Chapter 7

Fusion as an International Program

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INTRODUCTION

Many nations of the world have cooperated on magnetic fusion research for almost 30 years. Since U.S. magnetic fusion research was declassified in 1958, the major international programs have engaged in regular information and personnel exchanges, meetings, joint planning efforts, and jointly conducted experiments. [1]

The leaders of the U.S. fusion community continue to support international cooperation, as does the U.S. Department of Energy (DOE). In the past, the United States cooperated internationally on a variety of exchanges that have produced useful information without seriously jeopardizing the autonomy of the domestic fusion program. In recent years, in response to budgetary constraints and the technical and scientific benefits of cooperation, DOE has begun cooperating more intensively in fusion, and the major fusion programs have become more interdependent, **For the future, DOE proposes undertaking cooperative projects that will require the participating fusion programs to become significantly interdependent; indeed, DOE now sees more intensive international collaboration as a financial necessity.**

Why Cooperation Is Attractive

Without exception, all of the major fusion programs participate in international activities and look favorably on more intensive future activities. There are several reasons for this widespread interest.[2]

[1] Major fusion programs are currently active in the United States, Japan, the European Community (EC), and the Soviet Union. Primary contributors to the European Community's fusion program are the Federal Republic of Germany, France, Italy, and the United Kingdom, although other member nations are also involved.

[2] The reasons that follow were based in part on a discussion of Incentives to collaborate found in: Energy Research Advisory Board, *International Co//~? boration in the U.S. DOE's Research and Development Programs,* report to the U.S. Department of Energy, prepared by the ERAB International Research and Development Panel, DOE/S-0047, December 1985, p, 11,

Fusion Research Is Expensive

The high cost of fusion research is a practical incentive for nations to cooperate. The next-generation engineering test reactor, for example, is expected to cost well over $1 billion and possibly several times that much, requiring a substantial increase in U.S. annual fusion budgets if it were to be built domestically. It is not clear whether or not the governments of any of the major fusion powers would be willing to construct such an expensive experiment alone. Given the expense and considering the similarity in next-step program goals, the major fusion programs have agreed in principle that the world does not need four engineering test reactors of the same kind. Limited funding can be allocated more efficiently if nations are willing to collaborate on one major experimental facility.

Fusion Programs Are at Comparable Levels

The comparable levels of progress among the major fusion programs make higher levels of cooperation attractive, particularly over the next decade. While there are differences in emphasis and achievement, the programs have comparable scientific and technical capabilities and recognize the need for similar next-generation experiments. Cooperative projects are easier to implement in complementary programs because the benefits can be distributed equitably and because all participants stand to gain from their partners' expertise.

Fusion Can Advance More Effectively

International collaboration in fusion research is attractive because it provides a forum for scientists and engineers to interact. If the major programs can coordinate their activities, the intellectual resources available to address pressing issues in fusion research and development (R&D) can increase dramatically.

Forms of Cooperation

International cooperative efforts range from simply exchanging information in international meetings through the joint construction and operation of experimental devices to complete integration of research efforts.[3] Various types of cooperation entail different levels of program integration, information transfer, and trust. The potential risks and benefits of the programs vary correspondingly.

It is necessary to make a distinction between the terms "cooperation" and "collaboration." This report will adopt the usage of a recent National Research Council report on cooperation in fusion research.[4] Throughout this OTA assessment, "cooperation" will refer to all activities involving nations, or individuals from different nations, working together. "Collaboration," a more intensive type of cooperation, will describe activities involving a substantial degree of program integration, funding commitment, and joint management.

Types of Cooperation and Collaboration

- **Information Exchange. Information exchange is the most common form of international cooperation. Information on achievements and advances, as well as technical approaches and experimental data, is exchanged through several channels, including meetings, conferences, symposia, workshops, and publication in technical journals.**
- **Personnel Exchange. Personnel exchanges–visits and assignments—also are widely used. During a typical visit, research scientists tour one or more of the host program's facilities for 1** or 2 weeks. Assignments are extended stays in which the guest participant actually works on an experiment and contributes to the host program's research effort. For the duration of the assignment, the guest participant is a full-fledged member of the experimental or theoretical team. Assignments are one of the most effective ways to transfer expertise.
- **Joint Planning. Joint planning includes activities to identify areas for future cooperative research, to provide a forum** for coordinating experimental and theoretical programs on large experimental devices, and to avoid unnecessary duplication of effort while still ensuring verification of important experimental or theoretical results.
- **Joint Research. Through joint research, major facilities are made available for research projects of other programs.** The facility is financed and constructed primarily by the host program, with other participating programs either providing a percentage of construction and operation costs or contributing equipment. In exchange for their contributions, participating programs are granted access to the machine and experimental data. Frequently, contributions of the participants enable an existing machine to be upgraded; in some cases these contributions are essential to the construction of the machine in the first place. Activities involving joint research are becoming increasingly common.
- **Joint Construction and Operation. Joint con**struction and operation of major experiments and facilities are the most intensive forms of international cooperation; this form of cooperation is referred to as collaboration. Participating programs agree to pool their resources and construct a commonly owned and operated facility. There is no "host" program in this case; the facility is operated by a management team comprised of representatives from each program.

Plans for future U.S. participation in international fusion activities include collaborative projects in addition to the other levels of cooperation. The largest scale example of a collaborative project under discussion today would be a jointly constructed and operated engineering test reactor. The current proposal for this experiment, called the International Thermonuclear Experimental Reactor (ITER), involves only conceptual design and supporting R&D for the project. If this phase of the project is arranged and proves work-

3 A discussion of proposals for future cooperation and collaboration now under consideration can be found later in this chapter under "Prospects for International Cooperation."

4 National Research Council, *Cooperation and Competition on the Path to Fusion Energy* (Washington, DC: National Academy Press, 1984), p. 5.

able, more extensive collaboration on construction and operation could be considered.

If successfully negotiated, ITER probably will be the world's largest, most expensive, and most visible cooperative project. Therefore, this chapter primarily focuses on it. The full scope of DOE's plans for future cooperative activity includes a variety of additional, lesser facilities in areas such as materials research and technology development. DOE plans to investigate more intensive forms of cooperation–including joint research, planning, and possibly even joint construction and operation of facilities—on these other projects as well. The U.S. plans for future cooperation are analyzed in this chapter under "Prospects for International Cooperation."

Types of Agreements

Different levels of international agreements could be used to facilitate cooperation. These agreements can range from formal treaties down to informal workshops and publications:

- **Treaty. A treaty between governments is the most binding and formal agreement that can be established. Ratification signifies commitment to the substance of the agreement; obligations incurred under a treaty can be abrogated, but such action is not taken lightly or often. However, a treaty is the most difficult type of agreement to implement. There is a greater risk of negotiations breaking down during the development of a treaty, and more issues must be resolved in order** for a treaty to be ratified. Moreover, the ratification process for a treaty is time-consuming; a treaty may be obsolete by the time it is finally ratified. In the United States, a treaty must be signed by the President and ratified by a two-thirds majority of the Senate.
- **Heads-of-State Agreement. A heads-of-state agreement is less formal than a treaty but is considered binding by most governments. Such an agreement carries the full weight of the government in power, and abrogation by a signatory head of state** would bean unusual, though not impossible, act. When the subject of the agreement has a strong base of support among many different groups, the risk that the signing head of state, or a succeeding one, would disavow the agreement is small.
- **Ministerial-level Agreement. A ministerial agreement is arranged between ministries of the participating governments, and it is less formal than either a treaty or a heads-of-state agreement. It requires less** review and approval than the more formal agreements and is affected more directly by changes in budgetary constraints and political objectives. However, it still carries the full weight of the government. In the United States, ministerial-level agreements in fusion research are negotiated with participation of the Departments of Energy and State.
- Informal Arrangement. An informal arrangement can be undertaken between governments, laboratories, and individuals. It can provide an excellent means of transferring information among scientists, but it does not provide a basis for programmatic or international planning. This arrangement is typically instituted on an ad hoc basis, in response to particular needs and objectives of the participants.

Different types of agreements are appropriate for the various forms of cooperation that occur in fusion and in other areas (see table 7-1).

Most cooperative efforts occur under a general arrangement called an *umbrella agreement.* An

Table 7-1.—Comparison of Type of Cooperation and Level of Agreement

Type of cooperation	Level of agreement
Information exchange	Informal Arrangement Ministerial Agreement Heads-of-State Agreement
Personnel exchange	Informal arrangement Ministerial Agreement Heads-of-State Agreement
Joint planning	Ministerial Agreement Heads-of-State Agreement
Joint research	Ministerial Agreement Heads-of-State Agreement
Joint construction and operation	Ministerial Agreement Heads-of-State Agreement Treaty

SOURCE Office of Technology Assessment, 1987 umbrella agreement usually is established as part of a ministerial agreement before any specific cooperative agreement is instituted. It defines the principles of cooperation and provides a framework for developing future cooperative agreements. It is undertaken when governments are interested in cooperation and want to formalize the intent to cooperate. An umbrella agreement typically states that the participating governments support cooperation and are ready to begin negotiating specific cooperative projects.

Frequently, an umbrella agreement authorizes transfer of preliminary information and technology, sets up joint planning and negotiation efforts, and provides a forum for exploring the potential of future cooperation on medium- and long-term projects. An umbrella agreement is not a final agreement. It is not intended to address the substantive issues involved in decisions to undertake specific cooperative projects. It is a useful device, however, for defining areas of potential cooperation and for creating a framework for negotiating future agreements.

MAJOR INTERNATIONAL AGREEMENTS

Under current arrangements, the United States participates in cooperative fusion activities at all levels except that of joint construction and operation. To date, only one international fusion project has been collaborative in this sense: the joint European Torus project of the European Community (EC). Table 7-2 summarizes the principal existing international fusion arrangements; the organizations and agreements mentioned in the table are described below.

Multilateral Activities

International Atomic Energy Agency

The International Atomic Energy Agency (IAEA) has been one of the most important facilitators of fusion cooperation. The IAEA is an independent intergovernmental organization within the United Nations system, and its mission is to promote and ensure the peaceful use of atomic

Table 7-2.—Principal International Fusion Activities

Type of cooperation	Representative project	Agreement
Information exchange.	Large Tokamak Agreement	IEA
	Nuclear Fusion journal	IAEA
	Conferences	IAEA
Personnel exchange	Large Tokamak Agreement	IEA
	50 transfers each way	U.S.-Japan Bilateral
	Six transfers each way	U.S.-USSR Bilateral
	To be determined	U.S.-EC Bilateral
Joint research	ASDEX Upgrade	IEA
	Large Coil Task	IEA
	Doublet III-D Upgrade	U.S.-Japan Bilateral
	Tore Supra	U.S.-EC Bilateral
Joint planning	INTOR	IAEA
	Large Tokamak Agreement	IEA
	Joint Institute for Fusion Theory	U.S.-Japan Bilateral
	To be determined	U.S.-EC Bilateral
Joint construction and operation	Joint European Torus	European Community

SOURCE: Office of Technology Assessment, 1987.

energy. The headquarters of the IAEA are located in Vienna, Austria. All countries currently doing fusion research are members of the IAEA. It has facilitated two different types of cooperative activity: information exchanges and joint planning efforts.

Major informational activities conducted by the IAEA in the area of fusion research include hosting biennial meetings and arranging topical meetings and workshops on areas of special interest or concern. In addition, the IAEA publishes a technical journal, *Nuclear Fusion,* in which fusion researchers can share their findings.

The IAEA also facilitates a joint planning activity, called the International Tokamak Reactor (I N-TOR) design study. INTOR began in 1978, and it involves the European Community, Japan, the Soviet Union, and the United States. The goal of INTOR is to define concepts and designs for a conceivable next-generation fusion experiment. It is a forum where Western fusion scientists have regular contact with their Soviet counterparts. National teams work on parallel tasks and meet two or three times a year for several weeks to compare results and plan future work. Most analysts agree that INTOR discussions have successfully identified critical issues in both physics and technology.

International Energy Agency

The International Energy Agency (IEA) was created by 21 Western oil-importing nations in 1974 in response to the OPEC oil embargo. IEA’s main task is to plan for crisis response to future oil embargoes. In addition, the IEA also promotes international cooperation in research and development of energy technologies that have the potential to decrease the West’s dependence on oil imports, The European Community, Japan, and the United States participate in IEA’s cooperative projects. Magnetic fusion research is one of many areas IEA promotes, largely by facilitating joint research efforts. The IEA is headquartered in Paris, France.

In 1977, the Large Coil Task (LCT) was organized u rider the auspices of the I EA. As part of the LCT, the U.S. fusion program constructed the International Fusion Superconducting Magnet Test Facility at Oak Ridge National Laboratory in Tennessee at a cost of about $40 million. This facility is designed to test superconducting magnet coils.[5] It holds six large coils, one each constructed by the European Atomic Energy Community, the Japan Atomic Energy Research Institute, and the Swiss Institute for Nuclear Research and three constructed by U.S. manufacturers.[6] Each coil cost between $12 million and $15 million to construct. international involvement in the LCT has distributed the costs of the project among several nations, and it has also enabled different types of coils to be tested in a common facility, allowing direct comparison. Moreover, the LCT is the major instance in the fusion area that involved industry in international cooperation.

Several other cooperative projects also occur under IEA auspices. The European Community and the United States participate in joint planning on next-generation stellarator experiments to coordinate their research efforts. It appears that Japan will soon be joining this project. Through the IEA, the United States and the European Community are also conducting joint research on the Axisymmetric Divertor Experiment (ASDEX) and its upgrade (ASDEX-U). These facilities are located at the Institute for Plasma Physics at Garching, Federal Republic of Germany, and U.S. participation in this research has made it unnecessary for the United States to construct similar facilities. The IEA provides no funding for any of these projects, only an umbrella framework and minor secretariat functions.

The most recent IEA agreement, signed in January 1986, provides for cooperation among the three large operational tokamak experiments (jT-60 in Japan, the joint European Torus (JET) in the European Community, and the Tokamak Fusion Test Reactor (TFTR) in the United States). Under this agreement, the three programs conduct personnel and information exchanges for tokamak experiments. An executive committee, consisting of two members from each fusion program,

[5]For a discussion of the role of superconducting magnets in a fusion reactor, see the section of ch. 4 titled “The Magnets” under “Fusion Power Core Systems. ”

[6]U .S. Department of Energy, Office of Energy Research, *Magnetic Fusion Energy Research: A Summary of Accomplishments,* DOE/ER-0297, December 1986, p. 19.

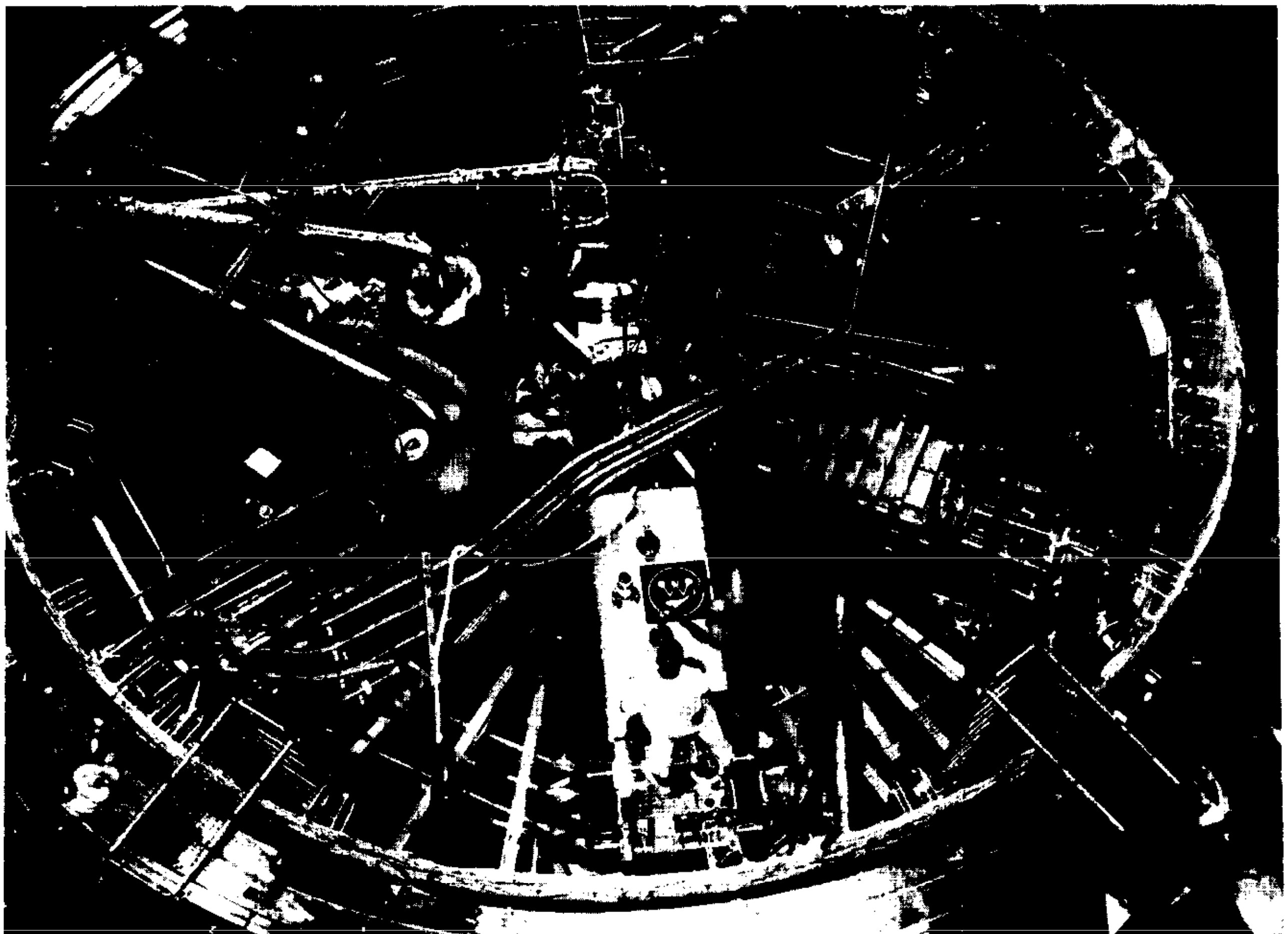

Photo credit: Oak Ridge National Laboratory

The International Fusion Superconducting Magnet Test Facility at Oak Ridge National Laboratory, containing the six superconducting magnets.

will meet at least once a year to coordinate research. The agreement is in effect from 1986 to 1991. This agreement has the potential to evolve into joint planning and program coordination.

Joint European Torus

The joint European Torus is Europe's most important experimental fusion facility and the world's largest tokamak. JET is a joint undertaking of the member nations of the European Community; it has been designed, constructed, and operated by the EC. The JET Working Group was created to explore the project in 1971; the device was approved by the EC Council of Ministers in 1978, following a political wrangle of 2 1/2 years over project location.

The JET experiment is located adjacent to the Culham Laboratory, in Abingdon, United Kingdom. The land on which JET is constructed is temporarily leased from the United Kingdom; at the completion of the project the land will be returned. Construction of JET began in 1977, and the facility began operating in 1983; current plans call for JET to operate until about 1992.[7]

[7] For an account of the design phase and the political negotiations concerning JET, see Denis Willson, *A European Experiment: The Launching of the JET Project* (Bristol, U. K.: Adam Hilger Ltd., 1981).

Photo credit: JET Joint Undertaking

The Joint European Torus, located in Abingdon, United Kingdom.

Legally, JET is an independent international entity; it is not a national project. The JET administrative structure is multinational. The project is managed by a project director on site, but all important strategic decisions must be presented to and approved by the JET Council, which is comprised of two members from each participating nation, one of which is a scientist. When the project is completed, the administrative structure will be dismantled.

JET is staffed by two distinct and roughly equalized groups: the multinational staff supported by the EC and a local staff supported by the United Kingdom Atomic Energy Agency. Provisions have been made for staff to return to their national fusion programs after completion of their appointments at JET.

The EC pays 80 percent of the costs of JET through the contributions of member nations. in addition to their contributions through the EC, the national programs also contribute directly to the project. Direct national contributions represent 10 percent of the costs. The final 10 percent is a site premium paid by the United Kingdom. This premium offsets the financial benefits that the host country receives from the project. In the last 5-year budget plan, approved in 1985, funding for the overall EC fusion program for 1985-89 was set at 690 million European Currency Units (worth at that time about $766 million). Of this amount, roughly half will go to JET.

The JET model has been effective and efficient. Through cooperating on the project, national programs have saved money, have had access to a world-class experiment, and have advanced the state of European scientific research.

Bilateral Activities

United States-Japan Bilateral Agreement

In 1979, a ministerial-level agreement was signed committing the United States and Japan to cooperate on general energy research and, more specifically, to develop commercial fusion power for the 21st century. Within the framework of this umbrella agreement, the United States and Japan have negotiated several specific cooperative agreements. The U.S.-Japan cooperation is the most extensive international cooperation in fusion research in which the United States participates. Information and personnel exchanges, joint research activities, and joint planning activities all occur within the context of the umbrella agreement.

About 50 formal personnel exchanges occur each way annually between the United States and Japan.[8] There are also a few (usually under 10) personnel exchanges arranged yearly on an ad hoc basis; these informal exchanges enable the partners to accommodate unique program needs.

[8] Michael Roberts, Director of International Programs, U.S. Department of Energy, Office of Fusion Energy, letter to the Office of Technology Assessment, Aug. 6, 1986.

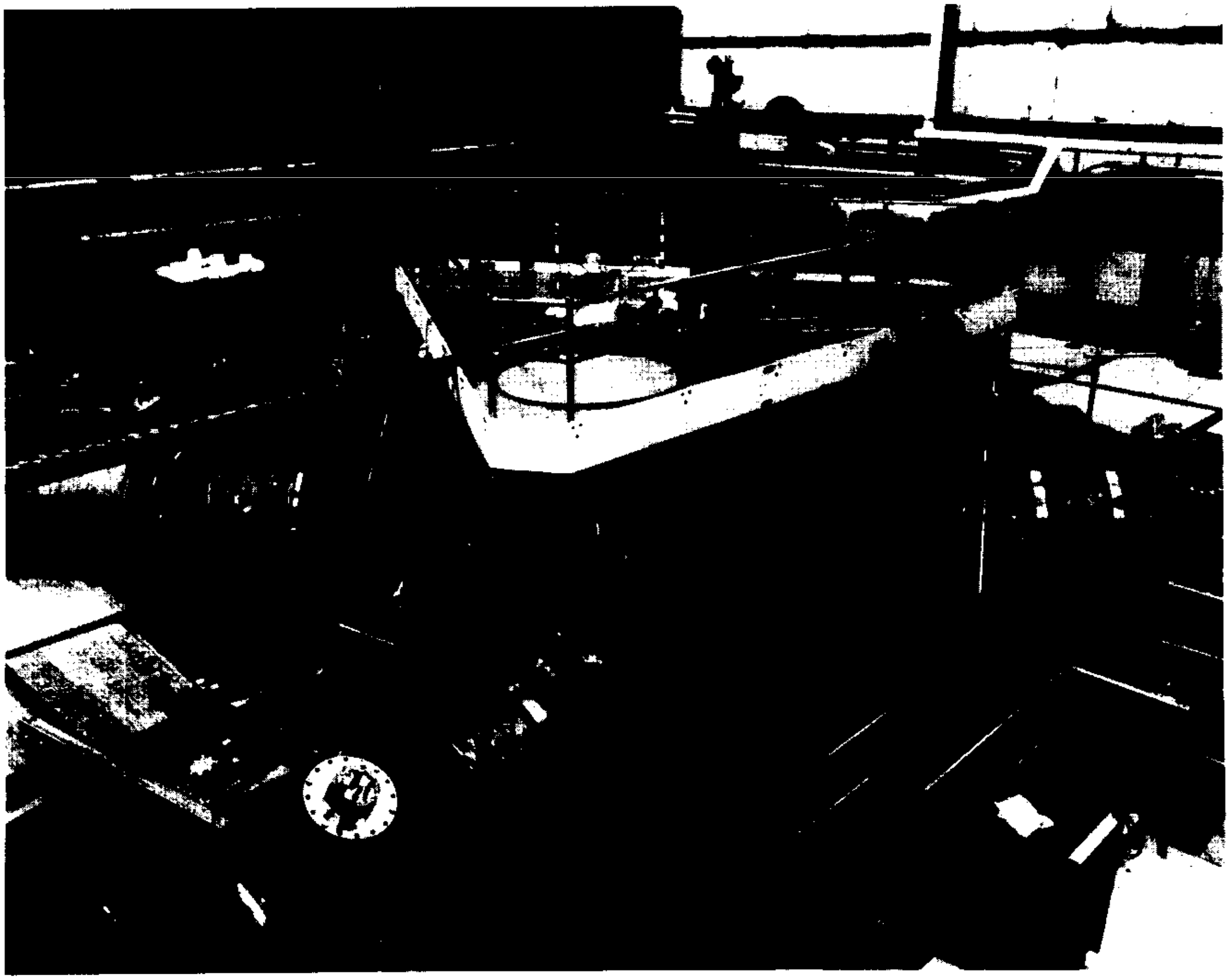

Photo credit: GA Technologies, Inc.

D II I-D fusion device at GA Technologies, San Diego, California, showing neutral beam injection systems.

Under the umbrella agreement, a specific agreement to conduct a major joint research project was also signed in 1979. Through this agreement, Japanese involvement in the upgrade of the U.S. Doublet III (D III) tokamak was formalized.[9] The Japanese and the Americans shared machine time on the experiment equally, and both have had access to all data generated in the experiments run on the machine.

[9] U.S. Department of Energy, *Magnetic fusion Energy Research,* op. cit., p. 20.

The United States hosts the Doublet project, which is located at GA Technologies' laboratory in California. Since 1979 the project has had joint funding and a joint management team. Between 1979 and 1984, the United States contributed $104 million and the Japanese contributed $62 million to finance an upgrade in the D III facility (after the upgrade the name was changed to D III-D). In 1983, the agreement was extended until 1988, and additional upgrades were undertaken for which the United States is contributing $37.8 million and Japan $8.5 million. Currently, discussions are underway to extend cooperation until 1992.[10]

The Doublet cooperation has provided both parties with access to a state-of-the-art tokamak for much less than the cost of independently constructing and operating the experiment. In fact, it is unlikely that the D III upgrades would have been possible without Japanese funding contributions. In addition, Japanese and U.S. scientists both have made valuable technical contributions to the experiment that have improved the scientific quality of the project.

Within the context of the U.S.-Japan umbrella agreement, the countries also have undertaken joint planning activities. The United States and Japan have created a joint Institute for Fusion Theory (JIFT) and designated two theory centers, one at the University of Texas at Austin and the other at Hiroshima University in Hiroshima, Japan. Each fusion center has continued to operate independently, and a coordinating committee has been created to oversee and guide cooperative activities.

United States-U.S.S.R. Bilateral Agreement

The Soviet Union has cooperated extensively with the United States and has made substantial contributions to the U.S. fusion program (see the history of tokamak development in ch. 3). The United States and the Soviet Union have had a formal agreement to cooperate in fusion research since 1958. In 1973, this agreement was strengthened, under the Nixon-Brezhnev Accord, to extend and broaden cooperation in fusion research. Most of the detailed information that the U.S. fusion program has about the Soviet program comes from the U.S.-Soviet exchange activities.[11]

Under the terms of the Nixon-Brezhnev Accord, 12 personnel exchanges occur between the United States and the Soviet Union annually, six in each direction. These exchanges are limited by the United States to fusion science issues, such as experiments and theory, with no regular interaction on technology development.[12] Most of the personnel exchanges are visits; some are assignments, however, which have given Soviet scientists an opportunity to work with U.S. scientists on research projects, and vice versa,

The U.S.-U.S.S.R. bilateral agreement is vulnerable to the political situation between the two countries. For example, no exchanges occurred during 1980 or 1981, the years following the Soviet invasion of Afghanistan. However, since the 1985 U.S.-U.S.S.R. summit meeting in Geneva, bilateral activity between the nations has progressed to a point where collaboration with the Soviet Union on the conceptual design and supporting R&D of a major fusion experiment is being considered.[13]

United States= European Community Bilateral Agreement

The United States and the European Community have cooperated extensively for more than 30 years without a formal bilateral agreement. Until recently, most cooperation involving the EC and its member states was conducted indirectly through the I EA. While this cooperation was rewarding, many tasks were not easy to arrange under the existing arrangements.

A ministerial agreement was signed between the United States and the EC in December 1986. Because the agreement was signed so recently, details for all of the activities that will occur within its framework have not yet been formalized. Arrangements have been made for joint research at the JET facility in the United Kingdom and at the Tore Supra facility in France. The agreement will provide an annual forum for management discussions about bilateral cooperation issues and will establish a legal basis that can simplify the exchange of hardware and the initiation of some cooperative endeavors. It also will increase the mobility of European scientists; within the EC, a formal agreement helps facilitate personnel exchanges.

[10] *Testimony of Dr. David Overskei,* Senior Vice President at GA Technologies, Inc., before the House Science, Space, and Technology Committee, Energy Research and Production Subcommittee on the Fiscal Year 1988 Magnetic Fusion Energy Budget, Feb. 24, 1987, p. 4.

[11] U.S. Department of Energy, Office of Fusion Energy, *Evaluation of Benefits of Cooperation on Magnetic Fusion Energy Between the United States and the Soviet Union for the period 1983 to 1985,* November 1985.

[12] Ibid., app. A.

[13] The Geneva summit meeting and the subsequent proposal for a major fusion collaboration involving the Soviet Union are discussed on p. 184.

EVALUATION OF COLLABORATION

Benefits and Risks

Knowledge Sharing

All forms of international cooperation involve information transfer. Throughout the history of fusion research, access to information–including technical know-how, experimental data, and new theoretical ideas—has enabled fusion scientists to learn from each other. Innovative ideas and a wider variety of approaches to projects are more likely to arise in an international versus a purely domestic program.[14] Researchers can compare their experimental results with those of other programs, making it possible to verify results, identify anomalous data, and distinguish experimental results based on fundamental characteristics from results based on special features or flaws in a particular experimental device. Thus, scientific progress can occur more rapidly through cooperation.

On the other hand, some observers feel that extensive knowledge sharing between national fusion programs should be discouraged in the interests of national security and national competitiveness. These individuals believe that the advantages of information transfer, in terms of improved scientific research, do not outweigh the disadvantages of participating in extensive cooperative projects.

Cost Sharing

One advantage of international cooperation is that it potentially can save significant amounts of money. Information and personnel exchanges enable independent programs to learn, at low cost, about the research activities of other programs. joint planning activities enable fusion programs to coordinate activities to avoid duplication of effort and to conduct mutually beneficial research. Most dramatically, joint research and joint construction and operation of projects distribute the costs of major experimental facilities, while still providing the experimental results to all participants.

The full extent of the cost savings is unclear, however. As the National Research Council report pointed out, because cooperation requires extensive negotiation and more formal management structures, the total administrative costs of constructing and operating a cooperative project are higher than if the same project were constructed independently.[15] Moreover, there are additional costs if the facility is not sited in the United States, such as lost domestic contracts, employment, and support facilities.[16] Although these added costs temper the financial benefits of international cooperation, it is expected that the contribution of any one partner will be less than the cost of that partner proceeding independently with an identical project.

Risk Sharing

International cooperation on major experimental facilities can mitigate the risk of project failure by spreading the financial and programmatic costs over all participants. Constructing and operating large experimental facilities is expensive; the cost of failure, both monetarily and on a program's morale and future plans, can be high. Through sharing knowledge between major fusion programs, there is a greater probability of scientific or technical success, In addition, the formal agreements required to negotiate an international project and the political implications of abandoning such an undertaking may serve to stabilize national commitments to the project.

On the other hand, some scientists feel that the absence of competition and duplication among

[14] See U.S. Department of Energy, Office of Energy Research, *International Program Activities in Magnetic Fusion Energy,* DOE/ER-0258, March 1986, p. 5; or National Research Council, *Cooperation and Competition,* op. cit., p. 19.

[15] National *Research* Council, *Cooperation and Competition, op. cit.,* p. 31. Actual statistics are difficult to collect; however, one survey of technical personnel involved in the I NTOR workshop indicated that constructing INTOR as an international project would increase total costs by about 70 percent, staffing requirements by 15 percent, and require 2 years longer to complete. It is not clear that these projections are generally applicable; cooperative construction of JET probably did not inflate costs this much. However, no matter to what degree, collaboration will tend to increase construction times and project costs.

[16] Testimony of Dr. Walter A. McDougall, Associate Professor of History at the University of California–Berkeley, *Science Policy Study Volume 7: International Cooperation in Science,* Hearing before the Task Force on Science Policy of the Committee on Science and Technology, House of Representatives, 99th Cong., 1st sess., June 18-20 and 27, 1985, p. 70.

experimental facilities may increase technical risk and that extensive cooperation may increase the risk of abandonment before project completion. Some members of the fusion community point out that coordinating research to the point of jointly constructing a single international facility, as opposed to comparable national facilities, would eliminate the potential for validating experimental results through comparisons between different machines of similar size and purpose. With more than one machine, a number of different scientific and technical approaches could be explored, and experimental results among machines could be compared. In addition, some feel that the absence of competition among facilities will lead to more conservatism in design and operation, which can limit progress. Finally, all participants must fulfill their financial and personnel obligations if the project is to succeed, especially with larger, more complex projects that extend over several years. The entire project can be jeopardized if even one nation abrogates the agreement, and cancellation can have implications far broader than just one abandoned project.[17]

Diplomatic and Political Implications

A large cooperative experiment will clearly have significant diplomatic and political implications. Many proponents of international cooperation believe the diplomatic and political consequences can be positive. The commitment to cooperate on an experimental fusion device is not trivial; a commitment represents confidence in the reliability of the other participants and faith that they can work together to the benefit of all involved. Through the negotiating process, differences between partners can be reconciled and a commitment to a common goal can be affirmed.

In addition, the diplomatic value of a decision to cooperate could be used to further U.S. objectives and improve U.S. relations in areas otherwise unrelated to fusion, For example, an agreement to cooperate on magnetic fusion could be reached as part of a larger non-technical diplomatic initiative. Some observers argue that such diplomatic benefits have been particularly valuable in the case of U.S.-Soviet cooperation, and that more intensive cooperation with the Soviets should be pursued.

Some people consider these non-technical diplomatic benefits a positive feature of large-scale cooperative projects. Others, however, fear that the diplomatic implications of collaboration could result in the subordination of technical objectives to non-technical goals, which would be undesirable. Moreover, some observers fear that international projects should be viewed cautiously because broken cooperative agreements could complicate international relations. If a nation abandoned its commitment in the course of a cooperative undertaking, there could be important political consequences. The fear of these consequences might even cause reluctance to terminate a technically undesirable project.

Domestic Implications

In addition to its technical benefits, many proponents of cooperation support it as a method of preserving the U.S. fusion program. These individuals are concerned, at least in part, that current budgets are insufficient to maintain a viable domestic fusion effort. At current funding levels and as currently structured, the U.S. fusion program cannot construct and operate essential experimental facilities on its own without dramatic curtailment of other necessary aspects of the fusion effort. Collaboration proponents therefore see intensive international cooperation as critical for a challenging, growing U.S. research program. This point is made in the National Research Council report:

> For the United States at this time, large-scale international collaboration is preferable to a mainly domestic program which would have to command substantial additional resources for the competitive pursuit of fusion energy development or run the risk of forfeiture of equality with other world programs.[18]

Increased international cooperation in fusion energy research can also stabilize the commitment of the U..S Government to the magnetic fusion program.[19] Moreover, international projects

[17] National *Research* Council, *Cooperation and Competition,* op. cit., p. 23.

[18] 1 bid., p. 11.

[19] Ibid., p. 22.

often have more visibility than domestic undertakings and therefore can better mobilize public support.

However, incentives for future collaboration on big fusion projects must be traded off against a variety of other domestic concerns. Some members of the fusion community, for example, worry that the United States might link the continued viability of its fusion program to international activities that it cannot adequately influence. *0 Others are concerned that U.S. policy makers might sacrifice the Nation's domestic fusion program in order to promote international cooperation,[21] particularly if domestic budgets were not increased sufficiently to cover the additional cost of an expensive cooperative project. In addition, some individuals are concerned that undesirable changes in the direction of fusion research might be made to facilitate increased cooperation. Finally, there is concern that the participation of domestic universities and industry in fusion research could be limited if the program emphasizes international cooperation.

Obstacles[22]

A number of potential obstacles must be addressed through negotiation before the United States can participate in large-scale cooperative projects in fusion research.

Technology Transfer

Transferring high technology to our partners could be the most serious political obstacle to more intensive international cooperation. Many critics worry that militarily significant technology could be transferred, either directly or indirectly, to the Soviet Union through fusion cooperation, especially through joint construction and operation projects. Some analysts are also concerned that cooperation in fusion could jeopardize U.S. competitiveness in international markets.

National Security .–Some of the technologies developed for use in fusion experiments–e.g., high-power neutral beams, high-power microwave technology, and plasma diagnostics—can, with varying degrees of modification, have military applications. Various individuals and government agencies contend that the Soviet Union will be able to utilize technology transferred through more extensive fusion cooperation for military applications. According to Richard Perle, former Assistant Secretary of Defense for International Security Policy, "Soviet officials and agents have successfully exploited the openness of the U.S. and European scientific communities to gather militarily useful technical information."[23] Opponents of extensive cooperation with the Soviets contend that it would be difficult, if not impossible, to control the transfer of militarily sensitive technology in an experimental facility such as ITER. In particular, opponents contend that long-term association with Western scientists will provide disproportionate benefits to the Soviets. Opponents say that through the ITER project, Soviet scientists will be able to acquire Western know-how, technology, and experience in leading-edge technologies.

Supporters of cooperation do not claim that military applications of fusion-related technologies are irrelevant, but they believe that many of the concerns raised by opponents are overstated. When examined in detail, proponents argue, most of the objections disappear, and those that remain can be addressed on a case-by-case basis. As the Director of the Office of Energy Research at DOE has stated:

> It is my opinion . . . that a device of the sort we are talking about could be built and that the necessary computer activities associated with it could be carried out in a manner that did not involve any violation to COCOM regulations.[24]

[20]Ibid.

[21] Ibid., p. 23.

[22]The information in this section is based on a workshop on Issues in International Cooperation held by the Office of Technology Assessment, Washington, DC, on Oct. 14, 1986 (list of panelists presented in front of this report); on reports done under contract to OTA by specialists in Japan, Europe, and the Soviet Union; on discussions and interviews conducted with members of the fusion community; and on the National Research Council report *Cooperation and Competition,* op. cit.

[23]Richard Perle, Assistant Secretary of Defense for International Security Policy, "Technology Security, National Security, and U.S. Competitiveness, " *Issues in Science and Technology,* fall 1986, vol. III, *No.* 1, p. 112.

[24]Testimony of Alvin W. Trivelpiece, Director of the Office of Energy Research, U.S. Department of Energy, *Fiscal Year 1987 De-*

Proponents point out that, generally, fusion technologies are not directly applicable to military needs; those technologies that do have defense applications must undergo substantial modification and redesign before reaching military significance. For example, although many of the technologies currently being investigated in the Strategic Defense Initiative were first developed for or used by the magnetic or inertial fusion programs, U.S. scientists are nevertheless spending billions of dollars to apply these technologies to weapons systems. Applying fusion technologies to military uses may require as much indigenous technical capability as developing the technologies in the first place.

Furthermore, supporters of U.S.-Soviet fusion collaboration argue that those technologies posing true risks can be identified through careful review procedures and that problems can be handled on a case-by-case basis. If, for example, a particular component poses a significant technology transfer risk, the Soviets could be asked to provide it, its use could be restricted, or the experiment could be redesigned to eliminate it.

Proponents of increased cooperation insist that there are significant benefits to the United States from collaborating with the Soviet Union that must be weighed against the risks. Magnetic fusion research is not classified; information about experiments, techniques, and methodologies are available in international publications. Moreover, as the Associate Director of Confinement at Oak Ridge National Laboratory noted:

> Everything in the world is not done here. In many areas we are not ahead . . . We got the fact that you could make a gyrotron [a high-power microwave generator] from the Russians. All sorts of things came out of the Russian program .[25]

Over the years, the Soviet Union has made valuable contributions to fusion research, and its participation in a major project would improve the quality of the undertaking.

Undoubtedly, measures taken to resolve technology transfer concerns will constrain the free flow of information and technology between the partners in collaboration. Such constraints may pose an obstacle to collaboration in their own right: it is possible that after compromises have been made to satisfy technology transfer concerns, the proposed collaborative project might not satisfy the needs of the parties in the activity, including the U.S. fusion community. If, for example, it was decided that the use of old technology would avoid the risk of transferring state-of-the-art technology, the overall capabilities of the device could be reduced, and as a result the project could become less attractive.

The national security debate is not easily resolved, and it involves underlying motivations and assumptions concerning the U.S.-Soviet relationship that go far beyond the details of any specific technical exchange. Given the depth of the debate within the U.S. Government, it appears that the United States will not be able to participate in a major joint undertaking with the Soviet Union until these issues are settled. Many observers contend that resolving the national security questions ultimately will require a presidential decision.

U.S. Competitiveness.–Many analysts are concerned about the competitiveness of American industry in international markets, and some are hesitant, in particular, about the long-term implications of intensive cooperation with the Japanese and the Europeans in fusion.[26] At present, U.S. industry is only minimally involved in the fusion program. If no provisions are made to directly involve U.S. industry in future collaborative projects such as ITER, some observers fear that U.S. industry could fall farther behind Japanese industry—particularly since Japanese industry is more directly involved in fusion research.[27]

partment of Energy Authorization: Magnetic Fusion Energy, Hearings before the Subcommittee on Energy Research and Production, Committee on Science and Technology, House of Representatives, 99th Cong., 2d sess., Feb. 25-26, 1986, p. 24.

COCOM is the acronym of the Coordinating Committee, an informal, voluntary, cooperative alliance through which the United States and its allies seek to control the export of strategic goods and technology to the Eastern bloc, It is an intergovernmental committee, and 15 nations participate in it—the NATO countries (except for Iceland and Spain) and Japan. Members of COCOM have agreed to restrict export of certain specified items to Communist countries for strategic reasons.

[25]Mark Crawford, "Soviet-U.S. Fusion Pact Divides Administration," *Science,* May 23, 1986, p. 926, quoting John Sheffield, Associate Director of Confinement at Oak Ridge National Laboratory.

[26]The General Accounting Office documents this concern in its report *The Impact of International Cooperation in DOE's Magnetic Confinement Fusion Program,* report to the Honorable Fortney H. Stark, Jr., House of Representatives, GAO/RCED-84-74, February 1984, pp. 13-14.

[27]For a more detailed discussion of industrial participation in the U.S. fusion program, see the section in ch. 6 titled "Private Industry."

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DOE does not consider U.S. competitiveness issues to pose a serious obstacle to increased cooperation in fusion. As DOE points out, magnetic fusion is currently in a pre-competitive stage. Because there are few commercial applications of the technology, there are no substantial risks from sharing the technology internationally, According to DOE, there appears to be little risk that the United States would sacrifice its future competitive position through near-term cooperative endeavors.

Technical Differences

Successful cooperation on a major device like ITER requires that the partners agree on a common set of goals and objectives, that their fusion programs beat comparable levels, and that they be moving in compatible directions. Differences between the long-term objectives of the partners' fusion programs or research plans must be accommodated or resolved.

At present, all the major world fusion programs agree on the need for an experiment such as ITER and welcome it as an opportunity for more intensive cooperation. However, given the differences in detailed technical objectives among the programs, designing an experiment that satisfies each program's goals simultaneously will involve a great deal of negotiation and compromise.

Project Location

Siting major projects, whether domestically or internationally, is traditionally time-consuming and politically sensitive. According to the National Research Council, selecting a project site is a "frequent sticking point in large international projects." [28] Intense competition for the site of a major international fusion project can be expected, since such a facility will be beneficial to local institutions, may provide some advantage to local industry, and will carry a great deal of prestige.

Most analysts believe it is unlikely that the facility will be located in either the United States or the Soviet Union. It is not expected that either nation would participate if the project were located within the other's borders. In addition, with both the Western Europeans and the Japanese sensitive about superpower dominance, they too might be reluctant to site the project in either the United States or the Soviet Union.

Even after the competition is narrowed down to one nation or region, internal competition for the site will be intense. In the case of the JET project, for example, the siting negotiations took over 2 1/2 years to resolve and almost caused the abandonment of the project.[29] The siting decision for ITER probably will be even more difficult, since it will be a larger facility and more nations will be involved. Collaboration on ITER requires that the project have value to all participants, including those that do not host it.

U.S. Commitment

Another difficulty for U.S. participation in a major international joint undertaking is the degree of commitment by the U.S. Government to the fusion program. The U.S. fusion program has faced decreasing budgets, in real terms, for 9 of the last 10 years, and, given this recent history, international partners could reasonably question U.S. commitment to the development of fusion energy, Moreover, many nations already believe that cooperating with the United States is risky. A recent Energy Research Advisory Board panel on DOE's international research and development activities concluded:

> . . . the Department [of Energy] has a poor reputation abroad for long-term commitment to international collaborative programs. This poor reputation will make it extremely difficult for DOE to attract foreign countries into significant new partnerships . . . the responsibility lies with DOE to improve its own image abroad.[30]

The United States needs to establish a strong and stable commitment to its domestic fusion program as well as to international projects in order to win the confidence of potential partners.

[28] National Research Council, *Cooperation and Competition*, op. cit., p. 57.

[29] Denis Willson, *A European Experiment: The Launching of the JET Project*, op. cit.

[30] Energy Research Advisory Board, *International Collaboration in the U.S. Department of Energy's Research and Development Programs*, op. cit., p. 2.

Equitable Allocation of Benefits

Negotiating an agreement in which the benefits of the project are distributed equitably in relation to the investment of the participants will be complex. Among the benefits are the distribution of available staff positions, the amount of design and equipment fabrication work to be done by contractors, and the access or rights to information and technical know-how generated by the project. Benefits associated with hosting the site of the experiment also must be accounted for, a task that has frequently resulted in requiring the host to contribute more to the project's costs. In the JET project, for example, the United Kingdom contributes 10 percent of project costs as a site premium, over and above its contribution as a participant.

Administration

For cooperation to be successful, it will be necessary to resolve a variety of administrative issues faced in all cooperative programs.

Different Institutional Frameworks.–Each national agency involved in negotiations operates under different rules and procedures. In addition, the negotiating agencies generally have varying degrees of autonomy, flexibility, and decision-making power.

Decentralization of the U.S. Government.—The decentralized character of the U.S. Government poses a challenge to developing major international agreements. Each executive branch agency has different concerns, making it difficult for the U.S. Government to reach the consensus needed to "speak with one voice." Therefore, negotiators will have to ensure either that there is widespread commitment to the project within the U.S. Government or that the project has support at levels of government high enough to assure such a commitment.

Different Budget Cycles.–Agreements will have to reconcile differences in national budget-setting procedures in order to finance a major cooperative undertaking. The European Community, for example, has a multi-year budget cycle, whereas both the United States and Japan have annual budget cycles. Even these annual budget processes are quite different. Whereas the Japanese budget process is very incremental, with major changes in program funding levels being unusual, in the United States the budget cycle is less stable and less predictable. Funding choices are reevaluated annually in the United States, and changes in priorities are common. Thus, there is some concern that the United States might make a commitment to begin a long-term project and then change its mind.

It has been suggested that the United States adopt a multi-year budget cycle or take major international projects "off-budget." While such actions certainly would reduce the budgetary obstacles to cooperation, the chance of such a change is slim, because the ramifications of such a decision would extend far beyond any particular project.

Different Currencies and Economic Systems.–It is generally considered easier if international project management minimizes currency transfers between nations. Different budget cycles, fluctuating exchange rates, and different economic systems —particularly with regard to the Soviet Union—make limiting the exchange of currency an attractive goal. Therefore, having participants contribute components and services is preferable to having them contribute funds to a central management agency that contracts for construction of necessary components.

Different Legal Systems.–Nations also have different legal systems that can complicate negotiations. Defining legal ownership of the experimental facility and of the information generated there is a critical facet of a workable agreement.

Personnel Needs.–The staff of a joint undertaking will include participants from all programs involved in the project, and administrative arrangements will have to accommodate their needs, Currently, relationships between staff and their respective governments differ over such issues as the ability to sign contracts, intellectual property rights, and compensation.

Staff for the project would come to a *central* location from many countries and would in most cases bring their families. They would expect, without undue difficulty, to find housing with access to shopping facilities and other amenities.

In particular, they would want an international, rather than national, educational system for their children. Moreover, most staff will return to their home fusion programs after completion of their assignments at the joint facility, and they will need to be assured that their positions at home will remain available to them.

Management Approaches

If the conceptual design phase of the ITER project is successful, it could be followed by a decision to jointly construct and operate a major fusion experiment. The prospects for such an activity are being investigated by the major fusion programs. Any agreement to undertake such a project would be complex, and a variety of management and organizational issues could arise in project negotiation and implementation. This section explores the applicability of management structures developed for existing international projects, both in fusion and in other areas, to the potential collaborative fusion endeavor.

The organizational structure of a large-scale international project such as ITER depends on its overall goals and objectives, which will be determined through negotiation. The main requirement for the organizational structure is that it define each participants' degree of control over the project by establishing such things as the project's technical and political decisionmaking procedures, the allocation of contributions and benefits among the partners, the degree of autonomy between the collaborative project and the supporting domestic fusion programs, the arrangements for staff and contractors, and the routine operation and long-range planning of the enterprise.

The degree of control that any participant exerts over the direction of the project can vary significantly, from minor technical influence to oversight of the entire project. Generally, however, the amount of control a partner exercises is proportional to the amount of financial support it provides. **In the case of ITER, it appears likely that financial support will be fairly evenly divided among partners; thus, project control probably will be shared by the partners.**

The management structures of the existing cooperative projects examined below offer some insight into how—or how not—to organize fusion collaboration. Since each project's goals are different, it is unlikely that any of these existing arrangements will be applicable as is for future fusion collaboration. Each project weighs its goals and requirements independently, and, through negotiation, unique trade-offs among competing goals are made. Studying the organizational structures of existing international projects, however, can be useful in exploring future projects such as ITER.

International Tokamak Workshop (INTOR)[31]

Conducted under IAEA auspices, the INTOR design study for a next-generation fusion experiment has features that may be useful for future collaborative projects. INTOR has successfully enabled the international fusion programs to cooperatively develop a design for and explore the technical characteristics of a next-generation machine. Moreover, the INTOR process was developed without causing concerns about national security and is the most extensive cooperative fusion activity involving the Soviet Union. Since INTOR is strictly a design effort, however, it provides no guidance for the construction and operation of future fusion collaborative experiments.

Joint European Torus (JET)[32]

The JET management structure is another approach for major collaborative projects. The JET facility was designed and built by multinational teams, is financed by the EC and the participating national fusion programs, and is managed by a multinational council. The project has been successful, and the EC currently is exploring the possibility of using the same approach to manage a next-generation experiment (the Next European Torus or NET).

Though the JET approach has proven successful for European fusion collaboration, it is not directly applicable as a model for ITER. First, the

[31] The INTOR project is discussed in more detail on p. 159

[32] See pp. 160-161 for a detailed description of JET.

JET agreement was negotiated within the existing umbrella structure of the European Community in which most of the administrative obstacles to international collaboration were already resolved. Negotiating a major fusion cooperation that included parties outside of the EC would be significantly more complex because there is no previously negotiated legal framework.

In addition, the JET approach was not designed to provide a mechanism for limiting the transfer of potentially sensitive technologies. Within the JET framework, all participants have access to the information and technology used or developed in the project. Finally, the JET structure operates through the cash contributions of participating programs to its central management agency. Hard currency transfers among the participants in an ITER-type project would be more difficult to arrange.

Large Coil Task (LCT)[33]

The Large Coil Task is a superconducting magnet testing project that has been conducted under the auspices of the IEA. The United States has taken the lead on the project, financing construction of the magnet testing facility and three of the six test magnets. The facility was designed jointly, and three magnets were designed, constructed, and financed by foreign participants in the project. All information and non-proprietary technology used in construction of the test magnets and all data generated through the experiment are available to participating programs.

Although the LCT was not designed to preclude information and technology transfer, its structure could be slightly modified and used if limiting such transfer was an objective. If a given task were broken down into distinct components, each subtask could be assigned to a partner who would be responsible both financially and technically for its contribution. Provided that the "independent development" met technical specifications, each partner's contribution could be integrated into the overall machine, minimizing exchange of information.

This approach might resolve technology transfer concerns, but it could also introduce considerable difficulties into project management. Since a primary goal of collaborating on a next-generation fusion experiment would be to make experimental techniques and results available to all the cooperating parties, the independent development approach probably would not be acceptable in ITER. In addition, it would be difficult to divide a major fusion project into isolated modules connected at interfaces; ITER probably will be a complex and interrelated assemblage of systems and components. Moreover, coordinating a project in which data and access were restricted would require an extremely effective management team.

Another problem with applying the LCT model to a future collaboration like ITER is control of the project. In the LCT, the United States contributed most of the financial support and assumed principal technical control. For ITER, on the other hand, it appears unlikely that any partner will assume the responsibility of becoming project leader and shouldering most of the cost. Thus, the management design of the LCT will not be applicable to ITER.

Doublet III Project (D III)[34]

Doublet III is the most extensive cooperative fusion project in which the United States currently is involved. The United States is the host country for the Doublet project, and the Japanese have contributed over one-third of the funds necessary to support the project in recent years. This direct contribution of currency distinguishes the Doublet cooperation from other fusion activities in which the United States participates. The project is jointly managed by a team of U.S. and Japanese scientists; machine time and experimental results are shared equally between the two nations. Doublet's management structure has distributed control of the project and financial responsibility effectively among the Japanese and American participants.

Several factors, however, may complicate the use of the Doublet approach for more intensive

[33]The Large Coil Task is described in more detail on p. 159.

[34]For more detailed discussion of Doublet-III D project, see pp 162-163.

future undertakings. The scope of the project, though extensive by U.S. standards, is quite limited when compared with the scale of potential future projects such as ITER. Only two nations are involved, and the amount of currency transferred is small compared to the projected cost of ITER. Also, the original D I I I facility was an independent U.S. project, and the Japanese did not become involved until the upgrades were undertaken. Thus, the Doublet project did not have to address facility design and construction issues from the beginning, as a completely collaborative project would.

European Laboratory for Nuclear Research (CERN)[35]

CERN was established in 1954 by several Western European nations. Its objective was to advance knowledge in high energy physics, and it has provided a framework for extensive cooperation in the design and construction of large-scale experimental facilities. It has enabled the European nations to conduct physics research on a scale that would have been impossible for any of them acting independently.

CERN is coordinated by a council consisting of two representatives—one administrative and one technical—from each participating nation. Participants make cash contributions to CERN based on a percentage of each nation's gross national product (GNP). No nation can contribute more than 25 percent of CERN's costs annually. There are no "national rights" within the CERN structure. Participating nations are not guaranteed particular positions for their representatives, specified shares of CERN's procurements, or priority for projects within CERN.

Many features of the CERN management structure could be attractive in future fusion cooperation. For example, the practice of making decisions based on merit, not national rights or privileges, is considered by many analysts to be responsible for CERN's excellent technical record. In addition, involving both technical and administrative people in decisionmaking has resulted in informed, comprehensive decisions.

Yet CERN, like JET, does not provide a complete model for a future ITER. First, CERN relies on cash contributions, which may not be appropriate for ITER. Second, CERN does not have mechanisms in place for protecting sensitive technologies. Third, some more formalized system of "national rights, " at least with respect to immediate economic return and longer term research and development return, may be necessary to allocate the benefits of ITER among diverse economies that are not already as interdependent as the individual European Community economies are.

Space Station

The space station, a proposed multi-billion dollar orbiting facility, is the only attempt by the United States to cooperate internationally on a scale financially comparable to future fusion plans. Under U.S. proposals for space station collaboration, the United States would take the lead on the project and invite participation of others, particularly Japan, Canada, and the European Space Agency. Currency exchanges would be minimal. Each of the programs would contribute its own hardware to the station, and these contributions would be joined together at carefully defined interfaces. Each program would retain essential control over development of its own hardware, but the United States would bear overall responsibility for program direction and coordination, for overall systems engineering and integration, and for development and implementation of overall safety requirements. This approach is intended to ensure compatibility and cooperation without transferring technology that the partners may wish to protect.

Some aspects of the space station project could provide a model for large-scale fusion collaboration. In particular, the space station may develop a workable mechanism for limiting the undesirable transfer of technology among the participants. In addition, it is likely that administrative aspects of the agreement might have relevance to future joint undertakings in fusion. Both the space station and a future fusion collaboration such as ITER would have to address issues such as ownership of equipment, intellectual property rights, dispute settlement, liability, selection and assignment of

[35] This dicussion based on pp. 92-93 of the National Research Council report, *Cooperation and Competition,* op. cit.

personnel, and establishment and maintenance of safety standards. If the space station can resolve these issues successfully, it could provide a model for ITER.

In many ways, however, it is difficult to apply the space station approach to future fusion collaborations. The space station is designed to be modular, with participants contributing independently developed components. As noted earlier, the independent development approach would probably be unacceptable and unworkable for ITER. In addition, the United States is taking the lead on the space station, dividing tasks and shouldering much of the cost. It is not clear that such an approach in a major fusion collaboration would be acceptable to either the United States or other participants. Moreover, it is not certain that the United States would accept a subordinate role in a fusion collaboration if another nation were to assume leadership of the project. Fusion projects also have to address siting issues, which the space station avoids because it is not located on national territory. Finally, the space station project does not include the Soviet Union, and thereby avoids the additional security and diplomatic concerns introduced by Soviet participation.

Summary of Potential Management Approaches

It is unlikely that any existing cooperative project will provide a model management structure for a major international effort such as ITER. The strengths and weaknesses of existing projects, with respect to large-scale fusion collaboration, are summarized in table 7-3.

Table 7-3.—Applicability of Existing Projects to Future Fusion Collaboration

Project	Strengths	Weaknesses
INTOR	• Proven approach to project design phase • Most extensive fusion collaboration involving the Soviet Union	• Poorly suited for construction and operation
JET	• Successful design, construction, and operation of world-class facility	• Negotiated within preexisting cooperative framework • Might not address technology transfer issues adequately
LCT	• Successful joint research project • Could provide for control of technology transfer	• United States was lead agency and bore majority of costs • “Independent development” approach might be unworkable for ITER • Might not ensure technical equality of participants, depending on distribution of tasks
D III	• Successful management structure	• United States was lead agency and bore majority of costs • Small-scale project when compared with ITER • Joint project dealt only with upgrade of previously constructed experiment • Involves hard currency transfer
CERN	• Successful design, construction, and operation of world-class high-energy physics program • Not bound by “national rights” system	• Involves hard currency transfer • Might not address technology transfer issues adequately • Lack of “national rights” system may limit equitable allocation of project benefits
Space Station	• Successful conclusion of negotiations will show that large-scale, multi-year, and multi-billion dollar collaborations can be established by the United States	• Negotiations have not been finalized • Independent developments approach might be unworkable for ITER • Does not address siting issues • Provides no experience with Soviet participation

SOURCE: Off Ice of Technology Assessment, 1987

COMPARISON OF INTERNATIONAL FUSION PROGRAMS

Comparing levels of effort among the international fusion programs is complex. Qualitative measures show that the programs are similar in direction and achievement, but these measures are subjective. Quantitative measures are more objective, but they may be distorted. Moreover, different techniques give different results.

Figure 7-1 compares the programs' research and development emphases on confinement concepts, and figure 7-2 compares their technology development efforts.[36] Variations among programs are influenced by differing program concentration, funding levels, technological capabilities, and program history.

Qualitative Comparisons

Qualitative comparisons show that the four major fusion programs are comparable in levels of effort and accomplishment and in their near-term research objectives, although the stated long-term goals and rationales for the programs differ (see table 7-4). Three of the programs operate tokamak experiments of similar capability and complexity, and the fourth (the Soviet Union) is in the process of building a large tokamak of somewhat similar capability; each program also studies alternative confinement concepts. All of the programs recognize the need for a next-generation experiment during the mid-1990s to advance fusion technology and science.

Table 7-4.—Program Goals of the Major Fusion Programs

Program Goal	Rationale
Us.	
Demonstrate science and technology base for fusion power	Determine potential as an energy option
EC	
Prototype construction	Develop energy option Promote industrial capability Strengthen political unity
Japan	
Demonstration plant	Develop energy option Fulfill national project
U.S.S.R.	
Fusion hybrid system[a]	Support fission program Maintain international activity

aFusion hybrids are discussed in app. A.

SOURCE Michael Roberts, Director of International Programs, U.S. Department of Energy, Office of Fusion Energy, briefing on "Internatlonal Discus. sions on Engineering Test Reactor, " before the ETR Workshop, Rockvine, MD, July 16, 1966

Quantitative Comparisons

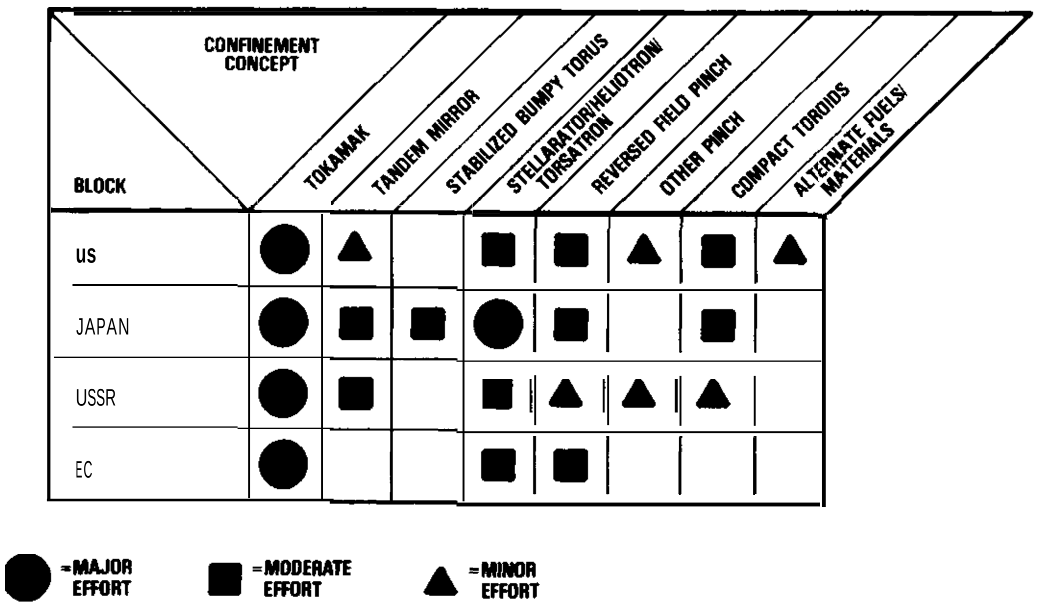
There are a variety of ways to compare quantitatively the levels of effort among the U. S., EC, and Japanese fusion programs, but each way has flaws. (Data for the Soviet Union is not included in this discussion; it is difficult to obtain reliable information on the size of the Soviet program, its funding level, and the number of people it employs.) Figure 7-3 compares DOE's estimates of the annual fusion budgets of the three programs converted into dollars. According to this figure, the United States has had the highest level of effort in fusion research. However, this conclusion is dependent on the exchange rates used in the currency conversion. The relative magnitude of the U.S. effort is due in part to the extraordinary strength of the dollar in the mid-1980s with respect to European and Japanese currencies. To the extent that goods and services purchased with fusion research funds are not traded on international markets, fluctuations in exchange rates distort the calculations of relative expenditures. Sudden shifts in the value of the dollar have dramatic effects on dollar-based comparisons of the fusion budgets, but do not represent actual changes in fusion work effort.

To correct for distortions from fluctuating exchange rates, DOE has used another method to compare fusion programs.[37] In this method, the

[36] The discussion in this and the following paragraph is based on documentation by Dr. Stephen O. Dean, President of Fusion Power Associates and author of figures 7-1 and 7-2. His insights represent a view commonly held by the fusion community regarding the relative levels of effort among the major fusion programs. The technical characteristics of the confinement concepts are explained in ch. 4.

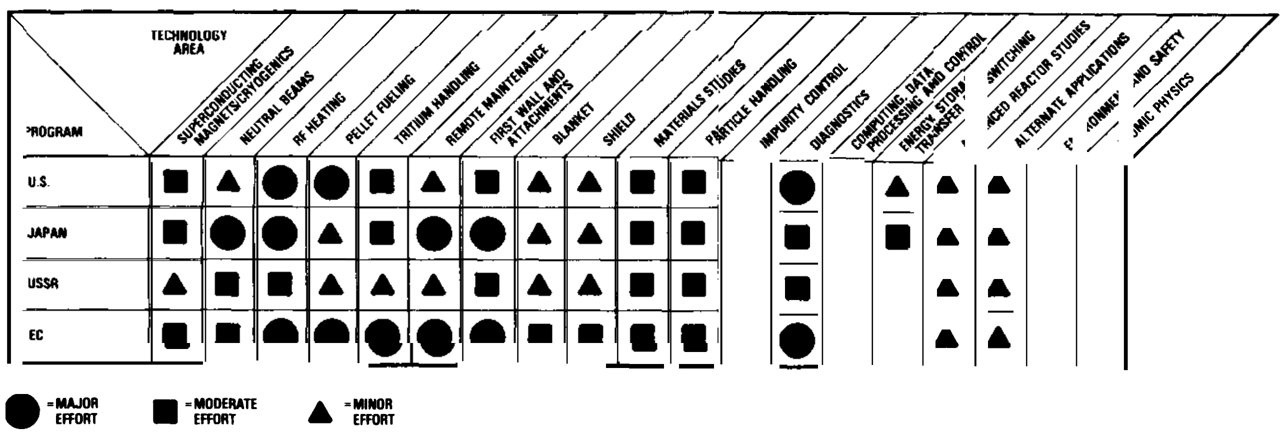
[37] John Willis, U.S. Department of Energy, Office of Fusion Energy, Oc. 9, 1986, personal communication to OTA.

Figure 7-1.— Emphases of Major Programs on Confinement Concepts, 1986



SOURCE: Fusion Power Associates.

Figure 7.2.–Emphases of Major Programs on Technology Development, 1986

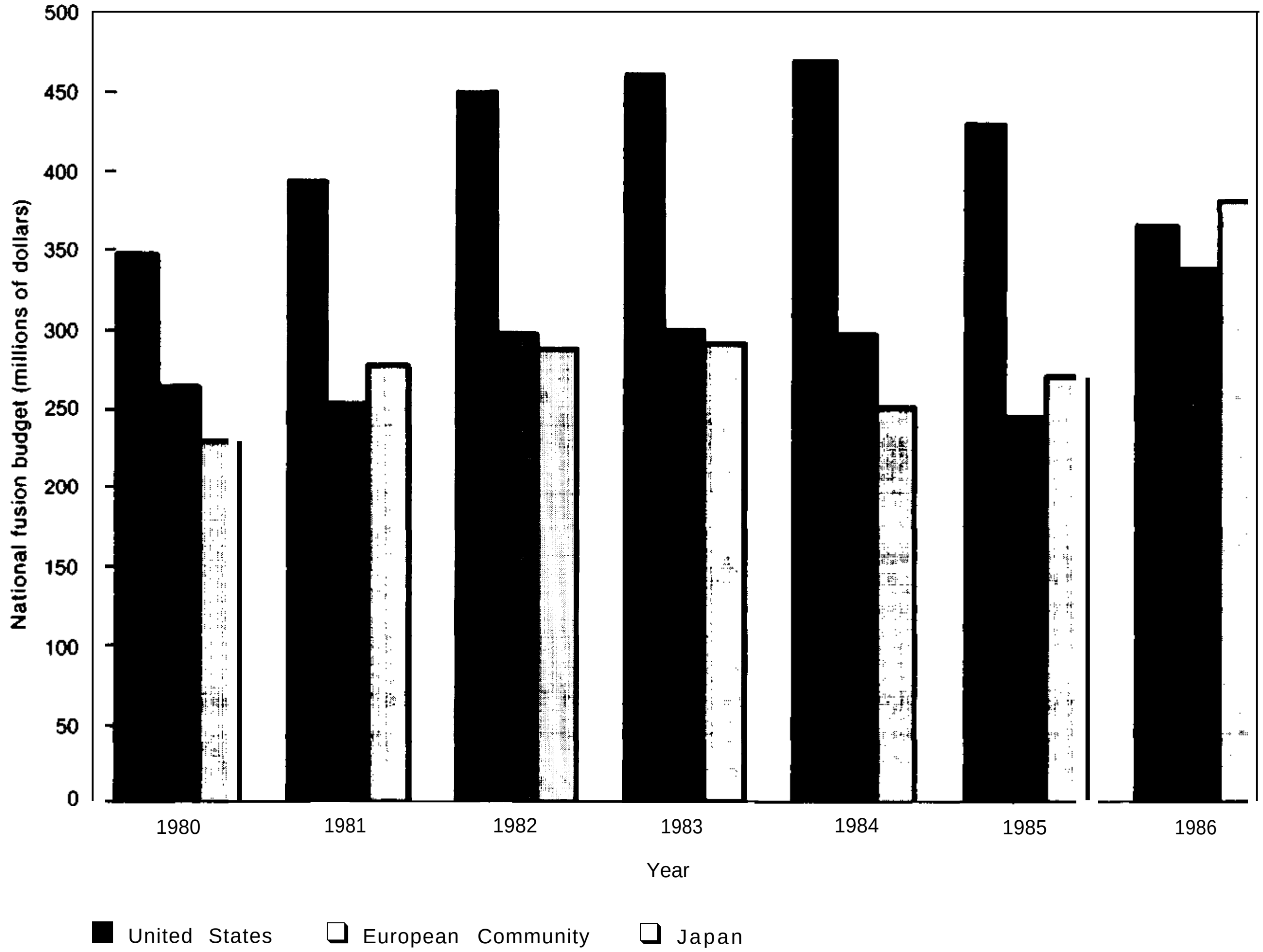


SOURCE Fusion Power Associates.

fusion budget of each program is divided by the average annual manufacturing wages prevailing in the country or region, with both values measured in local currency. The resulting value is a measure of the level of effort of each program in units of "equivalent person-y ears." Comparisons are shown in figure 7-4.

This figure does not literally represent the number of people employed by the respective fusion programs, but rather represents an arbitrary means of comparing relative levels of effort. Expenditures on construction and operation of facilities are converted, along with actual personnel costs, into "person-years" of effort. The validity of this meas-

Figure 7-3.—Comparison of International Fusion Budgets (in current dollars)



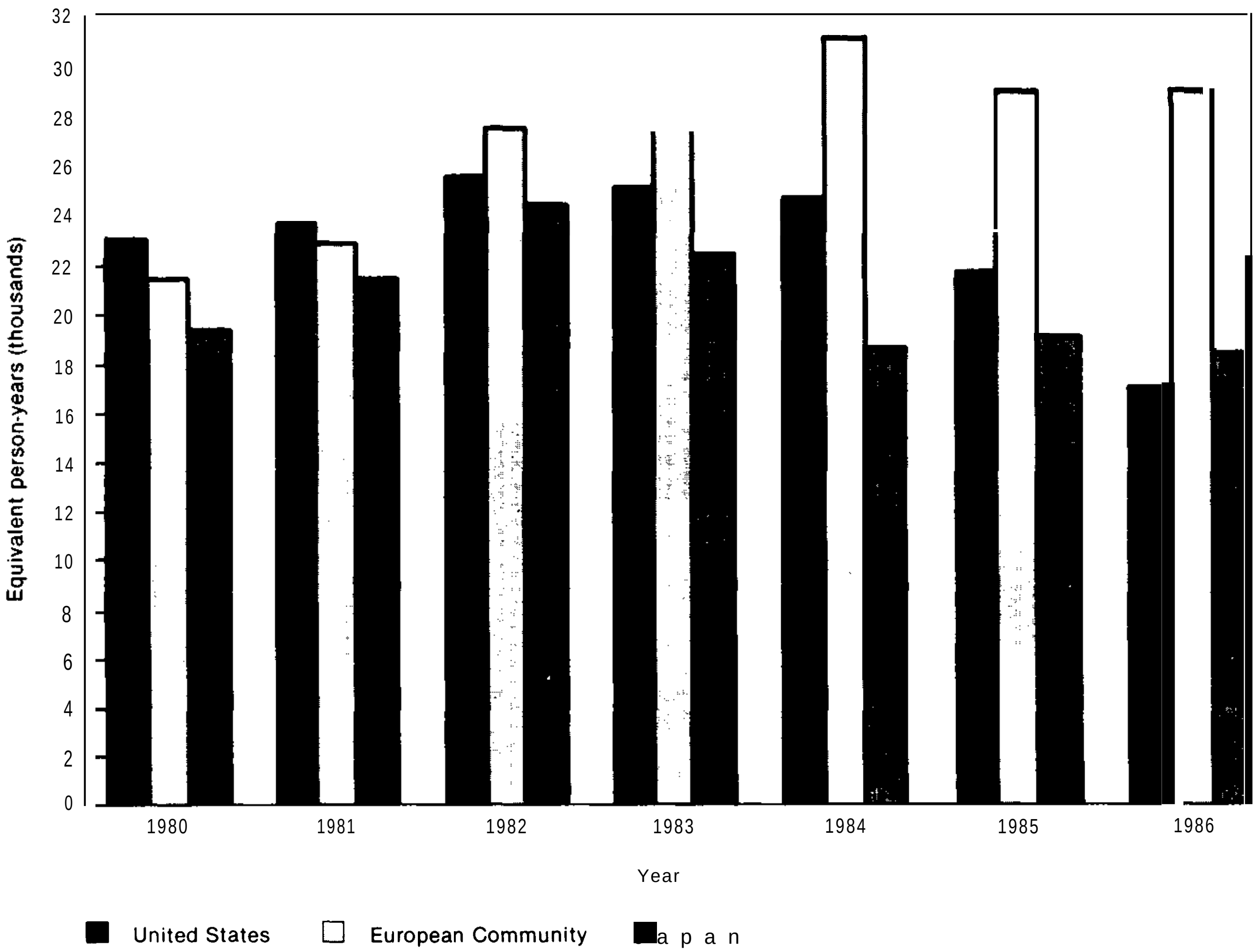
SOURCE: U.S. Department of Energy, Office of Fusion Energy, 1986,

ure depends on how well the quoted manufacturing wage rates reflect the wages relevant to the fusion program, on how similar the productivity of labor is between programs, and on how similar the relative values of capital and labor expenditures are among the three programs.

Figure 7-4 shows that by this measure, both the Japanese and the U.S. levels of effort dropped slightly from 1980 to 1986. In both programs, the fusion budget rose in real dollars. However, increases in the average industrial wage rate over the same period resulted in a substantial drop in "equivalent person-years."[38] Unless the majority of the costs incurred by the Japanese and U..S. fusion programs actually rose by the same amount as the wage rate, the conversion to "equivalent person-years" overestimates the decline in these fusion efforts.

[38]Within the three programs, the average industrial wage rate from 1980 to 1986 rose 38 percent in the United States, rose 76 percent in Japan, and fell 6 percent in the European Community. Over the same period, the fusion budget rose only 4.6 percent in the United States, rose 24 percent in Japan, and rose 97 percent in the European Community, in real dollars.

Figure 7-4.—Comparison of International Equivalent Person-Years



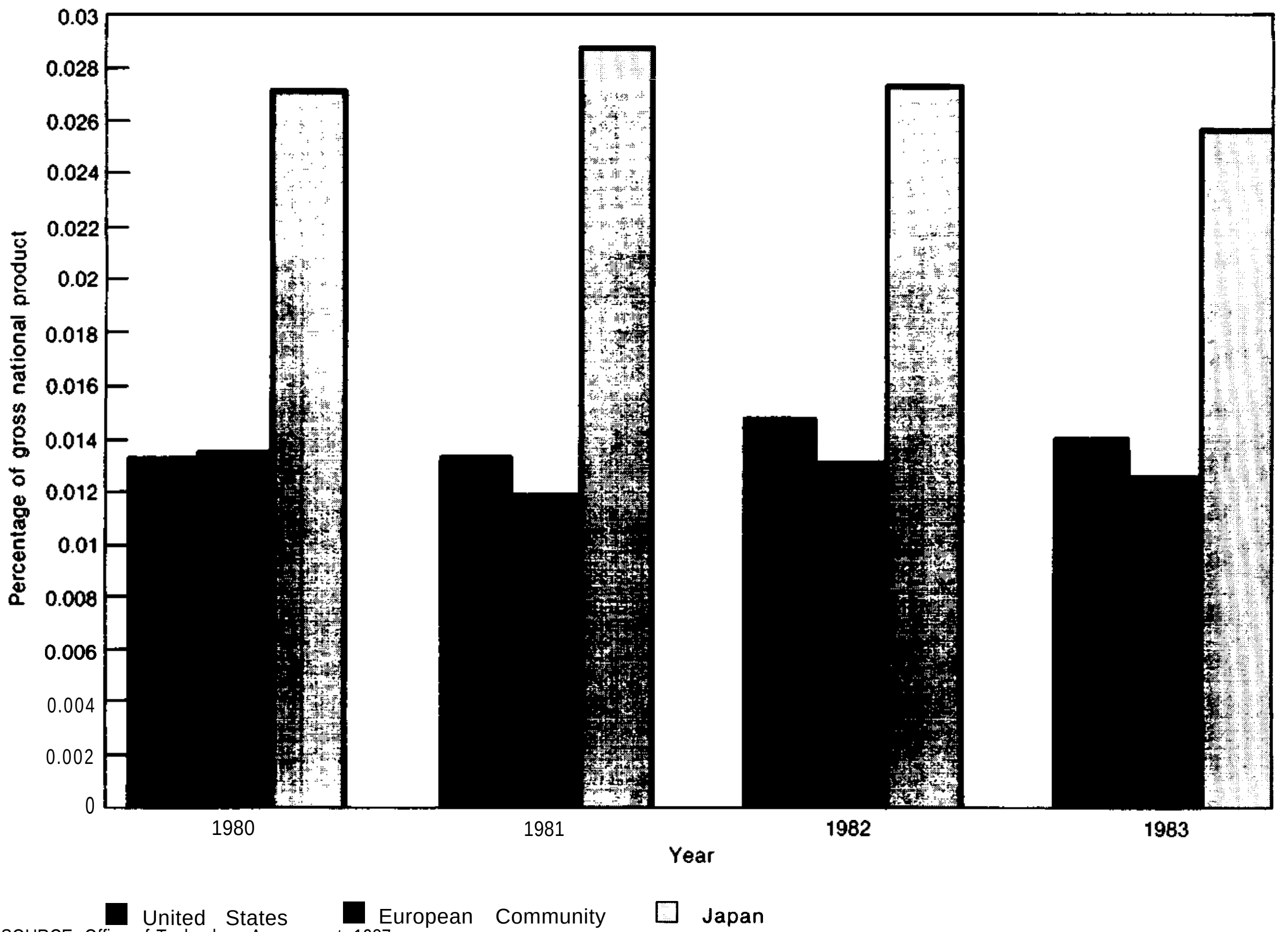
SOURCE: U.S. Department of Energy, Office of Fusion Energy, 1986.

OTA used a third method of comparison to construct figure 7-5, which illustrates the fusion budgets as a percentage of each program's GNP. Under this method, the fusion budgets, as reported by DOE, are divided by the national GNP.[39] Although all values are converted to dollars, inaccuracies in the conversion process should not affect the final result since both GNP values and fusion budgets were adjusted. This approach, which shows that the Japanese devote the greatest proportion of their resources to fusion, measures the relative level of effort of fusion research compared to the rest of the economy of each party. It does not present a comparison of absolute levels of effort, but might be taken to indicate some measure of the commitment of each nation to its fusion program. Of course, many external factors that strongly influence each nation's spending priorities cannot be shown in this figure. For example, this figure does not show the great asymmetry in defense expenditures of the various nations.

An additional problem confounds all of the quantitative methods: the calculations are based on program budgets that are not directly comparable. Budget figures provided by the Japanese

[39] GNP for the European Communit, was calculated by adding the GNPs of the member nations.

Figure 7-5.—Comparison of International Fusion Budgets by Percentage of Gross National Product



SOURCE: Office of Technology Assessment, 1987

Government, for example, do not include personnel costs. In the figures shown here, these costs were estimated by DOE for the Japanese program and added to the Japanese figures. In the EC and the United States, distinctions must be made between budget authority (how much the program was authorized to spend) and budget outlay (how much the program actually did spend), and these values can be substantially different.

Obviously, quantitative level-of-effort comparisons based on budget levels may not be reliable. Each method of analysis discussed here suggests different results, and no conclusions can be drawn.

POTENTIAL PARTNERS

Since DOE is investigating the possibility of increased levels of collaboration, an analysis of the goals and incentives of the potential collaborative partners is important.

The United States

Program Goals

The stated goal of the U.S. fusion program is to establish the scientific and technological base necessary to evaluate the potential for fusion energy by early in the 21st century. In 1988, design and construction of the next major facility, the Compact Ignition Tokamak (CIT), may begin, if approved by Congress. The United States recognizes the need to have an engineering test reactor by the mid-1990s to study technical issues related to reactor design and operation, but, due to funding limitations, DOE would like to construct such a reactor in collaboration with one or more other fusion programs. In the conceptual design and supporting R&D proposal currently being negotiated, this project is called the International Thermonuclear Experimental Reactor (ITER). The U.S. fusion program does not currently have plans to construct an engineering test reactor independently. Beyond a collaborative engineering test reactor, the U.S. program has no plans to construct a demonstration reactor.[40]

Views on Collaboration

The United States is extremely interested in future international collaboration, particularly on construction and operation of ITER. A primary incentive is financial; at present, the domestic fusion program is not able to command the financial resources necessary to construct experiments of this scale by itself. Another incentive is DOE's belief that a well-developed scientific and technological base for fusion will be easier to establish if the major fusion programs share information and expertise.

At this point, the U.S. fusion program is considering the possibility of collaborating on ITER with any or all of the major fusion programs. Of the major programs, the United States has cooperated most extensively with Japan. Formal ties between the United States and the European Community are more recent, but the EC fusion program is highly advanced and would be an attractive partner. The U.S. fusion community also highly values input from its Soviet counterpart, which has made significant contributions to past cooperative projects and which continues to make technological advances. However, the politics of the U.S.-Soviet relationship are more volatile than those between the United States and Japan or the EC. This difference will make major collaboration with the Soviet Union the most difficult to arrange.

Nevertheless, Soviet participation in a multilateral fusion project has been supported at the highest levels of both governments. At the Geneva Summit of 1985, President Reagan and General Secretary Gorbachev "advocated the widest practicable development of international collaboration" in fusion research .4' The United States explicitly made this arrangement conditional upon allied participation, and a strictly bilateral collaboration between the two countries on ITER would be very unlikely.

[40] See the Section of ch. 4 titled "Research Progress and Future Directions" for a more detailed discussion of the U.S. research plans and facility needs.

[41] From statement at the Reagan-Gorbachev Summit, November 1985.

The European Community[42]

Program Goals

The member countries of the European Community are making a long-term investment in fusion for its possible value as a major new energy source that could contribute to Western Europe's future energy security. Collaboration within the EC has been extremely successful; it has been a source of pride.

The joint European Torus (JET) is the EC's most important experimental fusion facility and the world's largest tokamak.[43] Planning has begun for a second facility—the Next European Torus (NET)—which, like ITER, is intended to confirm the scientific feasibility of fusion and address the question of engineering feasibility. The current schedule for NET calls for a detailed design decision in 1989 or 1990 and a decision on construction in 1993. A third facility envisioned by the EC is a prototype fusion power reactor to demonstrate the economic feasibility of fusion. The timetable for this prototype depends on the success of JET and NET. Construction is projected to begin between 2010 and 2020.

Views on Collaboration

The European Community is interested in international collaboration for a variety of reasons. In recent years, the EC has confronted tight budgets and competing demands for funding, which increase the attractiveness of working with partners outside of Europe. Like other nations, the EC recognizes the substantial benefits of cost savings and knowledge and risk sharing. Moreover, through the JET project, the EC has had positive first-hand experience with the scientific, technical, and management aspects of collaboration. In addition, the EC fusion effort has cooperative relationships with the other programs, principally the United States for which it has considerable respect. It also respects the Soviet and Japanese fusion programs, but contact with them has been less frequent.

Even without international collaboration, the European Community's program has established political support and momentum through JET. The EC has a clear strategy for future fusion research, in which NET plays a vital role, and it appears committed to carrying this program out. Nevertheless, the European Community is willing to investigate prospects for a large-scale collaboration with the other major fusion programs. At the same time, **the EC plans to continue working independently on NET unless and until the ITER effort offers convincing guarantees of success. The EC might not wish to participate in a major project that is not located in Europe.**

The Soviet Union[44]

Program Goals

The Soviet Union has an active fusion research program, which is supported by a strong commitment to nuclear power for geographical and fuel cycle reasons.[45] The breeder reactor is the primary focus of the Soviet atomic energy program for the 1990s, and the fusion reactor is the focus of the next century. The Soviet Union is also investigating the potential of fission-fusion hybrid reactors for its thermal and breeder reactor program.[46]

The Soviet Union is currently constructing a major tokamak experiment, T-15, which is similar in objective and capability to the large tokamaks currently being operated in the United States, EC, and Japan. Completion of T-15 was

[42] This discussion is based in part on information provided by an OTA contractor, Professor Wilfrid Kohl, in a report titled "The Political Aspects of Fusion Research in Europe." Kohl is director of the International Energy Program at the Johns Hopkins University School of Advanced International Studies.

[43] The JET project is described in detail in "Multilateral Activities.

[44] Information on the Soviet Union's fusion program was provided to OTA by Dr. Paul Josephson, "The History and Politics of Energy Technology: Controlled Thermonuclear Synthesis Research in the USSR." Josephson has studied Soviet science and technology policy issues at the Massachusetts Institute of Technology's Program in Science, Technology, and Society.

[45] Seventy percent of Soviet energy consumption and population is located in the European part of the country, but 90 percent of the fuel resources are located in Siberia and Soviet Central Asia. The cost of transporting the energy thousands of miles from east to west, either in its primary form or as electricity, is high. Therefore, the government is pursuing the rapid commercialization of nuclear energy near the western population centers.

[46] Fission-fusion hybrid reactors use the neutrons generated in fusion reactions to produce fissionable fuel. For more information, see app. A.

originally scheduled for 1982, but the project has been delayed repeatedly due to engineering problems and is now expected to operate in 1988. The Soviets are considering construction of a device called the Operational Test Reactor (OTR) to succeed T-1 5.[47] This device is believed to be analogous to the next-generation devices planned in other major national programs, except that it is also intended to verify how effectively fusion can be used to breed fuel for fission reactors.

Views on Collaboration

The Soviet Union has regularly made proposals to enhance international cooperation in fusion. The INTOR project was initially proposed by the Soviets, as was the genesis of the current proposal for an international next-generation experiment. The Soviet Union has made major contributions to past international projects and has clearly found the activities rewarding.

It appears that budgetary constraints are putting pressure on the Soviet fusion program. While it is difficult to provide actual data on the size of the Soviet fusion budget, a review of Soviet journals indicates that plasma physicists currently are more circumspect in their predictions for fusion power than they used to be, and that they are fighting to retain their fusion budgets in the face of intense pressure from other energy research programs such as breeder reactors.[48]

There is high-level political support for collaboration in fusion, and General Secretary Gorbachev has stressed repeatedly its importance. He raised the issue with President Reagan at the Geneva Summit in 1985 and again in a speech before the Supreme Soviet in 1986. On the latter occasion, he said:

> On the initiative of the U. S. S. R., work involving scientists from different countries has begun on the tokamak thermonuclear reactor project [INTOR], which opens up an opportunity to radically resolve the energy problem. According to scientists, it is possible to create as early as within this century a terrestrial sun . . . thermonuclear energy. We note with satisfaction that it was agreed in Geneva to carry on with that important work.[49]

In addition to incentives to collaborate, there are also obstacles from the Soviet perspective. These include pressures within the U.S.S.R. to avoid technological reliance on the West and shortages of hard currency with which to participate. Another obstacle is any unforeseen deterioration of the U.S.-U.S.S.R. relationship due to political developments unrelated to fusion; in 1980, for example, the Soviet invasion of Afghanistan interrupted cooperative fusion work that had been relatively stable until then.

It appears that the Soviets would be comfortable collaborating with any of the major fusion programs on ITER, judging from the positive Soviet evaluation of INTOR. However, as yet neither the Japanese nor the Europeans have sought to build a machine with the Soviets.[50] **Because of the Soviet Union's relatively long-term involvement with the United States in bilateral scientific agreements, the role of these scientific exchanges in the pursuit of improving relations, the present international outlook of Soviet leaders toward technology, and Soviet respect for American science and technology, the Soviets appear interested and willing to collaborate with the United States.**

Japan[51]

Program Goals

Many Japanese see fusion as the ultimate solution to Japan's energy problems. Japan is more dependent on imported energy than any other major economic power, and the Japanese are concerned about how precarious this dependence makes their economy. Nuclear energy has

[47] Michael Roberts, U, S. Department of Energy, Office of Fusion Energy, briefing on "International Discussions on ETR, " Rockville, MD, July 16, *1986*.
[48] P. Josephson, "History and Politics, " op. cit., pp. 16-19.

[49] M S. Gorbachev, as cited in Kadomtsev, " Tokamak, *Soviet Life*, August 1986, p. 13.
[50] Mark Crawford, "Researchers' Dreams Turn to Paper in U.S.-USSR Fusion Plan, " Science, vol. 234, Nov. 7, 1986, p. 667
[51] This section is based in part on a report completed for OTA by Dr. Leonard Lynn, "Political Aspects of Fusion Research in Japan, " Lynn is a professor who analyzes Japanese science and technology policy in the Department of Social and Decision Sciences at Carnegie-Mellon University.

helped the Japanese decrease their dependence on oil, and Japanese policy makers favor the continued use and development of nuclear power. Japan's general long-range energy policy calls for an increased reliance on conventional nuclear energy over the next 25 years. It is anticipated that this policy will be followed by a reliance on fast breeder reactors around 2010 and a transition to fusion energy about 30 years later.

The largest experimental fusion facility in Japan is JT-60. Japanese scientists have begun conceptual design studies for a next-generation tokamak, the Fusion Experimental Reactor (FER), which is intended to succeed JT-60. FER, which could be built in the late 1990s, would resemble NET or ITER and probably would be designed to achieve ignition and demonstrate the technical feasibility of the nuclear fusion reactor.

Views on Collaboration

International collaboration is attractive to the Japanese for many of the same reasons that it is attractive to other countries. The Japanese, like others, feel that the financial and human resources required to construct a next-generation fusion device may be too great a burden to bear alone. Moreover, the Japanese have both contributed and received valuable technical information from past fusion cooperative projects.

Although the Japanese are interested in collaborating on fusion research, there maybe some obstacles to such collaboration. The Japanese confront a major debt burden that has grown rapidly in the last few years and that has increased government pressure to cut spending.[52] In addition, the Japanese might be unwilling to participate if the experiment is not sited in Japan.

The Japanese are willing to explore the possibility of multilateral collaboration on ITER, however, and they are currently participating in discussions of the project with the United States, the European Community, and the Soviet Union. **Of the three, Japan appears most interested in collaborating with the United States.** In addition to extensive cooperative experience with the United States, the Japanese also have a bilateral arrangement with the EC that involves meetings of experts and information exchange.[53] However, the Japanese and European programs currently are less familiar with each other than either is with the United States. The Japanese have the least experience cooperating with the Soviet Union.

[52] Ibid., pp. 46.47. Public debt climbed from 22 trillion yen in 1976 (13 percent of GNP) to 130 trillion yen in 1985 (42 percent of GNP). In 1986, the cost of servicing this debt accounted for more than 20 percent of government expenditures. This compares to 14 percent of government expenditures going to service the U.S. national debt in 1985.

[53] Ibid., pp. 42-43.

PROSPECTS FOR INTERNATIONAL COOPERATION

U.S. Plans for Future Cooperation

DOE is interested in the prospects for more extensive international cooperation on future magnetic fusion experiments. In fact, a recent DOE report on international activities in magnetic fusion states:

> The objectives of U.S. international collaboration are to share the many high priority tasks, to reduce the total costs associated with the required major facilities and to combine intellectual forces in pursuit of the most essential problems.[54]

International collaboration in fusion research and development has become a key factor in DOE'S program planning.

Possible Areas for International Cooperation

There are several possible areas of cooperation delineated in DOE's report.[55] These areas are linked to the four key technical issues in the DOE Magnetic Fusion Program Plan (see the section in ch. 4 titled "Key Technical Issues and Facilities" under "Research Progress and Future Direc-

[54] U.S. Department of Energy, Office of Fusion Energy, *International Program Activities In Magnetic Fusion Energy,* op. cit., p. 1.

[55] Ibid., Attachment 3, pp. 1-5.

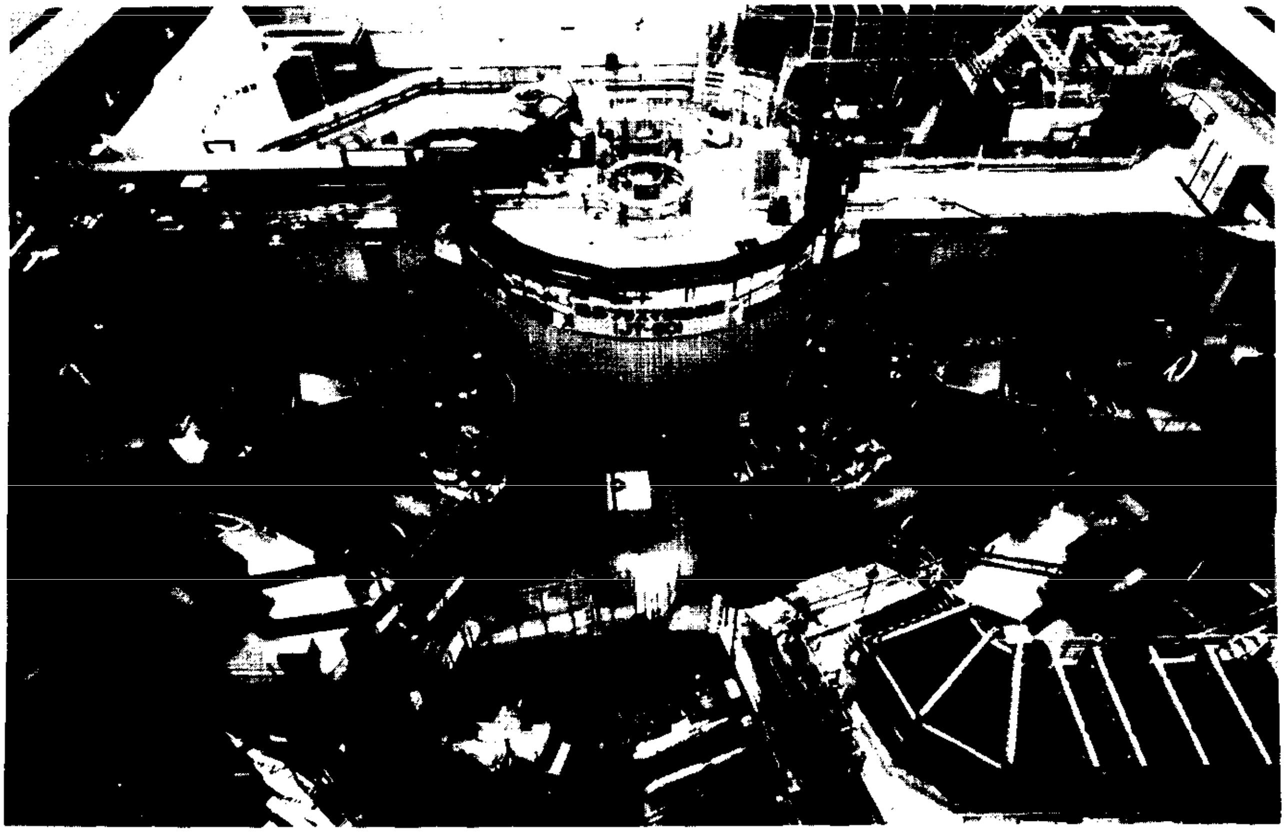


Photo credit: Japan Atomic Energy Research Institute

The JT-60 tokamak, located in Naka-Machi, Japan.

tions"). In confinement systems, DOE states that possible initiatives include gaining long-term access to the JET experimental programs and possibly those at JT-60, developing a coordinated program to develop the reversed-field pinch concept, and using selected foreign facilities to continue development of superconducting magnets. in burning plasmas, the United States would seek foreign participation in the planning and operation of CIT. In nuclear technology for fusion systems, DOE is investigating proposals to extend the current cooperative activity in technology research and development and to coordinate efforts in development of tritium handling technology. In fusion materials, DOE further proposes to coordinate research with the other major programs.

Considerations of the International Thermonuclear Experimental Reactor

To date, DOE's proposal to design ITER collaboratively has drawn the most attention among the many cooperative efforts outlined in DOE's report. Within the framework of the Versailles and Geneva summits, DOE has been involved in negotiations with the other major fusion programs to develop the conceptual design and supporting R&D for ITER. The proposal does not currently extend to joint construction and operation of the experimental facility. At the conclusion of the conceptual design effort, the parties would be free to build such a device, either alone or collectively.

The Versailles Economic Summit.—Several na-tions participate each year in an economic summit meeting.[56] These nations began considering the implications of technology for economic growth and employment at the urging of French President Mitterand in 1982 when the meeting was held in Versailles, France, and a process for considering specific ideas on this topic was established. The prospect of international cooperation in magnetic fusion was one of 18 ideas specifically investigated. Cooperative efforts in fusion research have been discussed since then, and a great deal of effort has gone into developing plans for a workable joint undertaking.[57]

Under the framework established at the Versailles summit, the Fusion Working Group was created in 1983. The Fusion Working Group is involved in early joint planning efforts and discussions aimed at identifying necessary major facilities. in 1985, the Fusion Working Group created the Technical Working Party to consider technical and research-related issues in international fusion projects. In late 1985, the Technical Working Party endorsed the U.S. plan to construct CIT.

In 1986, the Fusion Working Group reached a consensus on the desirability of future collaborative activities. Participants issued a joint statement that an engineering test reactor (now called ITER) is a common midterm goal for the fusion programs of the United States, Japan, and the European Community.[58]

The Geneva Summit.–Fusion cooperation was also discussed by the United States and the Soviet Union at the Geneva summit in November 1985. Prior to the summit, in an October 1985 meeting between French president Mitterand and Soviet General Secretary Gorbachev, Gorbachev had expressed interest in pursuing international collaboration on a large next-generation fusion experiment. The Geneva summit between President Reagan and Gorbachev, held in Geneva, Switzerland, followed up on this point. At the conclusion of the meeting, President Reagan and General Secretary Gorbachev issued a joint statement supporting fusion collaboration to the "widest degree practicable." The statement did not recommend a specific proposal or approach.

Current Status of the ITER Project.–No formal agreement has been reached on the ITER project. Recently, the United States proposed that the potential partners begin a 3-year joint planning activity to do conceptual design and supporting R&D for the device. Areas of collaboration would include defining the scope of the project, developing a conceptual design for the device, and coordinating the research needed to support the design effort.

Representatives from the United States, Japan, the European Community, and the Soviet Union met in March 1987, in Vienna, Austria, to discuss the conceptual design phase of such a project. This meeting, held under IAEA auspices, marked the first time that all four parties met to discuss collaboration on ITER. The meeting produced general agreement on the nature of the project "and the necessary steps to formalize it. The IAEA stated at the end of the meeting:

> The Parties were favorably disposed to the proposal for joint conduct of conceptual design and supporting R&D for an international thermonuclear experimental reactor. The Parties reached an understanding that the proposal was a sound basis for further discussion. The four Parties will each identify their representative to a group of experts to make proposals for a common set of detailed technical objectives for the conceptual design and to prepare the basis for further consideration by the Parties .59

In some ways, the arrangement proposed by the United States resembles the International Tokamak Reactor (INTOR) study. The proposal is more extensive, however, than INTOR. First, ITER deliverables would have a defined schedule, whereas the INTOR schedule is indefinite. Second, the ITER project would receive higher level attention than INTOR. Third, under the ITER

[56] Participants are the United States, Canada, the Federal Republic of Germany, France, Italy, Japan, and the United Kingdom. The European Community as a whole is also represented.

[57] Michael Roberts, Director of International Programs, U.S. Department of Energy, Office of Fusion Energy, briefing on "International Programs in Fusion, " presented to ERAB Fusion Panel, Washington, DC, May 29, 1986.

[58] Summit Working Group on Controlled Thermonuclear Fusion, *Summary Conclusions,* Schloss Ringberg, Jan. 17, 1986.

[59] International Atomic Energy Agency, as quoted in *Executive Newsletter,* Fusion Power Associates, April 1987, p. 4.

project, there would be full-time design teams working in each program; the INTOR design teams are part-time. Finally, the ITER project, unlike INTOR, would include cooperation on supporting R&D.

DOE has proposed that there be a full-time group of managing directors to coordinate the planning effort. According to DOE, this phase of the activity could utilize the International Atomic Energy Agency as an umbrella organization to facilitate the project. For simplicity, the coordinating site could be located at the IAEA headquarters in Vienna, Austria. No other site agreements would be necessary at this stage because all other work would be undertaken within the national programs.

The total cost of the 3-year conceptual design phase of ITER is estimated to be between $150 million and $200 million, which includes its supporting R&D. The U.S. cost of the undertaking is projected at between $15 million and $20 million annually. This annual budget represents about a tripling of the amount the United States currently spends on design studies.

DOE anticipates that the conceptual design phase of the ITER project will occur between 1988 and 1990. At the completion of this phase, interested parties would be in a position to begin negotiations on whether or not to jointly construct and operate the device. Any party could withdraw at this point, decide to construct and operate the experiment independently, or choose to pursue the effort collaboratively.

Analysis of U.S. Proposal for ITER

The U.S. Government's recent proposal marks the first step toward a collaborative ITER. No agreement has been reached; the details of the proposal will be modified during negotiations with other fusion programs. Therefore, it is impossible to assess the proposal completely.

The proposal is based on the INTOR model, which provides an example of successful, if limited, cooperation on project design. Like INTOR, in which the Soviet Union participates without threatening U.S. national security, this proposal does not raise technology transfer concerns because it will include only common design, not common technology development.

The current proposal does not address the problems that would be encountered in jointly constructing and operating ITER. These obstacles will still arise when and if the decision is made to build and operate the device. The current proposal does provide a mechanism whereby the conceptual design and supporting R&D can be completed, enabling informed decisions about proceeding with collaboration to be made at a later date.

Completing the conceptual design phase of ITER may help resolve some of the obstacles to subsequent collaboration. For example, the conceptual designs developed over the next 3 years may enable concerns about technology transfer to be analyzed specifically and their implications for national security to be resolved definitively. Furthermore, issues such as siting the facility or determining a technically acceptable project design may be settled, either through the initial phase of the project or through concurrent discussions and negotiations. **At the completion of the design phase, the major fusion programs should be better situated to develop detailed plans for further collaboration.**

The current ITER proposal begins conservatively, utilizing an already well-established cooperative arrangement. Participants will be able to work on the project without making a firm commitment to future involvement in joint construction and operation. Perhaps most importantly, U.S. Government agencies will have more time and additional information with which to establish clear policy guidelines.

SUMMARY AND CONCLUSIONS

Magnetic fusion has a long history of international cooperation. For the future, the major fusion programs recognize the benefits of sharing costs, risk, and knowledge; they value the opportunity to achieve collectively what no program could afford to achieve alone. Any or all of the major world fusion programs would be technically attractive collaborative partners for the United States. Higher levels of cooperation have drawbacks, however. Cooperation may actually increase the total cost and risk associated with fusion projects, and the benefits of knowledge sharing may be cut short if technology threatening national security or national competitiveness is transferred to the partners.

There are many successful examples of cooperation in fusion research and other scientific areas. JET, for example, is a collaborative undertaking in which the major European fusion programs have jointly constructed and operated a world-class tokamak facility. CERN, a major nonfusion project, is an example of the European nations pooling their resources and developing a state-of-the-art high-energy physics program.

While future cooperation can build on the solid foundation of the past, collaborative projects such as ITER will have to resolve many new issues. Collaboration on this scale involving countries outside Europe is unprecedented. Negotiating and approving the necessary international agreements will be possible only if the parties involved are committed both to the collaborative project and to their domestic programs. International collaboration cannot substitute for a domestic fusion program. If the domestic program is sacrificed to support an international project, the rationale for collaboration will be lost and the ability to conduct the project successfully will be compromised.

The U.S. Government’s current ITER proposal appears to be a workable first step toward a major experimental facility. The proposal minimizes the risks in the project’s early stages by decoupling design from construction and operation.

The proposal has far to go. Although successful completion of the conceptual design and supporting R&D will be important for addressing the issues related to construction and operation, the design process alone will not resolve these issues. In the United States, at the moment, the most significant issue on joint construction and operation is the possible transfer of militarily relevant technology. Agencies within the U.S. Government disagree about the severity of this problem, and the dispute must be settled internally before a major collaboration can proceed.

project location is another critical issue. Just as siting was a major problem for JET, it is likely that a decision on ITER location will not come easily. What does seem clear is that it is unlikely that either the United States or the Soviet Union will be chosen as the site for ITER.

Ultimately, reaching an agreement to jointly construct and operate an international experiment will require high-level government support. A clear presidential decision to support the undertaking will be required. Even that, by itself, is insufficient to guarantee the viability of a project involving all branches of the U.S. Government and extending over several Presidential Administrations. Moreover, the national programs will have to formalize their support in an agreement that will establish confidence in the management and operation of the project.

DOE considers international collaboration on ITER and other projects essential to the progress of the U.S. fusion program. If more extensive cooperation proves impossible or unacceptable, DOE’s program plans must be reevaluated: either the U.S. program will need more funding or its schedule will have to be slowed down and revised.