Appendix A: Science Goals of Other Nations

A

International scientific activities influence U.S. science policies and vice versa. This influence is likely to become more pronounced as research costs rise and the technological expertise of other countries increases. Since World War II, Europe and Japan have developed world-class scientific research programs and facilities. For example, the European Union has assumed a leadership position in high-energy physics research with its facilities and programs at the European Laboratory for Particle Physics (CERN). The Japanese have made important strides in their work on linear electron-positron accelerators and silicon tracking detectors used in particle physics research. Such advances in these and other research areas make it necessary for the United States to examine other nations' science policy goals and to reassess ours in terms of both the potential for international collaboration and our own goals. Accordingly, this appendix discusses other nations' science goals and funding priorities.[1]

Table A-1 presents a comparison of research and development (R&D) spending in the United States and several other nations. In 1991, the United States spent nearly $150 billion on R&D. Industry was the leading source of funding, contributing 56 percent of the total. Defense-related R&D commanded the largest share (more than 50 percent) of the federal contribution.

As a share of gross domestic product (GDP), U.S. R&D expenditures rank second. Japan's rank first. If only nondefense R&D is considered, the U.S. position would be lower. (See figure A-1 for a comparison of the Organization for Economic Cooperation and Development (OECD) countries' R&D expenditures as a share of GDP.)

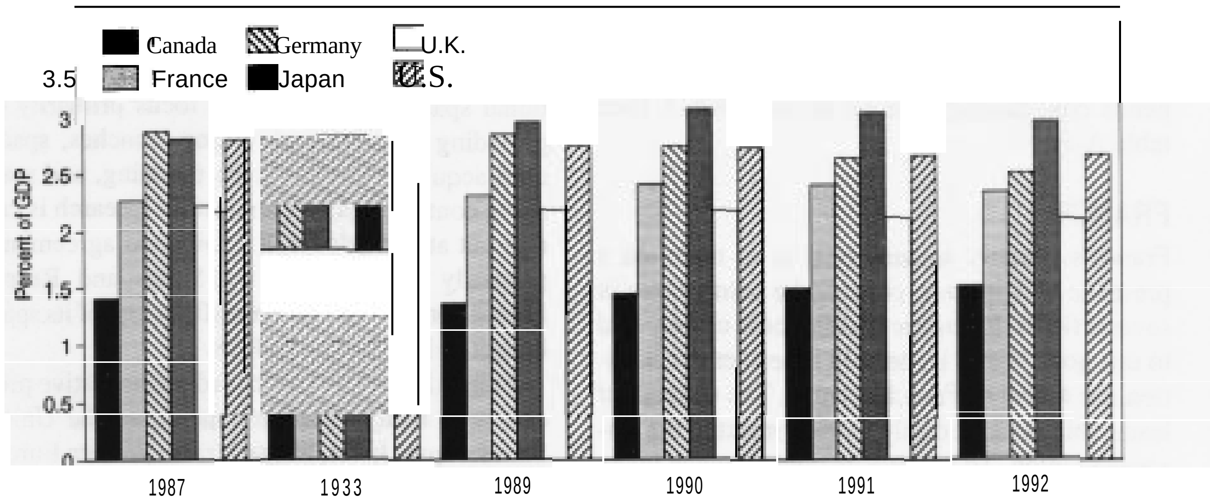
GERMANY

In basic science, Germany's main goal is to secure its place as a major player in the world science arena. Closely linked to this goal is the commitment to maintaining and enhancing the quality of science.[2] The Federal Ministry for Research and Technology (BMFT) reports that international recognition of Germany's scientific achievements has grown in the last decade. Germany has

[1]For an indepth discussion of international research organizational structures and mechanisms, see U.S. Congress, Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade,* OTA-SET-490 (Washington, DC: U.S. Government Printing Office, May 1991).

[2]Federal Ministry for Research and Technology, *Report of the Federal Government on Research 1993* (Bonn, Germany: July 1993).

FIGURE 1-A: Gross Domestic Expenditures on Research and Development in Selected Countries as a Percentage of GDP



SOURCE: Organization for Economic Cooperation and Development, *Main Science and Technology Indicators,* No. 1 (Paris, France: 1994), p. 15.

developed and maintained a high profile in several disciplines, including nuclear physics, high-energy physics, and synchrotrons radiation research. The Hadron-Electron Ring Accelerator (HERA) electron-proton collider has attracted physicists from around the world. Germany is also looking to expand its role in other areas such as bioscience and materials science.

Although basic science continues to serve as the foundation for technological innovation and economic competitiveness, applications-oriented research is growing in importance. Priority is given to scientific endeavors that translate into marketable processes and products (e.g., computer sciences, materials, bioscience, and environmental research). Agricultural research is also a top government priority. In the future, this trend may translate into fewer national large-scale basic science projects.

Because of budget constraints, BMFT has indicated that over the next few years, the government will focus on utilizing existing large-scale facilities and equipment rather than financing new ones. For example, Germany has no plans to upgrade its synchrotrons facility (DESY) in the near future. In this regard, building cooperative partnerships and networks may intensify. Germany already has science and technology (S&T) agreements with more than 50 countries. Bilateral S&T agreements with the United States cover space research and technologies, biotechnology, nuclear reactor safety research, and energy technologies. The German government views these cooperative arrangements as important components of its overall research program. The government also promotes international scientific collaboration as a way to exchange information, pool resources, and tackle thorny global problems. Moreover, international collaboration may be necessary to sustain existing big science projects.

Germany is a member of several international organizations, including CERN, the European Space Agency (ESA), the European Southern Observatory, and the European Research Coordinating Agency (EUREKA). Germany contributes 22.5 percent of CERN's budget, the highest percentage of all member states. As a major contributor, Germany has played a pivotal role in recent decisions about the Large Hadron Collider (LHC) project at CERN.

In 1991, Germany spent a total of $35.6 billion on R&D. Most of the budget was earmarked for medium- to long-term research projects with high technology and economic potential.[3] Like the United States, German industries fund more than half of its nation's R&D. However, Germany expends considerably less on defense R&D. (See table A-1.)

FRANCE

France's primary science goal is to maintain a presence and, in some cases, to be competitive in several fields. Scientific excellence is closely tied to this goal. World leadership is neither a motivation nor a goal of French science. The concept of leadership is viewed only in the context of the European Union. To achieve its goals, France looks increasingly to international collaboration in big science projects. The pooling of financial, technical, and intellectual resources is the main motivator to participate in international projects.

In France, the science community plays a major role in setting the nation's scientific agenda. Projects generally move from the bottom up, and science budgets are estimated in five-year cycles. Unlike the United States, French government agencies do not have to go through the annual budget process once project commitments are made.

France has strong science programs in high-energy physics, space, astronomy, fusion, biological science, and nuclear physics. In the field of high-energy physics, national projects are funded by the Institute for Nuclear Physics and Particle Physics. Although France does not have a large, national high-energy physics facility, it is a major participant and contributor to CERN. France is also the host nation of the Institute Laue-Langevin (ILL) neutron facility, the preeminent neutron-scattering facility in the world. In addition, France hosts the 12-nation European Synchrotron Radiation Facility (ESRF) in Grenoble, the first of a new generation of high-intensity x-ray sources.

Among European countries, France is the leader in space science. Also, France was a driving force behind the creation of ESA. The National Center for Space Research is responsible for national space projects, which focus primarily on providing assistance at Ariane launches, spacecraft acquisition, long-range planning, and managing contractors. Most scientific research is carried out at ESA or through bilateral agreements, primarily with the United States and Russia. France commits about 60 to 70 percent of its space budget to ESA.[4]

France has actively pursued collaborative projects with many countries, including the United States, Japan, India, and several in Eastern Europe and Latin America. The United States and France have a long tradition of scientific cooperation and numerous cooperative projects. Franco-Japanese scientific collaboration is more recent, but it is growing in importance. As part of the European Union, France is a partner in the International Thermonuclear Experimental Reactor (ITER) project.

In 1991, gross domestic expenditures on R&D totaled $25 billion. Government outlays accounted for 57 percent of the total. Large science projects account for about 9 percent of the total science budget.

RUSSIA

The former Soviet Union (FSU) has a well-developed and respected scientific research community. During the Cold War, the Soviet government targeted several priority areas for extensive scientific research, partially in support of potential military applications, but also as part of the competition with capitalist countries to prove which system was the more innovative and productive.

---

[3]Glenn J. McLoughlin, *International Science and Technology: Issues for U.S. Policymakers,* CRS Report for Congress, 94-733 SPR (Washington, DC: Congressional Research Service, Sept. 16, 1994), p. 20.

[4]Gerard Petitalout, National Center for Space Research, personal communication, Nov. 9, 1993.

Basic research in priority areas including space, high-energy physics, high-temperature superconductivity, and oceanography was well financed, and scientists working on these subjects enjoyed social status, high remuneration, and preferential access to goods and services.

Since the breakup of the Soviet Union, fundamental changes have occurred in the political, economic, and social orders. These changes have had a profound impact on S&T policy in the former Soviet Union. The huge military budgets of the Cold War, which underwrote much of the research, have been slashed, and the competition with the West to prove which system is the best (through science or by other means) has ceased. With civilian budgets strained to the limit, many research institutes lack the financial resources even to pay salaries. According to one expert, funding for Russia's S&T programs has declined significantly in recent years: 26 percent from 1991 to 1992; 17 percent from 1992 to 1993; and 8.7 percent from 1993 to 1994.[5] In addition, the skyrocketing cost of living and the more lucrative financial opportunities in the commercial economy have driven thousands of scientists out of research completely. Even where scientists remain at their posts, there is often no money to finance the research itself. For example, oceanographic research ships are stranded for lack of funds, and no new research reactors have been funded.[6] Even subscriptions to foreign journals are beyond the means of some institutes.

Nevertheless, efforts to reconstruct and continue research are under way. Russia inherited the bulk of the FSU's scientific expertise, although other former republics have research facilities and well-respected scientists. In 1994, Russia funded 38 S&T programs. The programs selected were chosen from a group of 150. Top-priority items on Russia's scientific agenda include space, high-energy physics, global climate change, and synchrotron radiation sources. Russia's space program is given special priority—a separate line item budget, and funding almost equal to the entire S&T budget. High-energy physics also commands a huge share of the total Russian S&T budget, accounting for about 27 percent.[7]

The Russian government is trying to integrate some of its scientists into the world scientific community, and is attempting to use international collaboration and support to preserve the country's scientific and technical expertise. For example, in high-energy physics, Russia has signed a bilateral scientific cooperative agreement with CERN. Russia is interested in becoming a full member of CERN and is supportive of plans to build the LHC. In space, the Russians have become a critical partner in the International Space Station project. Russia will provide expertise and equipment developed from its long-duration activities in orbit, for which it will be paid $650 million by the United States. Russia will use the payment to partially finance its involvement in the project. Additionally, Russia is one of the four partners in ITER.

The U.S. government has undertaken several activities to support Russian scientists. Given the proliferation risk represented by unemployed former Soviet arms scientists, the U.S. government has financed a program, the Moscow International Science and Technology Center, to reemploy them in peaceful uses of their expertise.

The outlook for Russian science is troubled by continued economic and political uncertainties, and difficulties are likely for the next several years. However, stabilization of the Russian economy and successful transition toward markets could provide a sounder economic basis for the government to finance an effective, though much smaller, basic research program than in the Soviet era. Under these circumstances, Russian scientists would increase their engagement with the world

[5] Irina Dezhina, "Russia's Science and Technology Priorities," n.d.

[6] Sergei P. Kapitza, "Russian Science: Snubbed and Sickly," *Bulletin of Atomic Scientists,* May/June 1994, p. 48.

[7] Dezhina, see footnote 5.

scientific community, and international collaboration would become essential to the Russian research enterprise.

INDIA

The goal of India's science policy is a practical one: to apply scientific knowledge and its related benefits to advancing the well-being of its population. Tied to this goal is the development of a self-reliant S&T base.[8]

India has a strong tradition of basic science research, and its scientists are highly respected. Science gained even more prominence after independence in 1947, with the goal of developing economic and political power. Nehru's government developed large programs in physics, astronomy, chemistry, and nuclear energy, and several national laboratories were built. With the help of the United States, India developed a highly sophisticated nuclear energy program.

Also, India has successfully developed its own satellites and launch vehicles. Its first experimental satellite was launched on a Soviet rocket in 1975. India's space program is oriented toward Earth observation, weather prediction, and telecommunications; space exploration is negligible.

India has no high-energy physics facility, but its scientists participate in experiments at other nations' facilities. India had agreed, in principle, to contribute to the proposed, and now defunct, Superconducting Super Collider and has expressed interest in contributing to the LHC project at CERN.

Indian scientists are also actively involved in other international science projects, including astronomy, nuclear physics, and materials science. It has S&T agreements with many countries, and its collaboration with the United States is particularly strong.

In 1991, R&D expenditures totaled $6 billion, which is modest by industrialized country standards but above average for developing countries. The Indian government funds the lion's share of R&D and conducts most of the research. Defense-related R&D is the top priority for India, followed by space and health research. In recent years, government support for R&D has been declining. The outlook is for further cuts in government funding and more reliance on commercially funded projects.[9]

CHINA

Basic science has long been an important part of Chinese culture. Scientific achievements in astronomy, mathematics, medicine, and chemistry date as far back as ancient times. In fact, Chinese leadership in science was not challenged by Western countries until the 17th century.

In recent years, however, economic reforms have dictated China's emphasis on applied, rather than basic, science research. The primary goal of scientific research today is to contribute to the economy and provide a foundation for international competitiveness. Research that can contribute to doubling the gross national product (GNP) by the year 2000 and programs aimed at developing new high-technology industries are given the greatest government support.

In 1989, the Chinese Academy of Sciences issued a report on the status of basic research in China. The report characterized China's basic research structure as weak and its programs as well behind other nations in several fields, including biology, chemistry, and mathematics. Basic science has taken a back seat in China's changing economy.[10]

A bright spot is in the field of high-energy physics. Completion of the Beijing Electron-Pos-

[8]McLoughlin, see footnote 3, p. 39.

[9]"Time To Catch Up," *Far Eastern Economic Review*, vol. 155, No. 49, Dec. 10, 1992, p. 45.

[10]Chinese Academy of Sciences, *Investigation of the National Basic Research Disciplines of the Natural Sciences* (Beijing, China: Beijing Science Press, 1989), as reported in *World Science Report 1993* (London, England: UNESCO Publishing, 1993), p. 105.

itron Collider in 1988 provided a boost to China's high-energy physics program. However, other disciplines, such as condensed-matter physics, and atomic and molecular physics, remain weak.[11]

Another bright spot is China's space program. China is one of a few countries that has a national space program. It has been marketing its launch capabilities in international markets, and its satellites have been used for Earth observation and telecommunications.

Annual expenditures on S&T have averaged about 1 percent of the GNP, with basic science funding accounting for about 4.8 percent of the total. Both of these figures are well below the world average.[12] Given China's goals, it is not surprising that industrial development commands the largest share (47 percent) of R&D spending. Other priority items for funding are health and agriculture (about 10 percent of civilian R&D outlays).[13]

In the past, S&T projects were funded by the central government, according to state economic plans. Since 1986, funding has diversified somewhat, with several state ministries and private sector organizations supporting science research. However, limited funding remains a thorny problem for science. In addition to funding constraints, China's science community faces another serious problem—its aging scientists. Moreover, there is a dearth of younger scientists due, in part, to past political policies (e.g., the Cultural Revolution), and the decision of Chinese scientists trained in the West to remain rather than return home.

Most of China's scientific endeavors are national projects. The desire to tailor scientific projects to national economic needs, the reluctance to provide access to research work and information, plus the need to build up its own scientific infrastructure all contribute to China's high rate of unilateral projects. Nevertheless, China does have a large number of S&T cooperative agreements with other nations. For example, China and Brazil are jointly building two remote sensing satellites to collect weather data. Also, China has a broad range of bilateral S&T agreements with the United States and Europe. U.S. and French scientific cooperation with China is particularly strong. The foundation for U.S.-China scientific cooperation was established by the 1979 U.S.-China Agreement on Cooperation in Science and Technology. Agreements cover space technology (the National Aeronautics and Space Administration (NASA)), high-energy physics (the Department of Energy (DOE)), medicine, earthquake studies, nuclear safety, aeronautics, transportation, and telecommunications. Activities are generally funded under existing agency budgets.

BRAZIL

Budget constraints, the lack of human resources, and limited regional and international cooperation have hampered scientific development in Latin America. Therefore, science policy goals in Latin America focus primarily on building up its scientific infrastructure through education, cooperation, and integration or coordination with other sectors of the economy, particularly those having strong scientific components. Attracting young people to science professions and actively pursuing collaborative projects are important strategies for achieving scientific goals.[14]

Of all Latin American countries, Brazil has the largest R&D budget and the highest rate of scientific publications. In 1991, Brazil's science R&D expenditures were about $3.2 billion, roughly 0.7

[11]Ibid.

[12]United Nations Educational, Scientific and Cultural Organization, "China," *World Science Report* (London, England: UNESCO Publishing, 1993), p. 104.

[13]Center for Science, Trade and Technology Policy, George Mason University, "Large Science Project Priorities of Selected Countries," report prepared for the Office of Technology Assessment, Jan. 23, 1995, p. 18.

[14]Ibid., pp. 39-40.

percent of its GDP. The largest R&D expenditures are for agriculture, accounting for about 20 percent of government outlays. Health research and space research are also R&D priorities.[15]

In 1992, Brazil's civilian space budget was $98 million, a significant drop from the $247 million funded in 1991. Exploration accounts for about 36 percent of the total space budget.[16] As noted earlier, Brazil and China are jointly developing satellites to gather weather data.

In the field of high-energy physics, Brazil's budget is rather modest. It has no large facilities but does participate in programs in other countries. Brazil does, however, have a synchrotron radiation facility.

CANADA

Industrial and economic goals dominate Canada's science policy. The 1991 Science Council report noted the importance of the linkage between scientific research and technical innovation and competitiveness. Several research areas have been identified as vital to sustained economic growth in Canada. These include biotechnology, space, advanced industrial materials, and environmental and marine sciences.[17]

In 1991, total R&D expenditures totaled $7.8 billion. The private sector funded nearly 60 percent of Canada's R&D activities. Industrial development commanded the largest share of funds. Other priority areas included defense, space, and energy.[18]

Faced with growing budgetary pressures and the need to pool resources, Canada's basic science programs have both national and international elements. In high-energy physics, national efforts have centered on the construction and development of a relatively large national facility called TRIUMP. This national facility is funded by several government agencies and managed by four universities. Foreign experts serve as members of the facility's planning and advisory committees. Canada's investment in high-energy physics has been about $300 million per year, with annual operation costs budgeted at about $35 million.

Canada's space program is oriented toward Earth observation, including weather data, and communications. On the international level, Canada has alliances with NASA (e.g., for the space station) and with ESA. In the latter case, Canada submits proposals to the ESA board that, if accepted, are included in ESA's programs.

Canada has a strong tradition of scientific cooperation with the United States, Europe, and more recently, Japan. Canadian scientists are participating in international projects, such as the Global Climate Change Program, the Ocean Drilling Program, the Human Genome Project, the Gemini project, and ITER.

UNITED KINGDOM

Science policy in the United Kingdom focuses on two primary goals: 1) maintaining and enhancing the quality of science, and 2) providing economic and social benefits to the nation. In recent years, the government has strengthened the link between science and the creation of wealth. In its first review of science policy in more than 20 years,[19] the government outlined a strategy for ensuring the success of the industry-science marriage. The strategy hinges on developing stronger relationships between science and industry, participating in international research efforts, and improving the training and education of scientists and engineers. In particular, the research councils responsible for funding science projects have been re-

[15]Ibid., pp. 14, 38.

[16]Ibid., table 10, figure 6f.

[17]Science Council of Canada, "Reaching for Tomorrow: Science and Technology Policy in Canada, 1991," 1992.

[18]Center for Science, Trade and Technology Policy, see footnote 13, table 4.

[19]Chancellor of the Duchy of Lancaster, *Realising Our Potential, A Strategy for Science, Engineering and Technology,* presented to Parliament by Command of Her Majesty (London, England: Her Majesty's Science Office, May 1993).

organized and given the explicit mission of enhancing industrial competitiveness. In addition, the Technology Foresight Programme (TFP) was created to identify strategically important technologies and high-priority research areas. Information collected by TFP contributes to long-range R&D planning and funding decisions.

In 1991, total expenditures on R&D amounted to $19.2 billion, or 2.1 percent of GDP.[20] This percentage has remained fairly stable over the last decade. Defense research is given high funding priority, followed by industrial development, health, and the environment. Not surprisingly, the Ministry of Defense is the leading government supporter of R&D, contributing about 40 percent of total government outlays for R&D. Industry funds about half of all R&D activities. The electronics, chemical, and aerospace industries receive the largest share of industrial funding.[21]

Basic science is viewed as an international enterprise that depends on the pooling of intellectual and financial resources. The United Kingdom has been active in international activities at all levels in all areas of science, including high-energy physics, astronomy, fusion, and space. Collaboration ranges from informal agreements among scientists and institutions to bilateral agreements between governments, to international partnerships. The United Kingdom is a member of CERN, ESA, ILL, ESRF, and EUREKA. In addition to its membership in European consortia, the United Kingdom has a strong tradition of cooperation with the United States.

The United Kingdom has significant national research programs in fusion, astronomy, and nuclear physics. The reputation and expertise of its Culham Laboratory for fusion research contributed to the decision to site the European Union-funded Joint European Torus (JET) facility in England. It is also a member of the ITER project team.

Although the United Kingdom does not have a major high-energy physics facility, its scientists are actively involved at CERN. The United Kingdom contributes about 14 percent of the CERN budget.

JAPAN

Technology is the driving force behind science policy in Japan. Science is viewed as a foundation for technological and economic development and international competitiveness. Japan's focus on applications-oriented research can be attributed, in part, to industry's large share of R&D funding. In 1991, industry contributed 84 percent of the total R&D funds.

Another priority of science programs and industry is to "catch up" to the West, specifically the United States, in areas in which Japan feels it lags. National prestige and capacity building also figure into decisions about undertaking expensive national projects, such as the B-factory, and collaborating on international big science projects.

Research priorities are set at the highest government levels and are reached after extensive interagency consultation. Consensus decisionmaking drives this consultative process. The Council for Science and Technology (CST), which is chaired by the Prime Minister, is the cabinet-level coordinating body for S&T. It consists of distinguished representatives from academia, industry, and government. The Science and Technology Agency is the secretariat for CST, but other powerful agencies, such as the Ministry of Science, Education, and Culture, the Ministry of International Trade and Industry, and the Ministry of Finance, are also members of CST. CST is responsible for outlining the national research agenda, approving government agency plans, and ensuring that funding is appropriate to meet needs. New materials research (particularly superconducting

[20]Center for Science, Trade and Technology Policy, see footnote 13, table 4.

[21]McLoughlin, see footnote 3, p. CRS-54.

materials), biotechnology, space, fusion, and high-energy physics are top priorities.

In recent years, government support for basic research has increased, although industry is still likely to continue to fund and do the bulk of the work. This increase in support is viewed as a way to build Japan's science infrastructure and develop its standing in the world scientific community. The Japanese have come to believe that being leaders in technology innovation, manufacturing, and marketing is not sufficient to gain the respect of other major industrialized nations.

The government promotes international collaboration in big science projects as another way for Japan to develop as a world science leader. Also, the Japanese view international collaboration as an opportunity to pool resources and to address global issues. Japan has extensive cooperative agreements in space, fusion, high-energy physics, astronomy, ocean and environmental sciences, and health. The United States and Japan have a strong tradition of scientific cooperation. The U.S.-Japan Science and Technology Agreement fosters scientific information exchange and access to facilities, and provides for the protection of U.S. intellectual property rights.

The International Space Station project is the largest cooperative space venture in which the Japanese are engaged. Japan's contribution to the space station—an experimental module—is its most expensive space project to date. The module will cost about $3 billion to build, and Japan will share in operating costs as well.[22] National space efforts, directed by the National Space Development Agency, concentrate on developing satellites and rocket launchers. Satellites are used for Earth observation and telecommunications. In fiscal year 1994, funding for space was $2.18 billion.

Japan is also a partner in ITER. The potential for an unlimited, economical energy source and the development of advanced materials and magnet technologies are among the driving forces behind Japan's participation in this project. However, enhancing Japan's stature in science was an important selling point for both the space station and the ITER projects. In 1991, Japan spent nearly $300 million on fusion research.[23]

Japan has a very respected national high-energy physics program. Its National Laboratory for High Energy Physics (KEK) has attracted scientists from around the world. Japan also sends scientists to CERN facilities and has decided to contribute $60 million toward the construction of CERN's LHC project. KEK has cooperative agreements with the Stanford Linear Accelerator Center, the Brookhaven National Laboratory, and the Fermi National Accelerator Laboratory. Japan's top-priority national project is building the B-factory machine. Development of the B-factory machine is one area of high-energy physics in which Japan and the United States are pursuing parallel paths. Both countries can afford to build their own machines, which will not only provide their scientists with more opportunities to conduct experiments, but will contribute to national prestige. Japan's 1993 budget for particle physics was about $350 million.

In 1991, Japan spent about $67 billion on R&D. Industrial development accounted for the largest share of funds.[24] As a share of GDP, Japan's R&D expenditures are the highest. Unlike the United States, Japan spends less than 2 percent on defense-related R&D.

[22] John M. Logsdon, "US-Japan Space Relations at a Crossroads," *Science*, vol. 295, Jan. 17, 1992, p. 299.

[23] Center for Science, Trade and Technology Policy, see footnote 13, figure 8c.

[24] Ibid., table 4.