A main consideration in the eventual cost is the contingency added to cover errors or items unintentionally missed in the estimate. The Advisory Panel recommends an average contingency cost of $187 million for the whole system.[8] DOE does not include contingency costs in its estimate, contending that they "can be absorbed by adjustments in the total scope of the experimental plan."[9]

As shown in Table 6, the modified estimate of the cost of the detectors could be as high as $1.2 billion, or as low as $900 million, barring substantial advances in detector manufacturing beyond those assumed by DOE.

DOE maintains that the Advisory Panel's estimate is overstated because the capabilities of the detectors can be adjusted to control costs: the estimate was preliminary and did not seek to provide the maximum amount of physics per detector dollar. Some cost savings should therefore be possible without seriously affecting the quality of science. On the other hand, the mid-range of $900 million to $1.2 billion is about $1 billion. Thus, DOE is asserting that over $300 million, or about 30 percent, could be saved without affecting the quality of the science.

While DOE believes that it can "manage to cost," the experience with Tevatron I suggests otherwise. In that instance, the detector costs rose from $20 million to $57 million (see below for a detailed discussion). DOE holds that the cost increase resulted from a consolidation in accounting rather than from a true increase, but this argument still suggests that original estimates may be incomplete.

SUPERCONDUCTING MAGNETS

When engineering and contingency costs are included, magnet construction costs account for $1.4 billion--over 40 percent of the SSC

8. The Advisory Panel actually used $175 million, which is 25 percent of the average hardware cost, rather than 25 percent of the upper and lower cost estimates. See SSC Central Design Group, "Cost Estimate of Initial SSC Experimental Equipment," p. 93. CBO then converted this number to 1988 dollars, using the DOE's inflation index for energy research and nuclear construction.

9. SSC Central Design Group, "Cost Estimate of Initial SSC Experimental Equipment," p. 8.

construction costs of $3.2 billion. As Table 7 shows, over half of this ($796 million) is in the construction of the 7,680 dipole magnets. Construction of the dipoles will pose a substantial technological chal-

TABLE 7. DOE ESTIMATE OF SUPERCONDUCTING MAGNET COSTS (In millions of fiscal year 1988 dollars)

Category	Estimates
Construction	
Tooling	60
Dipole magnets	
Magnet coils	389
Yoke and helium containment	122
Cryostat assembly	122
Other	162
Subtotal	796
Quadrupole magnets	
Magnet coils	15
Yoke and helium containment	5
Cryostat assembly	9
Other	13
Subtotal	42
Correction magnets	83
Interaction region magnets	42
Installation and alignment	45
Total, construction	1,068
Engineering, Design, and Inspection	123
Contingency	217
Total	1,407

SOURCE: Congressional Budget Office, calculated from SSC Central Design Group, *Conceptual Design of the Superconducting Super Collider* (March 1986), pp. 696-699 and Attachment D, Appendix B, using the Department of Energy's inflation index for energy research and nuclear construction.

NOTE: Details may not add to totals because of rounding.

lenge, since these magnets would be longer and more powerful than most existing superconducting magnets. In fact, DOE has encountered many problems in its attempts to produce these magnets in a research environment.

The costs of the superconducting magnets are sensitive to many assumptions. Superconducting magnets have never been manufactured on this scale. While DOE has attempted to extrapolate from its Fermilab experience, it has made a series of assumptions about improvements in manufacturing capabilities and technology that may prove to be optimistic. DOE's own figures suggest that, should these improvements fail to materialize, costs could rise by over $270 million for several reasons.

- The cost of labor for assembly and fabrication is based on as yet unrealized automation of many production steps. If these improvements in productivity do not occur, then a DOE analysis suggests the superconducting magnets may cost $88 million more than projected. Similarly, if productivity is not increased, extra facilities, requiring extra tooling, may be required to meet schedules. DOE figures suggest these extra facilities would add $33 million to costs.

- The allowance for rejects is small, assuming that only 2 percent of the magnet coils and 0.5 percent of the completed magnets are rejected as unusable. The magnet cost also assumes that only 5 percent of the superconducting cable and just 1 percent of all other materials purchased are not used, either through excess procurement or wastage.[10]

- While there is now substantial excess capacity in the fabrication of high-purity niobium-titanium alloy and rod that will be used to make the superconducting cable, the bulk of current spare capacity is in one facility in one company. The DOE estimate assumes the supplier will be able to achieve economies in internal processing. Without these economies, material costs could rise by $32 million.

10. *SSC Conceptual Design*, Attachment D, Appendix B, pp. 492 and 493. The last assumption--1 percent of all other materials wasted--seems especially low.

There is also the question of how easily the Fermilab experience will transfer to the industrial manufacture of the superconducting magnets. Tevatron I magnets were built under the supervision of highly trained and motivated technicians. Industry's labor force may be less familiar with the magnets specifically and accelerators in general. This transfer of an institutional setting to industry lowers the confidence in DOE's estimates, although admittedly no other organization is as experienced in estimating magnet construction costs.

CONVENTIONAL FACILITIES

DOE currently estimates that the conventional facilities for the SSC will cost $860 million. In order to contain hazardous muon radiation emanating from the magnet rings, the SSC will require the construction of a tunnel in which to place the rings. Other more conventional buildings will also be needed. The tunnel and related collider facilities (including contingency costs) account for roughly half of the $860 million. Site and infrastructure preparation account for slightly more than $100 million. Table 8 presents the breakdown of DOE's cost estimate.

The site for the SSC has not yet been chosen. Consequently, the qualities of the site, which can add substantially to costs, are unknown and are among the largest budgetary risks posed by the SSC. The main cost risk is the large tunnel. For instance, depending on the site, the tunnel may be near the surface or between 200 and 400 feet underground.[11] Of the hypothetical sites used by DOE for estimating purposes, the deepest was 150 feet below ground.

The Central Design Group made three estimates of collider and experimental facility costs.[12] Site A was a hypothetical tunnel 50 feet underground and would require soft ground tunneling with a tunnel boring machine. Water might be encountered at this depth. Site B

11. See National Research Council, *Siting the Superconducting Super Collider* (Washington, D.C.: National Academy Press, 1988), pp. 26-37.

12. This discussion is based on *SSC Conceptual Design*, pp. 659-661.

TABLE 8. DOE ESTIMATE OF THE COST OF CONVENTIONAL FACILITIES (In millions of fiscal year 1988 dollars)

Category	Estimates
Construction	
Site and infrastructure	91
Campus area	46
Injector facilities	42
Collider facilities	
North arc	130
South arc	146
East cluster	34
West cluster	43
Surface buildings	2
Cryogenic buildings	15
Subtotal	370
Experimental facilities	66
Total, construction	615
Engineering, design, and inspection	98
Contingency	
Site and infrastructure	18
Campus area	9
Injector facilities	8
Collider facilities	92
Experimental facilities	20
Total, contingency costs	148
Total	861

SOURCE: Congressional Budget Office, calculated from SSC Central Design Group, *Conceptual Design of the Superconducting Super Collider* (March 1986), pp. 678-693, using the Department of Energy's inflation index for energy research and nuclear construction.

NOTE: Details may not add to totals because of rounding.

was 150 feet underground in predominantly solid rock below the water table using a tunnel boring machine. Site C was near the surface using surface excavation techniques. To obtain their cost estimate, the Central Design Group averaged the costs for the three sites. Thus, while the actual estimates for the collider facilities ranged from $328 million to $410 million, the cost estimates used an average figure of $370 million. This means that $40 million of the $92 million in contingency costs allocated for collider facilities might be used by the site selection. Indeed, of the sites that could be selected, only one site would use cheaper "cut-and-cover" techniques, and several sites are well below the depth of 150 feet.

On the other hand, DOE argues that the geology and tunneling criterion has the highest weight of the six technical criteria being used by the site selection panel and that cost is a consideration in the overall evaluation. Consequently, they feel that the chosen site is unlikely to be a high-cost site and that, as a result, costs may actually be lower than estimated.

SCHEDULE

Accelerators in the United States have often taken longer to build than originally planned. The Energy Saver slipped two years, and the Tevatron I slipped three to four years. Other countries have had similar experiences: the latest accelerator of the European Organization for Nuclear Research (CERN), the Large Electron Positron collider, was supposed to be finished in 1988, but the estimated date of completion is now July 1989.

In the case of the SSC, *SSC Conceptual Design* includes a construction schedule of eight years. A slip in one part of the schedule may delay other parts, increasing costs. The schedule includes no time for legal and other delays, which often occur around controversial construction projects, both public and private.

Conventional Facilities

In addition to not accounting for legal or other outside delays, the schedule is already tight. The DOE's panel reviewing the conceptual design for conventional facilities concluded that "examinations of the proposed schedules show them to be very tight, but adequately coordinated with schedules for technical systems installation and with the assumed funding profile. Changes in either will have major effects on the schedules and probably on the costs of conventional facilities."[13]

Superconducting Magnets

The schedule for the manufacture of the magnets is also tight. The current schedule has mass production occurring between 1992 and 1996, after periods of transferring technology and certifying and selecting vendors. There are to be 10 production lines each producing one magnet per day, a total of between 2,000 and 2,500 per year. This rate is three to four times the current production rate in the industry. The rate permits very little slippage, and assumes substantial automation and other improvements in the manufacture of the superconducting cable and the fabrication of the superconducting magnets. DOE argues that if cable and magnet production falls behind schedule, the overall rate could be restored by additional production lines; however, such additions would increase costs.

Thus, on the one hand, if the manufacturing technology fails to progress as assumed, the SSC superconducting magnets may be delivered at a much slower rate than called for by the plan. On the other hand, without knowing the exact site geology, it is quite possible that the tunnel might not be ready to receive the magnets, should they be produced on schedule.

INCREASES IN CONSTRUCTION COSTS OF PREVIOUS ACCELERATORS

Cost escalation has been a consistent problem with DOE particle accelerators in the recent past. Some have exceeded initial estimates, while others kept their construction costs within estimates by sub-

13. Department of Energy, *Report of the DOE Review Committee on the Conceptual Design of the Superconducting Super Collider* (May 1986), p. 6-2.

sidizing them from other budget areas.[14] In one case, such large technical problems were encountered that the program was terminated. On the other hand, DOE argues that the focus on several recent cases ignores several decades of record timeliness and cost efficiency. CBO did not analyze the performance of the 1960s. Of the six projects begun since 1970 in the United States, however, three have either gone over budget or been terminated. Those three are the accelerators most similar in technology to the SSC.

Four major particle accelerators have been completed since 1980: the Energy Saver and Tevatron I and II at Fermilab, and the Stanford Linear Collider. The Energy Saver and Tevatron I experienced substantial cost increases, while Tevatron II, a much more straightforward project, was on budget.[15] There has been no systematic analysis of the Stanford Linear Collider, but it is CBO's understanding that it experienced no major cost increases, although money may have been transferred from operating funds to cover increased construction costs.[16] These histories indicate three potential problems with the current DOE cost estimate for the SSC:

- Individual items may simply cost more to procure than was originally thought. This was true of the Energy Saver, which was built during a period of high inflation.

- Technical problems may arise where none appears at present. The Tevatron I, for example, experienced substantial increases in costs because DOE ran into unexpected technical problems.

- Progress in particle physics between now and the end of construction may require redefinition of the project. For

14. The sample of recent particle accelerators is very small (five attempted, one canceled) and the confidence in any conclusion based on this sample must be considered low. Given all the factors affecting accelerator costs, however, particularly technical risks, initial accelerator cost estimates are very uncertain.

15. For an analysis of Tevatron II, as well as the other accelerators, see General Accounting Office, *Information on DOE Accelerators Should Be Better Disclosed in the Budget* (April 1986), p. 45. For DOE comments on GAO estimates, see p. 83.

16. Solving the recent problems at the Stanford Linear Collider may require some additional funds, which are planned to come out of operating funds.

both the Energy Saver and Tevatron I, more research was needed than DOE scientists had originally thought.

The Energy Saver

The Energy Saver, also known as the Energy Doubler, is the name given to the addition of a ring of superconducting magnets to the original Fermilab proton synchrotron.[17] The addition doubled the energy beam of the synchrotron to 800 billion electron volts while reducing electricity consumption.

The Energy Saver was the idea of the physicists building the Fermilab proton synchrotron in 1971, and they began research while working on the synchrotron. In 1979, after eight years of research, the Congress approved the Energy Saver as a construction project. (The authorization did not include R&D and other development costs.) Table 9 compares the initial estimate with the final cost. (For a comparison of current dollar cost increases, see Appendix C.) The largest cost increase was in the R&D necessary to complete construction. In 1979, DOE estimated that R&D for the project would total $50.2 million, but by 1982, R&D costs had increased to $103.7 million. Construction costs had also increased, and the total costs rose from the 1979 DOE estimate of $113.4 million to the final 1982 estimate of $186.1 million, a 64 percent cost increase. Scheduled completion had also slipped about two years.

Tevatron I

Even before completion, physicists at Fermilab envisioned additions to the Energy Saver. The Tevatron I design modified existing Fermilab facilities in three ways: it added an antiproton cooling and accumulation system, modified the Energy Saver superconducting accelerator ring so that it could be used as a storage ring for colliding beams or protons and antiprotons, and provided two new experimental areas for simultaneous particle physics experiments.

17. The discussion of the history of the Energy Saver is largely based on Lillian Hoddeson, "The First Large-Scale Application of Superconductivity: The Fermilab Energy Doubler, 1972-1983," *Historical Studies in the Physical and Biological Sciences*, vol. 18, part 1 (1988), pp. 25-54.

TABLE 9. CHANGES IN THE COST OF ACCELERATORS
(In millions of fiscal year 1988 dollars)

Category	Initial Estimated Cost[a]	Final Estimated Cost
	Energy Saver	
Facility	55.1	67.2
Research and Development	50.2	103.7
Other	8.1	15.3
Total	113.4	186.1
	Tevatron I	
Facility	47.4	93.7
Research and Development	16.9	57.9
Other[b]	7.8	0.0
Detector	24.3	61.5
Total	96.4	213.1

SOURCE: Congressional Budget Office, calculated from Department of Energy budget requests for fiscal years 1979, 1981, 1982, and 1987. Details on the costs of detectors from Fermilab budget activity reports, 1981-1987. Numbers adjusted for inflation using the gross national product deflator.

a. Calculated from DOE's fiscal year 1979 estimate for the Energy Saver and DOE's fiscal year 1981 budget request for the Tevatron I.

b. Items in other categories were reclassified into other parts of the Tevatron I budget.

When the Congress authorized the project in fiscal year 1981, Tevatron I was to cost $47 million and to be completed by the third quarter of 1983. In addition, R&D costs were estimated to be $16.9 million and ancillary costs to be $7.8 million. The detectors were forecasted to cost an additional $24.3 million, of which the DOE share would be $12.2 million, the rest coming from international sources.[18] The project costs were to total $96.4 million, of which the United States was to pay all but $9.4 million. By the time the project was completed, the Tevatron I cost the United States $213.1 million, a 121 percent cost increase, and was between three and four years late.

18. An estimate of detector costs appeared in DOE's 1982 budget request. The 1981 budget request had no detector cost estimate and merely stated that the detector was to be paid out of capital equipment costs. The National Science Foundation was also to contribute to the detector.

Table 9 compares the 1981 Budget Request with the final project costs. (For a comparison of detailed current-dollar cost increases, see Appendix C.)

In the course of constructing Tevatron I, DOE decided to change the technology used to produce antiprotons.[19] DOE had encountered substantial technical obstacles. CERN, however, had discovered a better way to produce and control antiprotons. Consequently, DOE decided to redesign the entire antiproton production and control mechanism. Whereas previously the Tevatron I designers had hoped to use many of the existing Fermilab facilities, the new design required the construction of completely new facilities. The redesign and the increased cost associated with it caused a delay of two years.

Other Big Projects

Particle physics is not unique in suffering from cost escalation: big instruments and large construction projects in other areas often suffer the same fate. The National Aeronautics and Space Administration (NASA), which, like DOE, builds big scientific instruments, provides several examples of cost escalation. One such example is the Hubble Space Telescope, which is the first of four orbiting astronomy observatories.[20] CBO's analysis of the program indicated that between 1978 and 1988, the cost estimate rose 135 percent in real terms. While part of the cost increase is the result of the shuttle Challenger accident, by 1982 the costs had already gone up by almost 30 percent.

In its study of defense acquisition, the President's Commission on Defense Management studied cost growth in major projects in both the private and public sectors, including defense and nondefense applications. The two categories that most aptly describe the SSC--instru-

19. This discussion is based on a letter dated June 16, 1982, to Senator James A. McClure, Chairman, Committee on Energy and Natural Resources from Alvin W. Trivelpiece, Director, Office of Energy Research, Department of Energy.

20. Congressional Budget Office, *The NASA Program in the 1990s and Beyond* (May 1988), p. 42. Other NASA projects that are suffering substantial cost increases include the Ulysses mission to the sun, the Galileo mission to Jupiter, the Mars Observer mission, and the Magellan mission to Venus.

ments and large construction projects--both experienced, on average, cost increases of over 100 percent.[21]

Applicability of Past Experience to the SSC

Past experience may not necessarily be a perfect guide to how the construction of the SSC might develop. In many ways, the SSC is an extension of the Energy Saver and Tevatron I technology to higher energy levels. The technical difficulties encountered by those projects may benefit the SSC by allowing it to avoid the same problems. The superconducting magnet technology is now more mature than it was when the Energy Saver was first contemplated 17 years ago. Furthermore, Tevatron II and the Stanford Linear Collider show that accelerators can be built close to their estimated cost. On the other hand, Tevatron II was a much less complex project than the others.

These earlier accelerators were also authorized much earlier in their design cycle than the SSC would be. A substantial portion of the cost escalation in these projects occurred during the R&D phase, after they had been authorized but before actual construction began. Proponents of the SSC claim that because the design of the SSC has been thoroughly analyzed and the cost estimates have remained stable for several years, there is less chance of major design changes with their consequent cost increases. In addition, advances in CERN accelerator technology were also a substantial factor in the need to redesign the earlier projects. On the other hand, the R&D phase for SSC detectors has hardly begun, so there might be substantial cost increases in that phase. The superconducting magnets are also still in the research phase. Furthermore, although CERN accelerator technology is unlikely to influence the design of the SSC because the SSC is much more powerful, it is still possible that high-energy physics might progress enough to require substantial redesign of the SSC, as in the case of the Energy Saver and Tevatron I.

The other uncertainty in attempting to use these project histories to determine if SSC costs will escalate is that the SSC budget is much larger than that of the previous accelerators. Both the Energy Saver

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21. President's Blue Ribbon Commission on Defense Management, *A Formula for Action: A Report to the President on Defense Acquisition* (April 1986), p. 38.

and Tevatron I eventually cost $186 million and $213 million, respectively. The Energy Saver's 64 percent cost overrun (on the original estimate of $113 million) was $73 million. Thus, while large relative to project costs, relative to the budget for the SSC, these overruns were small. Similarly, for both the Energy Saver and Tevatron I, one-third to one-half of the cost escalation occurred in component acquisition, not R&D costs.[22] Since the SSC will need more components, there might be a greater risk of cost inflation.

SHARING THE COST OF THE SSC

DOE assumes that funds from nonfederal sources will help defray the costs of the SSC, beginning in 1991. These assumptions have been called into question even by proponents of the SSC as overly optimistic. The DOE budget request for 1989 assumes $1.8 billion in nonfederal funds, roughly one-third of project costs. The most commonly discussed sources for these funds are the state in which the SSC is located and the international community.

State Contributions

The SSC proposal requires substantial contributions from states, mainly in land and infrastructure.[23] The finalist states have expressed their willingness to contribute to the construction of the SSC through these avenues. In addition, some proposals would have the states contribute funds for the construction. Texas and Illinois have both approved major bond issues for this purpose, should the SSC be located in their states.

22. In the case of the Energy Saver, the magnet cost increase was partially offset by a fall in the cost of refrigeration that occurred because Fermilab was able to acquire used equipment. This is unlikely to occur with the SSC. For details of Energy Saver and Tevatron I cost overruns, see Appendix C. For more on Energy Saver construction, see Hoddeson, "The First Large-Scale Application of Superconductivity."

23. DOE's budget request assumes no costs in land acquisition and assumes the state will pay for substantial portions of the infrastructure, although DOE often includes the land and other excluded contributions in its assessment of nonfederal contributions.

While the competition among the states has been viewed as a fight for local benefits, there are legitimate reasons why states might be expected to contribute, since regional benefits will flow from the SSC. The presence of science and technology centers can aid a state in the process of economic development. High-technology industries, for instance, feed upon each other's growth.[24] Science-based employment can also counterbalance some cyclical fluctuations in traditional manufacturing and commodity-based employment. Because of the local public good benefits, state contributions to the construction, beyond providing the infrastructure, might be appropriate. On the other hand, the Congress instructed DOE not to consider financial contributions from states in its site selection deliberations in order to avoid putting smaller states at a disadvantage and turning the process into an auction. In addition, special agreements might have to be made with the selected state to incorporate its donations.

Foreign Contributions

Both opponents and proponents of the SSC agree that the federal government should seek international funding. International participation could come in the form of money or in-kind contributions, the latter being the most common. The items that have raised the most interest in international circles are the detectors and the superconducting magnets--the detectors would require substantial foreign contributions, while the magnets would reduce the potential of technology spinoffs for the United States.

Financial contributions from foreign sources of the magnitude assumed by DOE seem unlikely at this time. According to DOE, the European Community as a whole had a high-energy physics budget of $1.0 billion in 1988. CERN accounted for $534 million, or roughly half of this. CERN members are currently discussing another accelerator--the Large Hadron Collider--which they feel covers much of the same energy range as the SSC, but at a lower cost. According to DOE, in 1987, Japan had a particle physics budget of roughly $210 million per

24. For a discussion of histories and prospects for such development, see Peter Hall and Ann Markusen, eds., *Silicon Landscapes* (Boston: Allen and Unwin, 1985).

year.[25] Lastly, Canada spends little on high-energy physics: estimates range between $10 million and $50 million per year. Since all these sources have commitments of their own, it is unlikely they will have the funds to make contributions to the SSC that are as large as DOE estimates. On the other hand, non-CERN sources have contributed $100 million for CERN's latest detector, two-thirds of which came from the United States.

If the European Community forgoes building its next-generation proton accelerator, currently the Large Hadron Collider at CERN, then its members may have funds to spare for U.S. high-energy physics experiments. However, such a situation seems unlikely. As its next director general, CERN has chosen Carlo Rubbia, the person most closely associated with the Large Hadron Collider, and the European Community seems committed to CERN, although it is quite possible that the process of building the Large Hadron Collider may be stretched out longer than its proponents might desire.

There are sources of European and Japanese funds outside the particle physics programs, however. In-kind contributions of detectors, superconducting magnets, and other high-technology components might be viewed by foreign countries as a way of both stimulating their high-technology industries and obtaining a foothold in U.S. markets. The United States may wish to protect it own manufacturers from such competition. So far, however, only European firms have built powerful superconducting magnets in an industrial setting. No U.S. superconducting magnet firm has built an accelerator magnet this powerful, and DOE has no experience building superconducting magnets industrially. If the Congress puts "buy-national" restrictions on SSC appropriations, it may be forgoing the experience of firms that have actually built these powerful accelerator superconducting magnets and costs could be higher.[26] Buy-national provisions may also make it impossible to obtain international contri-

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25. Department of Energy, *Report of the HEPAP Subpanel on Future Modes of Experimental Research in High-Energy Physics* (July 1988), p. 59. The analysis assumes 1.49 Swiss francs and 148 Japanese yen to the U.S. dollar, respectively.

26. Such restrictions may also violate the Procurement Protocols of the General Agreement on Tariffs and Trade (GATT). See Congressional Budget Office, *The GATT Negotiations and U.S. Trade Policy* (June 1987). For a chronology of foreign experience building accelerator superconducting magnets, see *Superconducting Super Collider*, Hearings before the House Committee on Science, Space, and Technology, 100:1 (April 7-9, 1987), pp. 458-462.

butions for the construction phase. Given the stated intent of Europe and Japan of pursuing accelerator technologies that include superconducting magnets, U.S. firms are in any case unlikely to have monopolies on technology for the fabrication of superconducting magnets.

The Italian government contributed superconducting magnets, made by an Italian company, to the HERA project in West Germany. DOE claims the Italian government may be willing to make a similar gift to the SSC project. But only $100 million would be saved if the Italian government donated as much as 10 percent of the superconducting magnets. At this juncture, DOE has yet to produce other evidence to support the claim that foreign and state donations are likely to cover $1.8 billion of SSC costs.

CHAPTER IV

CONGRESSIONAL OPTIONS

The next Congress will decide whether to fund the construction of the Superconducting Super Collider (SSC), defer the decision, or cancel the program. The Congress could simply defer the decision on actual construction while continuing research, as it has in the past. If the Congress cancels the SSC, options for a substitute facility include joining the European Organization for Nuclear Research (CERN) in the construction of their next accelerator, the Large Hadron Collider, in Geneva. Alternatively, the Congress could fund additional research leading to the construction of an electron-positron linear collider in the United States. Lastly, the Congress could postpone the construction of the SSC until the development of suitable high-temperature superconducting magnets. The various options have different degrees of risks and likely benefits associated with them.

Table 10 compares the four accelerators discussed in this chapter according to their cost, completion date, mass reach, and design risk. The cost is the likely federal cost. The completion date is when the instrument is intended to become available for high-energy physics. Mass reach is the mass level of the interactions or particles. (Only a fraction of the total energy from proton collisions can be used by science. For example, while the proton collisions in the SSC will have a total energy of 40 trillion electron volts, the mass reach is only 3 trillion to 4 trillion electron volts. With electron-positron collisions, virtually all the particle beam energy is available for interactions of scientific interest.) In Table 10, mass reach is synonymous for the scientific potential of the instrument.[1] The design risk is a qualitative assessment comparing the current state of accelerator technology with the eventual ability of the instrument to perform as originally planned. The primary risk is not that the machine will not work, but rather that it will be less powerful or useful as a scientific instrument than its designers intended.

1. Physicists convert mass into terms of energy using Einstein's equation: energy equals mass times the velocity of light squared.

The SSC is the most scientifically capable machine, in terms of its energy level and accelerator technology, but it is also by far the most expensive of the near-term options. The Congress will therefore have to decide whether the added scientific value and the lower design risk are worth the additional $3 billion to $4 billion they are likely to cost U.S. taxpayers.

Of the cost estimates, that of the SSC is most reliable: the others include estimates based on technology that is not yet developed. The SSC estimate is based on the Congressional Budget Office's technical analysis of the Department of Energy's estimate. The other estimates are constructions based on reasonable assumptions, which are discussed below.

The phenomena physicists seek to explain with the next generation of accelerators occur at mass reach levels of up to roughly 1 tril-

TABLE 10. COMPARISON OF FUTURE ACCELERATORS

	Superconducting Super Collider	Large Hadron Collider	Electron-Positron Collider	SSC with High-Temperature Superconductors
Estimated Cost to the United States (Billions of fiscal year 1988 dollars)	4.5-5.1	0.6-1.0	1-2	4.4
Completion Date	Late 1990s	Late 1990s	Late 1990s	After 2010
Mass Reach (Trillions of electron volts)[a]	3-4	1.0-1.5	1	3-4
Design Risk[b]	lowest	high	high	highest

SOURCE: Congressional Budget Office.

a. Mass reach is related to energy and refers here to the scientific potential of each instrument.

b. Design risk is a qualitative assessment of the possibility that the accelerator will be less powerful or useful than originally planned.