the facility, agreed to pay proportionally more than they have for previous CERN projects. If additional funding is received from the United States and Japan, the LHC will likely be built in one stage and completed around 2004. If CERN is unable to secure funding from these and other nonmember states, construction will be stretched out into a second phase, which will end in 2008. See Dennis F. Cioffi, "CERN Reaches Consensus on Two-Stage LHC," *Physics Today,* vol. 48, No. 2, February 1995, pp. 48-50.

[34] See, for example, "Will Europe be Lost in Space?" *Nature,* vol. 373, Feb. 16, 1995, p. 545.

[35] 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. Krige, see footnote 23, p. 4.

[36] Ibid.

far beyond the initial science-oriented project goals. For this reason, not only are countries anxious to receive contracts for path-breaking technologies, they are also reluctant to finance, through their project contributions, contracts that develop these technologies (and create jobs) elsewhere—in effect, financing foreign commercial competitors.

Because of the differing commercial potential of various technologies, distribution of contracts has been a more important issue in some fields than in others. European collaboration has worked most smoothly when the science or technology concerned is not of direct commercial importance. For example, CERN's success, its lack of a fair-return policy, and the absence of large national facilities in all member states except Germany reflect European governments' perception that high-energy physics is a field of research with little potential for practical application, at least in the short to medium term. In space research, the situation is different, as evidenced by the existence of several independent European national space programs in addition to ESA, by ESA's industrial policy of fair return, and by the demand, particularly from the smaller or technologically less advanced member states, to move even closer to 100-percent return on their contributions.

Intellectual property issues also complicate collaborative arrangements. In structuring a research venture, managers must decide how to acquire, use, and safeguard technologies that are necessary to the project, but proprietary to a certain firm or country. Research projects must also design intellectual property mechanisms for processes and products produced by the venture itself. These issues may be even more complex than deciding where to assign contracts because they require, additionally, mechanisms for dispute resolution.

Ironically, the most difficult benefit to assign may be the least commercially important: where to site a project. There are unquestionably many financial benefits to be derived from hosting a major science facility, most of which come from construction, operation, and maintenance contracts, as well as payrolls, that can give a significant boost to a local economy. Also, a major science facility could attract new companies to an area. However, rather than the benefits derived from hosting the facility and its infrastructure, contracts to produce path-breaking technologies with commercial implications or spinoffs may actually be much more beneficial to a country's economy as a whole, helping to create entirely new sectors of industry and employment. Thus, for example, the United States might place a much lower priority on hosting ITER than on maximizing opportunities to develop and produce the magnets, other reactor components, integration systems, or advanced materials that could have considerable commercial potential beyond fusion. In effect, the United States could use the siting decision as a bargaining chip to obtain concessions for critical advanced technologies and services.[37]

Nevertheless, siting remains an important issue in collaboration because it is so closely related to prestige—the national prestige of the country hosting the project, as well as the status of a nation's scientific community. Thus, decisions about siting are a challenge to collaboration due to questions of *both* national prestige and distribution of project benefits.

■ Transfer of Leading National Technologies

The potential for transfer of technologies that have national security or commercial implications represents another impediment to collaboration. With respect to scientific and commercial considerations, the challenges presented by technology transfer are closely related to those posed by the distribution of benefits and the maintenance of national leadership. Countries and firms are reluc-

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[37] Even site-related contracts, such as construction and management services, need not accrue solely to the host country.

tant to participate in projects that may result in the transfer to potential competitors of technologies in which they hold a scientific or commercial advantage.

Countries with cutting-edge technologies essential to a project have used a variety of means to protect their edge while participating in collaborative research. For example, a country can try to safeguard its lead by compartmentalizing work in collaborations or by stipulating project rules that clearly spell out the ways in which the technology may be used. NASA has employed this approach through the rules described in box 3-3. When it is impossible to safeguard a technology, a country may still participate in joint research because it derives other scientific or commercial benefits that compensate for the costs of sharing its leading technologies.[38] For example, the United States has developed considerable and unique expertise in the design of superconducting magnets as an outgrowth of the SSC program. By participating in the LHC effort, this important expertise can be utilized and sustained over the next decade. Not sharing this expertise could hurt overall U.S. capabilities in hadron accelerator technologies, because U.S. physicists would not have access to a machine (LHC) that is at the edge of the energy frontier.

However, despite all precautions, technologies may still be “leaked.” Moreover, when countries sacrifice a lead in one technology for the sake of access to other technologies or benefits, calculation of the relative tradeoffs is difficult and imprecise. Countries, institutions, or firms may also choose to solve the potential technology transfer problem by withholding their leading technology and using less advanced technologies on a collaborative project.

The national security aspects of technology transfer—the transfer of technologies with proven or potential military applications—may be even more formidable. It is difficult to proceed with scientific collaborations that involve the transfer of militarily relevant technology. The United States has encountered serious obstacles in joint government-level military-related research with its allies.[39] This type of technology transfer is out of the question if the partner is a potential U.S. enemy or rival. Yet even when the United States is willing to share these technologies with friends, it may prove too difficult to design a collaborative and regulatory framework that would prevent further transfer or proliferation of the technology or technical capabilities.

Sociocultural Differences

Although often given short shrift in policy-related reviews of collaboration, sociocultural differences among scientists in an international research venture can pose obstacles to a successful collaboration. These impediments range from the obvious to the more subtle.

The first set of sociocultural obstacles involves daily life-style changes. Of these, the most obvious is the difference in language. For scientists working together in a single research venture, clear communication is vital, not only in daily scientific discourse, but also in establishing the mutual trust and collegiality that can foster creative synergies. Other differences in life-style, including working habits, housing, and cuisines, can also have negative effects on a scientist’s ability to feel relaxed, “at home,” and able to devote maximum mental energy to the project.

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[38] In the private sector, IBM, Toshiba, and Siemens have decided to pool resources to develop the next-generation semiconductor DRAM (dynamic random access memory) technologies. Each of the companies has developed leading-edge capabilities in semiconductor design and fabrication. However, the financial and technical challenges associated with the 64-megabit and 256-megabit memory technologies compelled these companies to share the risks and costs of development. Each is revealing important information to the other in order to make this effort successful. In so doing, these companies are hoping to achieve synergies and new technical approaches that will reduce manufacturing costs.

[39] 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 Offfice, May 1990).

The stress of living in a foreign culture can increase in direct proportion to the "distance" of that culture from a scientist's own. Thus, it may be easier for a Western scientist to adjust to life in another Western country than in an Asian country, and vice versa. Furthermore, scientists from the countries of Western Europe, which are smaller than the United States, as well as more closely interwoven geographically and culturally, share a long history of collaboration in economics, politics, and culture, as well as science. These scientists often adapt more readily to life abroad than scientists from larger, more geographically isolated countries. For example, some U.S. citizens have a more difficult time adapting to life abroad because preparation for international living played a much smaller role in their personal and professional upbringing than it did for their European counterparts.

Perhaps the most serious of these sociocultural challenges—highlighted by international participants at OTA's workshop on international collaboration—is the retention of cultural identity within families, especially among children. Scientists from the United States, Europe, and Japan noted that the biggest problem they face while working abroad is finding culturally appropriate educational services for their children. Whatever the difficulties and rewards of foreign life for them as adults, they place strong emphasis on being able to educate their children in their home culture or provide employment opportunities for spouses.

Officials at Fermilab, an institution with a strong history of international cooperation, say that to ensure a successful environment for collaboration, a host institution or country must invest resources to address the needs of foreigners. These include not only education, but also housing, food, and other areas. Addressing these sociocultural issues can be an unanticipated expense in an international partnership, in both large and small science projects. Fermilab, for example, employs someone full time to work exclusively on these matters.

■ Increased Management Complexity

Managing an international venture is a more challenging and complex enterprise than managing a strictly national project. Increased management complexity can manifest itself in several ways. These include increased transaction costs, increased complexity of multinational decision-making at both the administrative and the scientific levels, and in some cases, reduced financial scrutiny and accountability. All of these factors make international projects more costly than purely national ones, in terms of both budgets and management time. The factors that increase management complexity are reviewed below.

Transaction costs take many forms. These include the cost of constructing and maintaining multiple, parallel, and geographically disparate administrative structures on the national and international levels. International projects also involve higher expenses for certain overhead line items, such as translation services and travel. Differences in equipment and standards may create costly and confusing obstacles to joint research. Moving and maintaining scientists abroad can be extremely expensive, much more so than the cost of maintaining the same scientists at home on exclusively national projects.

Transaction costs in international collaborations can be considerable, far beyond normal expenses for exclusively national projects. Critics of international collaboration maintain that due to these costs, international collaborative projects are always more expensive (in the aggregate) than national ones. However, it should be noted that since these higher costs are spread among all participating countries, the net project cost to each country is still likely to be substantially lower than the cost of undertaking the project alone.

In addition to the transaction costs of collaboration, increased management complexity can be reflected in complex, binding international agreements that reduce project flexibility (and serendipity) and increase the time required to reach decisions collectively. For projects in which policy and funding decisions require consensus or the approval of several different countries, it can be difficult to make decisions and change direction as needed in the course of the project. With science projects that have important commercial implications for their member states, policy decisions may require high-level meetings. For example, major policy decisions at ESA are made by meetings of the ministers for space-related affairs from all member states. At CERN, an organization with more limited commercial applications, decisions seldom require such high-level meetings. Other aspects of increased management complexity include boundaries to the movement of people and materials across borders, problems in obtaining work permits for spouses of scientists, and so forth.

More serious in its consequences for scientific discovery is the greater difficulty in reaching consensus decisions. Although this type of consensus may compel greater care in research before the publication of new discoveries, it may also produce a conservatism that is counterproductive to the basic mission of scientific discovery. Thus, innovation and individualism may be discouraged. For example, some analysts have criticized ITER's planners for using a fairly conservative design in an effort to ensure that the ignition of fusion fuel can actually be achieved.[40]

In some cases, international projects are complicated by differences in management and accounting systems, which make it difficult to evaluate the contributions and activities of each member country or institution. U.S. public science institutions, which operate under extremely tight and well-elaborated rules, have at times had particular trouble obtaining the necessary financial information from partner institutions abroad. This makes it difficult for them to account for expenditures of collaborative funds and time.

CONCLUSION

The decision to pursue scientific research on an international cooperative basis is complex. It involves balancing the relative benefits of collaboration against the disadvantages of international research. OTA has found that the most concrete benefits of partnerships include opportunities to reduce net U.S. costs and to enhance a project's scientific capabilities. The desire to reduce costs and/or "to do better science" has featured prominently as a motive in all the collaborations that OTA investigated. In addition, some collaborations have also been motivated by the desire to enhance funding stability, to support U.S. foreign policy goals, and to address global scientific questions.

Although these motives to collaborate can be attractive, the potential disadvantages of scientific cooperation must also be considered. In the past, the strongest disincentives to U.S. participation in collaborative endeavors have been the potential loss of national leadership and project control, difficulty in distributing a project's costs and benefits, and the risk of technology transfer. From the standpoint of U.S. partners, the inability of the United States to guarantee long-term political and funding support for international projects has been the most serious challenge to collaborations with the United States. However, there is evidence that these concerns have been overstated. There is also reason to believe that U.S. partners may soon experience the same types of instability. Finally, some sociocultural challenges may exist that complicate collaboration. These problems, however, are almost always outweighed by the benefits that can be derived by pooling intellectual talent from around the world and by the increased understanding that results from the close interaction of diverse groups of people.

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[40] Because ITER is an ambitious, very expensive international collaboration (one of the first), a conservative and probably more expensive design is being used to reduce the chances that the machine will not perform as intended.