the leading edge in particle physics seems to follow big instrumentation, which is a concrete example of science historian Derek de Solla Price's hypothesis that science follows instruments.[19]

Recently, this hypothesis received corroborating evidence in elementary particle physics in a study examining the correlation between the number of particle physics articles and citations for each country and the energy level of particle accelerators in each country.[20] The researchers tracked the number of articles and citations in the major journals about particle physics between 1961 and 1984, and discovered that U.S. scientists dominated the field until the late 1960s, after which the European average rose. Beginning in the early 1970s, the first Fermilab accelerator went into operation and reestablished the U.S. preeminence in particle physics by every measure--number of articles, number of citations, and number of articles cited 15 times or more. Four years later, the Super Proton Synchrotron went into operation at the European Organization for Nuclear Research (CERN) facilities and European research came into ascendancy. The Germans followed the Super Proton Synchrotron with a large electron-positron collider (PETRA), and that was followed in turn by CERN's proton-antiproton collider in 1982. During this entire period, European research scored high in all the bibliometric measures. In the United States, the Tevatron I at Fermilab has just completed its first full year of operation and the Stanford Linear Collider is coming into operation. Judging from the previous pattern, U.S. particle physics should begin to rise in bibliometric scores. This reemergence may, however, be temporary as two new major accelerators--HERA in Germany and the Large Electron Positron collider at CERN--are under construction and may eclipse the U.S. instruments in output.

19. See Derek J. de Solla Price, "Of String and Sealing Wax," in *Little Science, Big Science...and Beyond* (New York: Columbia University Press, 1986), pp. 237-253."

20. John Irvine and others, "The Shifting Balance of Power in Experimental Particle Physics," *Physics Today* (November 1986), pp. 27-34. The use of articles and citations to measure scientific progress provides limited information. For a discussion of the limits of this type of analysis, see Office of Technology Assessment, *Research Funding as an Investment: Can We Measure the Returns?* (April 1986), especially pp. 29-37. For more recent analysis, see A. L. Porter, D. E. Chubin, and Xiao-Yin Jin, "Citations and Scientific Progress: Comparing Bibliometric Measures with Scientist Judgments," *Scientometrics*, vol. 13 (1988), pp. 103-124.

Despite the bibliometric evidence cited, if an instrument is located in Europe or the United States, it does not mean that only European or U.S. scientists benefit from it to the exclusion of others. The particle physics community is international, and scientists cooperate in experiments across national boundaries. Many U.S. scientists work on CERN projects. Wolfgang Panofsky, a U.S. physicist connected with the Stanford Linear Accelerator Center, estimated that almost one-third of U.S. high-energy physicists work on CERN projects. Conversely, many CERN and other foreign scientists work on U.S. particle physics projects. Leon Lederman, the Director of Fermilab, has testified that over 10 percent of all foreign scientists working in particle physics made use of the Tevatron accelerator at Fermilab.[21] Furthermore, the recruitment of promising young scientists is worldwide: science graduate students in the United States are often citizens of other countries.

The 1976 Nobel Prize for Physics is especially illustrative in this regard; it was awarded to two U.S. scientists, Burton Richter and Samuel Ting, for their discovery of the charm quark.[22] Richter designed the Stanford Positron Electron Accelerator Ring and used that machine to conduct the experiments for which he won the prize. Ting used the existing accelerator at Brookhaven National Laboratory for his work. Subsequently, Richter worked on the conceptual design for CERN's Large Electron Positron collider, which starting next year will be the biggest machine of its type in the world, and he is currently director of the Stanford Linear Accelerator Center. Ting is director of CERN's major Large Electron Positron collider experiment and serves on CERN's Long Range Planning Committee, while continuing as a professor at the Massachusetts Institute of Technology.

Big Science and Particle Physics Budgeting

The greatest cost in big science projects that depend on a single instrument is the construction of that instrument. But particle physics

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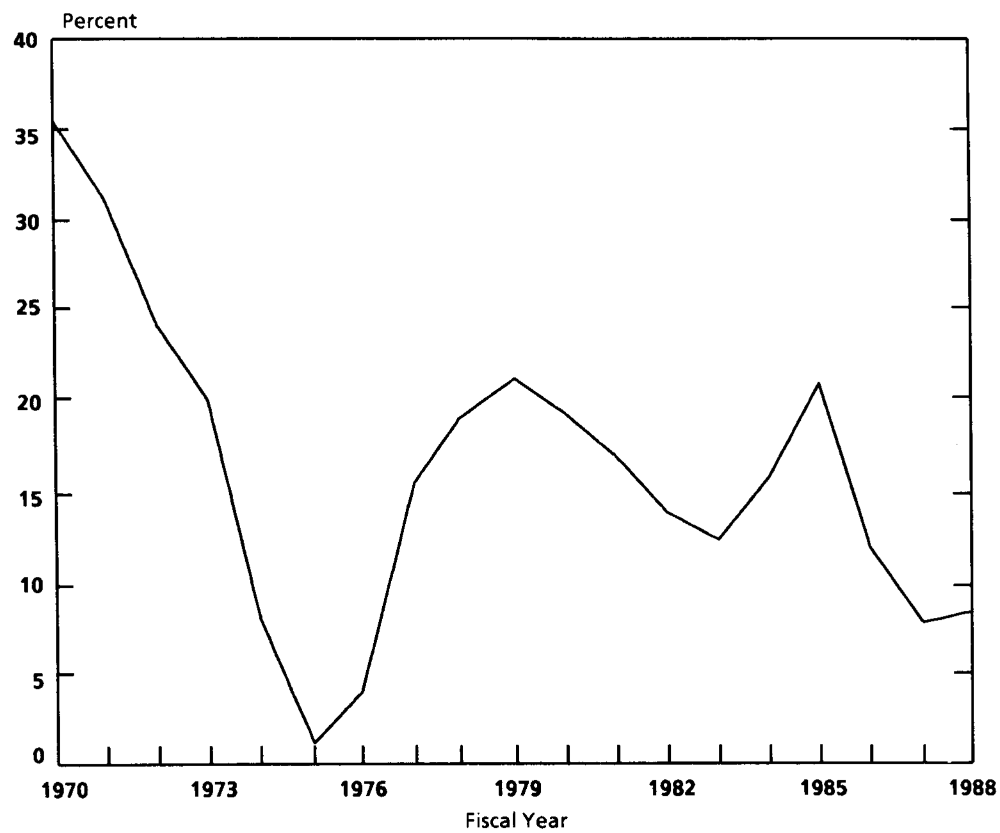
21. Lederman, Hearings on the Department of Energy's fiscal year 1989 budget request.

22. For more information on this discovery and a view of the international nature of the high-energy physics community, see Sheldon Glashow with Ben Bova, *Interactions: A Journey Through the Mind of a Particle Physicist and the Matter of this World* (New York: Warner Books, 1988), pp. 234-236.

has not seen much construction over the recent past, as few new instruments have been built. If anything, relative to total spending on high-energy physics, construction has been declining (see Figure 3). Spending in 1988 for particle physics construction is 22 percent of 1970 spending in real terms. By contrast, spending on operating and equipment has risen over the period, albeit primarily in the last six years, by roughly 29 percent.

Figure 3.
Construction Budget as a Percentage of Total Budget for High-Energy Physics



SOURCE: Congressional Budget Office, derived from data provided by the National Science Foundation, the Department of Energy, and the National Academy of Sciences. Numbers adjusted for inflation using the gross national product deflator.

Of course, the operation of big machines constitutes a significant fraction of all spending on operations and equipment. Operating costs differ from construction costs, however. When the machines are in operation, most of the costs are for science, as opposed to bricklaying. But when hundreds of people are working on an experiment, it may become "industrial science," taking on a different character from the traditional investigator in a laboratory. At this point, the different disciplines interact. In fact, according to proponents, the close cooperation of physicists and other researchers is one of the benefits that make accelerators powerful tools for the advancement of science.

On the other hand, the SSC will require that the Congress increase the current total investment in particle physics instruments by over 160 percent. Table 1 shows all the particle physics facilities currently in operation in the United States. (Other facilities were built, but they have been either decommissioned or are engaged in other

TABLE 1. CONSTRUCTION COSTS OF HIGH-ENERGY PHYSICS FACILITIES CURRENTLY OPERATING IN THE UNITED STATES (In millions of fiscal year 1988 dollars)

Site	Cost
Cornell Electron Storage Ring	32
Fermilab Proton Synchrotron	819
Fermilab Superconducting Synchrotron	75
Fermilab Tevatron I	96
Fermilab Tevatron II	56
Fermilab Collider Detector	61
Fermilab D-Zero Detector	48
Stanford Linear Accelerator	547
Stanford Positron Electron Project	149
Stanford Linear Collider	124
Stanford Linear Detector	51
Alternative Gradient Synchrotron	366
Total	2,424

SOURCE: Calculated from Congressional Research Service, *World Inventory of "Big Science" Instruments and Facilities* (December 1986), pp. 48-59, using gross national product deflator.

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

work.) The cost of construction for all these facilities totaled $2.4 billion.[23] These construction figures do not include costs for R&D, however. The equivalent cost for the SSC would therefore be $3.9 billion in 1988 dollars ($3.2 billion for the SSC itself and $719 million for the detector).

SPINOFFS FROM THE SSC

Government programs that concentrate on technology have occasionally produced technology by-products whose economic effect dwarfed those of the original program. The successes of the computer and integrated circuit industries, both of which were developed largely through federal government programs, have raised the hopes for all subsequent government programs that involve advanced technology. Yet, most government research programs produce few, if any, such spinoffs.

Spinoffs from experiments in particle physics are already in widespread use. Computer software originally developed for pattern recognition in particle detectors was used to develop the computer-aided tomography (CAT) scanning machines now used in medicine. Most recently, construction of the Tevatron I accelerator at Fermilab resulted in the creation of a superconducting cable industry, which in turn permitted the creation of magnetic resonance imaging machines for medical diagnostics. (For a discussion of spinoffs from particle physics technology, see Appendix A.)

Building and operating the SSC may produce several technology spinoffs, most of which cannot be predicted in advance. The mere presence of so many highly trained personnel working on major technology problems increases the probability that valuable knowledge will be produced. A similar amount spent on other R&D in technology, however, might also produce substantial advances. The major new development being pursued by the SSC is in the technology for very large superconducting magnets. Accordingly, this section con-

23. Congressional Research Service, *World Inventory of "Big Science" Research Instruments and Facilities*, pp. 48-59.

centrates on the potential for technological and commercial advantages from the development and manufacture of the SSC's superconducting magnets.[24]

How Would the SSC Affect Low-Temperature Superconductors?

The most expensive and technologically challenging component of the SSC is the double ring of superconducting magnets, which will guide and focus the beams of protons for the collisions. The current design for the rings involves 7,680 17-meter magnets and 1,776 4-meter magnets, containing nearly 20 million meters of superconducting cable cooled to near absolute zero.[25] The use of superconducting magnets makes the SSC feasible: with conventional magnets, the SSC would have to be several times its proposed size to contain the same amount of energy. The massive use of superconductors by the SSC has raised the question of whether this demand is likely to lead to the development of a U.S. superconductor industry, the way the Minuteman II Missile and Apollo Lunar Mission systems of the early 1960s led to the development of the U.S. integrated circuit industry.

The SSC will dramatically increase the demand for superconducting magnets during the five-year process of acquiring 10,000 magnets. The current total annual production of superconducting magnets in the United States is between 400 and 600. Once the production process begins, the SSC demand will dwarf worldwide demand for similar magnets, and the industry will experience a dramatic surge in growth. It will mature in two to three years and then start an equally dramatic decline in demand toward the original level. Such spikes in growth may destabilize the industry. While the SSC contract is being filled, other buyers could be driven out of the market by a lack of supply. Once the SSC contract is completed, the tooled-up magnet

24. The SSC Central Design Group, in *Conceptual Design of the Superconducting Super Collider* (Berkeley, Calif.: SSC CDG, 1986), (referred to hereafter as *SSC Conceptual Design*), suggests that the SSC will be using "off the shelf" components for its computer network. The SSC is therefore no more likely to make a substantial advance in computer technology than is any other large sophisticated user. CBO did not undertake an analysis of detector technology, because DOE has not yet completed the design of the detectors.

25. There are many other conventional accelerator and focusing magnets, for a total of approximately 10,000 magnets.

manufacturers will be seeking buyers for their products. But few such buyers may exist at that time.

Wide swings in demand and supply could have negative effects on this infant industry.[26] The actual outcome depends on the extent to which the SSC brings down the manufacturing costs of, and increases the demand for, superconducting magnets. The SSC will affect the manufacture of superconducting magnets in two ways: first, in the fabrication of the magnets themselves, and second, in the fabrication of the superconducting cable used to make the magnets.

Superconducting Magnets. Table 2 shows the cost breakdown of the dipole magnets as estimated by the Central Design Group of the SSC in March 1986. The process of making or assembling superconducting magnets appears to be dominated by capital and material costs. Of total costs of $796 million, material costs account for $658 million.[27] Only 17 percent ($137 million) of the total cost of the magnet is the cost of labor. Ten percent of the costs are related to the manufacturing process: allowances for rejects, allowances for material usage, industrial fees, and storage costs. The remaining 73 percent of the costs are for components and materials.

While some of the direct costs of making superconducting magnets could be affected by the large demand of the SSC, many of the material costs could not. Apart from reduced labor costs, there could be a reduction in the allowance for rejects, material usage, factory support, storage, and procurement. A more experienced labor force would smooth out these operations and thus create the savings. On the other hand, while most components that magnet makers buy for assembly will have a labor portion in their cost, no individual component (excluding the cable) is significant as a percentage of the total cost of the magnet. Moreover, some components, like iron laminations for

26. For instance, these wide fluctuations in demand could permanently affect both buyers and suppliers. The period of excess demand might drive potential users to designs not requiring superconducting magnets, lowering the path of future potential sales. Similarly, the period of excess supply might discourage investment, especially research, in this depressed field, lowering the path of future potential supply. This is only one of many possible scenarios.

27. *SSC Conceptual Design*, Attachment D, Appendix B, pp. 72-74. Converted to 1988 dollars using DOE's inflation index for energy research and nuclear construction.

TABLE 2. COST COMPONENTS OF DIPOLE MAGNETS
(As a percentage of total cost)

Category	Labor	Materials	Total
Coils			
Cold beam tube	1.0	5.0	6.0
Superconducting cable	0.0	29.7	29.7
Wedges	0.9	1.5	2.4
Main coil fabrication	1.9	0.4	2.3
Collaring	0.8	6.4	7.2
Other	0.7	0.5	1.3
Subtotal	5.3	43.5	48.9
Yoke and Helium Containment	1.2	14.2	15.4
Final Assembly Cold Mass, Cryostat	3.7	11.6	15.3
Electrical System	2.0	1.8	3.8
Magnet Interconnections	0.1	1.7	1.8
Magnetic Measurements	0.8	0.3	1.1
Factory Support	3.4	0.0	3.4
Material Procurement Allowance	0.0	1.0	1.0
Allowance for Rejects	0.5	1.3	1.8
Allowance for Material Usage	0.0	2.0	2.0
Industrial Fees	0.0	4.2	4.2
Storage and Handling	0.2	1.3	1.5
Total	17.3	82.7	100.0

SOURCE: SSC Central Design Group, *Conceptual Design of the Superconducting Super Collider* (March 1986), Attachment D, Appendix B, pp. 72-74.

the yoke, are unlikely to change their manufacturing technology in response to SSC demand.[28]

Thus, the labor component of this industry is already small and the proportionate reduction in labor costs will remain small. If, for example, the superconducting magnet industry could achieve a 20 percent savings in labor and process costs from learning and automation resulting from the SSC project, there would be a reduction of only 5.4 percent in the overall price of the magnets. Despite initial

28. Another effect of automation would be an increase in the production rate, but unless long-term demand from sources other than the SSC rises sharply, the increased production rate will not be important to the industry.

hopes, this is not a significant contribution toward maturing the superconducting magnet industry.

Superconducting Cable. The largest single cost component of the magnet is the superconducting cable that forms the coil of the magnet. The increased demand will affect both costs and fabrication processes of the cable industry. The cable is made of niobium-titanium alloy and copper. The materials are readily available and the SSC will not test the limits of niobium-titanium production.[29]

The cables are made by a detailed process involving several steps, each requiring a high degree of precision. The process is partly automated and the surge in demand should result in further automation. The SSC is developing machines to make the superconducting cable at a faster rate. Since 50 percent of cable costs are for labor, research, and other nonmaterial costs, manufacturers are also likely to gain experience and reduce their costs.[30] The SSC Central Design Group's cost breakdown assumes both types of cost savings will occur and has scaled down the cost of the cable from current costs in its estimate.

Overall Effects. Since cable costs account for 30 percent of the cost of superconducting magnets, a reduction in the nonmaterial costs of the cable of, for example, 20 percent to 40 percent more than assumed by the SSC Central Design Group would reduce magnet costs by 3 percent to 6 percent. On top of the 5.4 percent saved in magnet fabrication, this means that, under the most optimistic assumptions, the SSC would reduce magnet costs by only 10 percent to 15 percent, not really enough to stimulate many new applications, although the SSC may play a role in the diffusion of superconductor technology to industry and serve as a general demonstration project.[31]

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29. It is possible, however, that the few producers of this rare alloy could set monopoly prices once the highly inelastic demand of the SSC is determined. Thus, the price of the principal raw material used to make the cables for superconducting magnets could increase.

30. The 208 kilograms (kg) of cable per magnet will cost $28,000. A superconducting cable is 45 percent niobium-titanium and 55 percent copper. At $154 per kg for niobium titanium and $2 per kg for copper, the material costs in the cable are ((154 * 0.45) + (2 * 0.55)) * 208 = $14,643 per magnet. The cost of niobium-titanium used here is the average of the range of $60 to $80 per pound given in *SSC Conceptual Design*, Attachment B, p. 29.

31. Given the existence of a magnetic resonance imaging industry, however, it could be argued that further demonstration projects for superconductors are unnecessary. The roughly 2,000 imagers already in place could serve to demonstrate the usefulness of this technology.

The SSC thus appears to be a mixed blessing for the superconductor industry. It could have a drastic impact on the industry as a result of a one-time demand swing. The superconducting magnet makers may not gain much from the experience of producing 10,000 magnets but superconducting cable makers may benefit from the SSC order of superconducting cable. SSC proponents also argue that the SSC demand could attract large firms into the industry (currently, most manufacturers of superconducting magnets and cable are small). The presence of sizable federal contracts could bring in large firms that would be able to develop capacity in this growing field at government expense.

How Would the SSC Affect High-Temperature Superconductors?

The significance of this question lies in the recent discoveries of ceramic materials that exhibit superconducting properties at relatively high temperatures. At these higher temperatures, the superconductors can be cooled with liquid nitrogen instead of liquid helium; if even higher temperatures are achieved, conventional refrigeration equipment could be used. Because liquid nitrogen is much cheaper and easier to work with than liquid helium and conventional refrigeration is cheaper still, many new applications that depend on low costs for their success would be possible for superconductors. Thus, if the materials and manufacturing of these high-temperature superconductors, which are in very primitive state, can be improved, they have much greater potential than do low-temperature superconductors of being the basis of a new range of applications.

While forecasting technology is an imprecise art at best, a large part of the experience of building the SSC magnets may be irrelevant to high-temperature superconductors. The SSC magnets are currently designed around fine (6 microns in diameter) niobium-titanium filaments embedded (roughly 1 micron apart) in a copper matrix.[32] Each strand of wire has over 7,200 niobium-titanium filaments and there are over 20 strands in each cable. The process of developing the magnet coils of requisite strength from niobium-titanium has been one of metallurgical improvement, largely through the ability to make

32. See Eric Gregory, "Advances in Superconducting Wire and Cable for the Superconducting Supercollider," *Supercurrents* (March 1988), pp. 21-24.

the superconducting filaments of a consistent diameter and spacing them precisely in the superconducting strands of wire. The high-temperature superconductors, on the other hand, have thus far been largely ceramics, requiring very different handling. Other low-temperature superconductors behave more like the ceramic high-temperature superconductors, for instance niobium-tin, but these are much more expensive and difficult to work with than niobium-titanium and so have not been widely used in commercial or particle physics applications.

The SSC Central Design Group has been conducting experiments on test magnets at Fermilab and Brookhaven National Laboratory to determine the best design and manufacturing techniques for the magnets. Manufacturers will have the opportunity to study these techniques and see which should apply to the construction of the 10,000 magnets. The experiments of the Central Design Group so far indicate that precise metallurgy, not applicable to high-temperature superconductors, will dominate the SSC magnets.[33]

The other factor limiting the transfer of technology to high-temperature superconductors is that the first likely applications of these new superconductors seem to be in electronics, where the electric current densities and mechanical strength requirements are lower. It may be decades before power applications for high-temperature superconductors become practical. By then, the technology experts who worked on SSC magnets may be long since dispersed or forgotten. Firms or researchers working on power applications of high-temperature superconductors early in the next century are more likely to look to the advanced ceramics industry for solutions to their materials problems than to the SSC.

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33. Barbara Gross Levi and Bertram Schwarzchild, "Super Collider Magnet Program Pushes Toward Prototype," *Physics Today*, vol. 41, no. 4 (April 1988), pp.17-21.

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CHAPTER III

BUDGETARY RISKS IN THE SSC PROJECT

The Department of Energy currently estimates that the Superconducting Super Collider will cost $5.3 billion (in current dollars), to be spread over nine years.[1] A major aspect of Congressional concern about the SSC is whether costs will escalate substantially, if and when the SSC proceeds to actual construction.[2]

Previous construction costs for DOE accelerators have experienced substantial overruns reaching between 64 percent and 120 percent. In some instances, the costs increased simply because parts cost more than initial estimates. In other instances, research costs rose, or DOE encountered unexpected insurmountable technical problems that required an expensive redesign in one case and cancellation of a project in another. Given the risky nature of accelerator and other big science instrument design and construction, major cost increases in this program would not be unusual.

CURRENT DOE COST ESTIMATES FOR THE SSC

Table 3 presents the DOE estimate of the cost of the SSC by category of spending. DOE expects the SSC to cost a total of $4.4 billion.[3] SSC costs are dominated by technology (components, and research and development) and risk (contingency). Construction costs of the tech-

1. This does not include $80 million in research and development performed between 1984 and 1987. See Department of Energy, *Superconducting Super Collider* (April 1988), p. 27.

2. For a recent expression of Congressional concern, see *Energy and Water Development Appropriation Bill, 1989*, Report No. 100-381, Senate Committee on Appropriations, to accompany H.R. 4567, 100:2 (1988), p. 134.

3. Unless otherwise noted, all costs are in fiscal year 1988 dollars. The discussion of costs in this section is based on SSC Central Design Group, *Conceptual Design of the Superconducting Super Collider* (March 1986), (referred to hereafter as *SSC Conceptual Design*), Attachment D, pp. 657-702, and Department of Energy, *Superconducting Super Collider.*

nical components ($1.5 billion) and detectors ($0.7 billion) account for 50 percent of the total project costs. If R&D ($0.3 billion), which is dominated by magnet R&D, and the portion of engineering and design accounted for by technical components are added to this equation, then technology and its development account for over 60 percent of

TABLE 3. DOE ESTIMATE OF THE COST BREAKDOWN FOR THE SSC
(In millions of fiscal year 1988 dollars)

Category	Estimates
Construction	
Technical components	
Magnets	1,068
Cryogenics	129
Other	322
Subtotal	1,519
Conventional facilities	
Collider facilities	370
Other	244
Subtotal	614
Engineering and design	307
Management and support	205
Contingency	565
Total, construction	3,210
Detectors	719
Research and Development[a]	274
Pre-Operating	172
Total	4,375

SOURCE: Department of Energy.

NOTE: Estimates made before Congressional appropriations for fiscal year 1989.

a. Does not include $80 million for research and development performed between 1984 and 1987.

TABLE 4. FUNDING AND COST PROFILE FOR THE SSC
(By fiscal year, in millions of current dollars)

Category	1988	1989	1990	1991	1992	1993	1994	1995	1996	Total
					Funding Profile					
Total Funding	25	363	675	774	809	879	946	594	255	5,320
					Cost Profile					
Construction	0	150	350	510	630	660	690	670	350	4,010
Research and Development[a]	25	68	68	46	29	20	15	16	6	293
Pre-Operating	0	0	0	0	0	17	44	76	65	202
Detectors and Computers	0	12	22	110	125	145	147	175	79	815
Total Cost	25	230	440	666	784	842	896	937	500	5,320

SOURCE: Congressional Budget Office, derived from Department of Energy budget request and construction project data sheets for fiscal year 1989.

NOTE: Estimates made before Congressional appropriations for fiscal year 1989.

a. Does not include $80 million in research and development performed between 1984 and 1987.

total project costs. Risk, as expressed in contingency costs ($0.6 billion), accounts for a further 13 percent of total costs. DOE estimates that, once completed, the SSC will cost $270 million to operate annually, including $32 million per year for upgrades in the detectors.[4]

Table 4 presents DOE's projection of the SSC funding and cost profile in current dollars. The sum over the entire period is $5.3 billion. DOE assumes that cost inflation will average roughly 6 percent for construction; inflation for R&D and other costs will average slightly more than 2 percent. Should cost inflation deviate from the DOE estimate, these projections would change. Funding and costs will increase relatively quickly once construction is authorized, reflecting the fact that a great deal of planning has already occurred.

4. All these estimates were made before Congressional appropriations for fiscal year 1989. Some modifications may be needed.

OVERVIEW OF BUDGETARY RISKS

There are three ways to examine the current DOE cost estimates. They can be accepted as the best possible estimates at this time (DOE analysis); they can be analyzed for internal consistency (technical analysis); and they can be compared with previous DOE cost performance (historical analysis).

According to DOE, the current estimate (see Table 5) is accurate within 10 percent, given that the site has not been selected and the final design studies have not been performed. DOE argues that if the "right" site is chosen, the cost of conventional facilities might even fall relative to the estimate, which has some uncertainty built into it. The DOE estimate can therefore be portrayed as between $3.9 billion and $4.8 billion. (DOE has not provided information on the relative accuracy of categories within the total estimate.)

TABLE 5. SSC BUDGET ESTIMATES
(In millions of fiscal year 1988 dollars)

Category	DOE Analysis[a]	Technical Analysis[b]	Historical Analysis[c]
Construction	3,210	3,210-3,480	n.a.
Research and Development[d]	274	274	n.a.
Detectors	719	890-1,175	n.a.
Pre-Operating	172	172	n.a.
Total	3,937-4,812	4,546-5,101	6,398

SOURCE: Congressional Budget Office, based on data from the Department of Energy.

NOTE: n.a. = not applicable.

a. Current estimates by DOE, made before Congressional appropriations for fiscal year 1989.

b. Adjusted by CBO for internal consistency.

c. Adjusted by CBO according to previous DOE cost performance. No component-by-component analysis was made because future cost increases may not result from the same sources.

d. Does not include $80 million in research and development performed between 1984 and 1987.

Table 5 summarizes the Congressional Budget Office's technical analysis of the major components of DOE's current estimate. As detailed below, potential detector costs may be understated in the DOE estimate by $200 million to $500 million, according to the DOE panel on detector costs. Furthermore, DOE has made assumptions about productivity gains in superconducting magnet manufacturing that may not occur. If these gains do not materialize, costs could increase by $270 million. CBO did not subject the other parts of DOE's estimate to analysis. The lower bound of the technical analysis is well within the stated range of confidence of 10 percent for the DOE estimate, while the upper bound of the technical analysis is $300 million above the range of confidence and more than $725 million above the DOE's average estimate.

The historical analysis in Table 5 simply takes the current DOE estimate and increases it by the average cost increase for the four DOE accelerators built during the 1980s. The average overall cost increase was 46 percent in real terms. Two of the accelerators did not exceed their original cost estimate, whereas two suffered from exceptionally high cost escalation. No component-by-component analysis of cost increase was made because future cost increases may not result from the same sources.

DETECTORS

The detectors are a vital part of the SSC. They will collect all the information during proton collisions in the interaction regions. All scientific results coming from the SSC will depend on the quality and scope of these detectors.[5] The detectors required by the SSC, like the accelerator itself, are large: the largest components are magnets the size of a small house.

DOE's current cost estimate for SSC detectors is $719 million, but this estimate is highly uncertain, mainly because the SSC Central Design Group has not yet specified the type and number of detectors to

5. For a discussion of types of detectors and the roles they play, see National Research Council, *Physics Through the 1990s: Elementary Particle Physics* (Washington, D.C.: National Academy Press, 1986), pp. 132-156.

be used in the SSC. In 1985, the Detector Cost Model Advisory Panel of the SSC Central Design Group provided one possible configuration of detectors that could be used to evaluate the cost of the detector component of the SSC.[6]

When the Advisory Panel made its final recommendations, it kept a range of scientific expectations in mind, providing a scenario and not the final design. According to the panel, it is highly probable that the final detectors will bear little resemblance, apart from their function, to the proposed configuration of detectors, which merely provided a basis for a cost estimate.

The Advisory Panel estimated the costs using the data from detectors already in use or under construction. The panel estimated increases and decreases in component costs from the base cost of these detectors. It did not assume any economies of scale and assumed lower costs for the next generation of electronics used in the detectors. No costs were added for the moving and storage of the existing detectors that will be upgraded for the SSC.

Table 6 gives the cost breakdown for all the detectors and spectrometers evaluated by the Advisory Panel. The table provides a range of $682 million to $752 million for the total hardware cost of the detecors, depending on which combination is preferred. The panel recommends that the cost range should be widened by 15 percent on both sides to allow for the uncertainty, so the new range of the cost of hardware would be from $580 million to $865 million.

Some omitted associated costs should also be added to make the cost estimate more accurate (see Table 6). For example, the cost of R&D is not in the Advisory Panel's estimate. Since almost all new detectors and one upgrade are proposed, it is highly likely that some funds will be spent on R&D. Based on the Fermilab experience, DOE estimates that R&D costs will be $48 million. DOE maintains that conventional accounting for detectors never includes R&D costs, but this argument ignores the fact that DOE is the only U.S. organization

6. The proposed detectors and their cost estimate are detailed in SSC Central Design Group, "Cost Estimate of Initial SSC Experimental Equipment" (June 1986), Attachments A and B.

TABLE 6. RANGE OF COST ESTIMATES FOR ONE POSSIBLE CONFIGURATION OF DETECTORS FOR THE SSC
(In millions of fiscal year 1988 dollars)

Category	Low Estimate	High Estimate
Hardware Costs		
4pi Magnetic Detector	309	356
Spectrometer for High-Energy Muons	171	186
Upgraded and Forward/Intermediate Detectors[a]	181	189
Specialized Detectors	21	21
Subtotal	682	752
Expanded Range	580[b]	865[c]
Contingency	187	187
Total, hardware costs	767	1,051
Associated Costs		
Research and Development	48	48
Off-Line Computing	76	76
Total, associated costs	124	124
Total	891	1,176

SOURCE: Configuration from Detector Cost Model Advisory Panel of the Central Design Group for the SSC. Estimates by the Congressional Budget Office, calculated from SSC Central Design Group, "Cost Estimates of Initial SSC Experimental Equipment" (June 1986), Attachment B, Appendix B, Tables 1-10, using the Department of Energy's inflation index for energy research and nuclear construction.

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

a. The original estimates for the detector upgrade were $96 million to $133 million. Current estimates are $80 million. The forward or intermediate detector would cost $101 million to $109 million.

b. Hardware subtotal minus 15 percent.

c. Hardware subtotal plus 15 percent.

building large detectors for accelerators and thus sets the convention. An additional $76 million for off-line computing was also estimated by the same panel.[7]

7. SSC Central Design Group, "Cost Estimate of Initial SSC Experimental Equipment," Attachment C.