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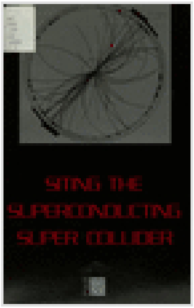

Siting the Superconducting Super Collider (1988)

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SITING THE SUPERCONDUCTING SUPER COLLIDER

Super Collider Site Evaluation Committee
National Academy of Sciences
and
National Academy of Engineering

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance. The report was reviewed by a committee of the Governing Board.

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Cover illustration: A computer reconstruction of an event observed in 1.8-TeV proton-antiproton collisions showing a section of the detector oriented perpendicular to the beam direction. The curved tracks give the trajectories of charged subatomic particles created in the collision. In this example, the detected particles cluster into two back-to-back "jets" that indicate that a very energetic billiard-ball-like collision took place.

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Preface

The National Academy of Sciences (NAS) and National Academy of Engineering (NAE) were asked by the Department of Energy (DOE) to undertake, on an exceptionally tight schedule, the monumental task of assisting the department in selecting a site for the proposed Superconducting Super Collider (SSC). A committee was appointed by the academies, and according to several news stories, about 750 pounds of proposals were sent to each committee volunteer. Although we have not, ourselves, weighed the proposals, we can verify the reasonableness of that estimate.

The Super Collider Site Evaluation Committee was charged with developing guiding principles for evaluating proposed sites, considering the relative advantages and disadvantages of various sites referred to it by DOE, and identifying an unranked list of best-qualified sites, giving particular attention to the technical requirements and such other factors—known in light of past experience with large science research laboratories—as would assure scientific productivity. The final selection of a site remains to be made by DOE, not by the academies, and will, of course, depend on considerations of concern to DOE, some of which may lie outside the areas of expertise represented by the academies.

It is important to keep in mind that the academies were asked to advise on desirable locations—those particularly promising for scientific productivity—for an SSC; they were not asked to evaluate the scientific feasibility, opportunities, or need for an SSC. It was, however, important for the committee to understand the nature of the SSC and the scientific expectations of the high-energy physics community in order to evaluate effectively what site-specific factors were likely to be important for efficient construction and scientifically productive operation of such a facility.

I am pleased to acknowledge the substantial contributions of many individuals, agencies, and organizations to this important effort and, on behalf of the academies, to thank them. First and foremost, I am indebted to the committee's volunteer members. Together we are grateful to our dedicated staff for their effective efforts in collecting and analyzing data, preparing drafts, and generally facilitating our work. Without their brilliant support, we could scarcely have completed this awesome assignment on schedule.

We are indebted to the U.S. Army Corps of Engineers for helping to analyze the strengths and weaknesses of the proposals in regard to real estate title and costs. We appreciate the assistance provided by special staff consultants, Jerry Okeson and Richard C. Armstrong, to committee members Edward Jefferson and LTG E.R. Heiberg, respectively, and the contributions of Don Deere, Jr., and James Gamble, who helped analyze the geology and tunneling aspects of the proposals. DOE staff graciously provided the information and resources we requested.

We appreciate the information and thoughtful comments provided by a number of colleagues who participated in subgroup meetings. Val Fitch, of Princeton University, offered a useful perspective on the site selection task at the committee's first meeting. Dan Lehman and Robert Selby, of DOE, and Tom Elioff and Mack Riddle, of RTK Associates, contributed to the July meeting of our Costs subgroup. Similarly, the August meeting of our Regional Resources subgroup benefited greatly from insights provided by Leon Lederman of the Fermi National Accelerator Laboratory, Wolfgang Panofsky of the Stanford Linear Accelerator Center, Louis Rosen of the Los Alamos Meson Physics Facility, Samuel Ting of Massachusetts Institute of Technology, and Paul van den Bout of the National Radio Astronomy Observatory, Socorro, New Mexico.

Finally, my colleagues and I want to recognize the effort expended by those who prepared the proposals we evaluated and the high quality of the result of that effort. Although we were charged with identifying a short list of best-qualified sites, many—indeed most—of the proposals were impressive; in general they were thorough, informative, and complete. It is reassuring that so many proposing organizations should have shown so much vision, competence, and commitment to excellence.

Edward A. Frieman
Chairman, Super Collider
Site Evaluation Committee

Executive Summary

At the request of the Department of Energy, the National Academy of Sciences and the National Academy of Engineering established the Super Collider Site Evaluation Committee to evaluate the suitability of proposed sites for the Superconducting Super Collider.

Thirty-six proposals were examined by the committee. (One of these was withdrawn from consideration during the course of the committee's evaluation.) Using the set of criteria announced by DOE in its *Invitation for Site Proposals*, the committee identified eight sites that merited inclusion on a "best qualified list." The list represents the best collective judgment of 21 individuals, carefully chosen for their expertise and impartiality, after a detailed assessment of the proposals using 19 technical subcriteria and DOE's life cycle cost estimates. The sites, in alphabetical order, are:

Arizona/Maricopa
Colorado
Illinois
Michigan/Stockbridge
New York/Rochester
North Carolina
Tennessee
Texas/Dallas-Fort Worth

1
Introduction

In 1965, the National Academy of Sciences assisted the Atomic Energy Commission in choosing a site for the 200-BeV accelerator laboratory that is now known as the Fermi National Accelerator Laboratory, and now houses the Tevatron, a 1-TeV accelerator (2-TeV proton-antiproton collider) that is currently the world's highest-energy machine. It can be viewed, then, as a continuing development in that vein that the National Academy of Sciences (NAS) and the National Academy of Engineering (NAE) were asked again to assist in selecting a site for a newly planned high-energy physics facility, the Superconducting Super Collider (SSC).

The process was initiated in 1984 by identical letters to the presidents of NAS and NAE from Alvin Trivelpiece, the then director of the Office of Energy Research (OER) of the Department of Energy (DOE):

> [DOE] is sponsoring a program of research and development on the design of a future accelerator facility, the Superconducting Super Collider. . . . Although the Department has not yet made a decision to proceed with the project, the process by which site selection for this facility would occur needs to be established now. . . . [T]he Department would like to enlist the aid of the NAS and NAE in the site selection process. Specifically, we would like the Presidents of the two Academies to jointly select a review panel of about 15 distinguished individuals with appropriate experience . . . to evaluate qualified proposals against the site criteria requirements . . . [and] select a small group of those proposals that

> they believe to be most excellent in every respect. . . . [The Academies would] then inform the Director of OER as to which proposals had been selected to be in this group together with the Panel's summary of the basis for selection. . . . [Although] the specific number of proposals . . . in this final unranked list cannot [now] be foreseen, it is expected that only a few of the most qualified would be included. . . . It is essential that all institutions or organizations that compete for it be certain that they will receive fair and equitable treatment in all phases of an orderly selection process. . . . I am confident that the Academies' participation would provide a review of the proposals that meets the highest standards.

The presidents promptly agreed that if DOE made a decision to proceed with such a facility and asked the academies to assist, they would be prepared to do so in the manner outlined.

A January 30, 1987, announcement by the Secretary of Energy, John S. Herrington, that President Reagan had approved construction of the SSC was followed on February 10 by the announcement of a schedule for submission and evaluation of proposals and by a request to the academies to assist DOE in its evaluation. DOE asked the academies to evaluate qualified site proposals and to recommend an unranked best qualified list of sites by the end of 1987. DOE would then designate a preferred site in July 1988, and in January 1989 the Secretary of Energy would announce the final site. DOE modified this schedule in July in response to newly enacted legislation limiting allowable financial offers from proposers. Proposals became due in September, and the academies' report was to be delayed until early January 1988.

The academies and DOE agreed on a "work statement" (see Appendix A), and the presidents of the academies appointed a committee of experts (see Appendix E) in June, including specialists in high-energy physics, engineering geology, accelerator design, economics, procurement, the environment, large construction, and large-facility management. The committee's charge, as approved by the Governing Board of the National Research Council, noted that the evaluation, to be developed in light of past experience with large science research laboratories, would stress those items that were likely to be most critical in determining scientific productivity of the SSC laboratory. The charge also explicitly recognized that the final site selection was not to be made by the academies or the National Research Council; it was to be made by DOE and to be dependent upon considerations of concern to DOE, some of which might lie outside the areas of expertise represented by the academies.

2
The Superconducting Super Collider

The NAS and the NAE were asked to assess site proposals for a Superconducting Super Collider (SSC), particularly in light of how a given site might enhance the scientific productivity of the laboratory, and to develop a list of best-qualified sites. The academies were not asked to evaluate the scientific merit, opportunities, or need for an SSC. The focus of the academies' activities was on the site-specific effects that might affect the construction and productive operation of a super collider.

Much has been written elsewhere about the scientific promise of the SSC; the interested reader can find discussion of the science in the following publications:

1. Committee on Science, Engineering, and Public Policy, *Report of the Research Briefing Panel on Scientific Opportunities and the Super Collider*, National Academy Press, 1985.

2. J.W. Cronin, "The Case for the Super Collider," *Bulletin of the Atomic Scientists*, May 1986, pp. 8-11.

3. J.D. Jackson, M. Tigner, S. Wojcicki, "The Superconducting Supercollider," *Scientific American*, Vol. 254, No. 3, March 1986, pp. 66-77.

4. L.M. Lederman, "To Understand the Universe," *Issues in Science and Technology*, Vol. I, No. 4, 1985, pp. 55-65.

5. C. Quigg, R. Schwitters, "Elementary Particle Physics and the Superconducting Super Collider," *Science*, Vol. 231, March 28, 1986, pp. 1522-1527.

6. R.F. Schwitters, "Super Collider," *American Politics*, July 1986, pp. 5-7.

THE SSC AS A SCIENTIFIC INSTRUMENT

The SSC will have two counterrotating, tightly focused streams of protons guided along nearly circular orbits by superconducting magnets (see Figure 1). The protons in each beam will be accelerated to 20 trillion electron volts (TeV),* and the two beams will be brought into collision at several interaction regions around the circumference of the accelerator, yielding at those points a total useful energy of 40 TeV. The energy available for creating new particles of interest at the collision points of the SSC will be 200 times the energy that would be available if only one such beam were directed at a fixed target (see Figure 2).

The events resulting from collisions of interest will be complicated, with hundreds of particles flying out from the collision point. These particles must be tracked and measured to reconstruct the underlying physics responsible for the event. One particular challenge to SSC experimenters will be the high rate of collisions—about 100 million per second—of which only a tiny fraction will provide the scientists with new information of interest in specific investigations.

Sophisticated detectors of enormous size (see Figure 3) will be installed at the collision points. These detectors employ tracking chambers, analyzing magnets, large calorimeters, and other devices to observe high-energy particles to provide information on the trajectories, energies, and identities of the particles in a proton-proton collision. In addition to the detection hardware, extensive and elaborate high-speed, sensitive electronics is required to register and interpret the large amount of data that results from each collision event. The data are screened by special-purpose, high-performance computers to select events of special interest and then archived for subsequent off-line analysis.

The very large scale and sophistication of the detectors are necessitated by the high energies of the particles to be detected and by the inherent complexity of the collision events of interest. Materials such

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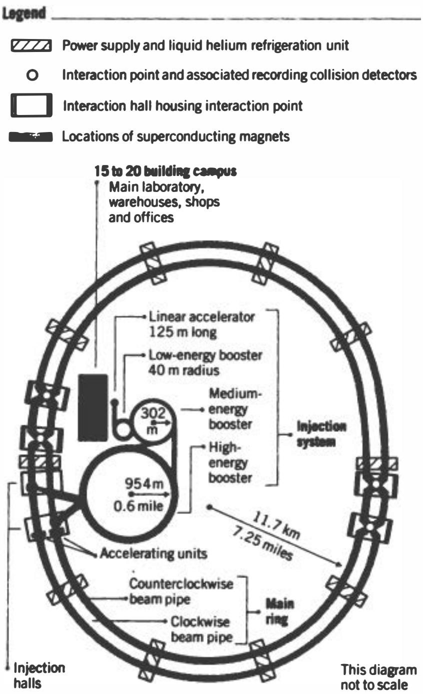
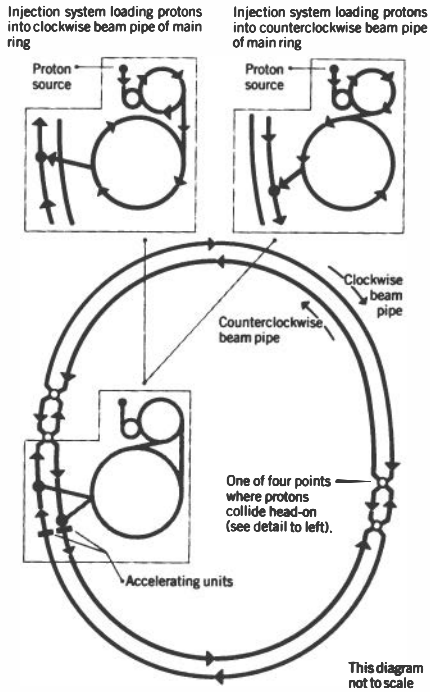
*An electron volt is a unit of energy equal to the energy given to each electron flowing through a circuit by a one-volt electrical battery.

The Superconducting Super Collider (SSC)

SSC anatomy (For scale drawing, see map at bottom right.)



Operation of injection system



Main ring sustaining dual proton beams

The size and power of the underground SSC would allow narrow beams of protons to collide at almost the speed of light, creating new subatomic particles observable only at very high energies that cannot be attained by existing accelerators. This diagram tracks the path of proton beams. Protons are produced by the ionization of hydrogen atoms.

The injection system (upper right), composed of a linear accelerator and three progressively larger circular energy boosters, prepares the protons for the main-ring collisions by accelerating them to higher and higher energies. Some protons are loaded into the clockwise beam pipe (green), then others into the counterclockwise one (black).

Inside the main ring (see central schematics), accelerating units speed the protons to 20 times their energy. The protons are guided in the high-energy booster and main ring by about 10,000 powerful superconducting magnets, refrigerated by liquid helium to 4.35° Kelvin (about –270° centigrade, –455° Fahrenheit). The magnets maintain the beams on their circular paths; special magnets near the interaction points force collisions between protons traveling in opposite directions. Detection apparatuses at each collision site will measure the energy released by the collisions and will trace the paths of particles produced by the collisions. By creating levels of energy similar to those of the "big bang," scientists hope to learn about the fundamental laws of nature that guided the creation of the universe.

Informational graphics: Michael Yanoff

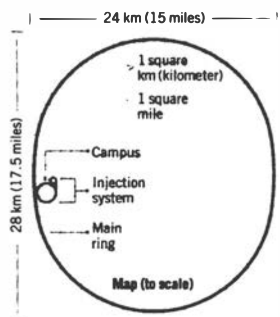


FIGURE 1 A simplified description of the Superconducting Super Collider from the *Bulletin of Atomic Scientists*, volume 42, page 9, May 1986.

as iron and lead are used to absorb the energetic particles. Enough of these heavy materials must be used to assure that all of the particles produced are absorbed. Further, because particles are released in different directions, detectors must fully surround the collision point. The various requirements set the scale of the detectors, some of which may weigh as much as 40,000 tons.

Different kinds of detectors will be installed at different collision points in order to allow the investigation of a number of physics problems. Many crucial experimental tests have been proposed and formulated, and conceptual designs of various detectors have been prepared.

The detectors will generally require large-scale collaboration—including international cooperation—among many university and laboratory groups. Traditionally, such collaborations evolve from the common interests of experimental physicists, who unite in semipermanent scientific groups of students, postdoctoral researchers, and university professors supported by the engineering and technical staffs of laboratories and universities. The data collected by the detectors become available to all the collaborating members working in separate smaller groups according to their scientific interests.

The proposed accelerator scheme makes use, first, of a proton injector system that will accelerate protons to about 1 TeV, at which point the protons will be injected into the main SSC ring for the final acceleration phase. The injector will consist of a series of four separate accelerators: a linear accelerator about 500 feet long that will raise the protons from rest to an energy of 0.6 billion electron volts (GeV); a low-energy synchrotron booster about 820 feet in circumference, using conventional magnets, that will raise the protons to 7.0 GeV; a medium-energy ring about 1.2 miles in circumference, again using conventional magnets, that will raise the energy of the particles to 100 GeV; and a high-energy booster (HEB), some 4 miles in circumference, that will use superconducting magnets to increase the proton energies to 1 TeV.

The main ring will be located in a 53-mile-long race-track-shaped tunnel, 10 feet in cross-sectional diameter with its centerline at least 35 feet below the earth's surface. The tunnel will contain two evacuated tubes with proton beams moving in opposite directions and about 9500 powerful electromagnets—spaced along the beam lines—to keep the proton beams tightly focused in the evacuated tubes and constrained to closed, nearly circular orbits. (About 8000 bending (dipole) and about 1500 focusing (quadrupole) magnets will be used)

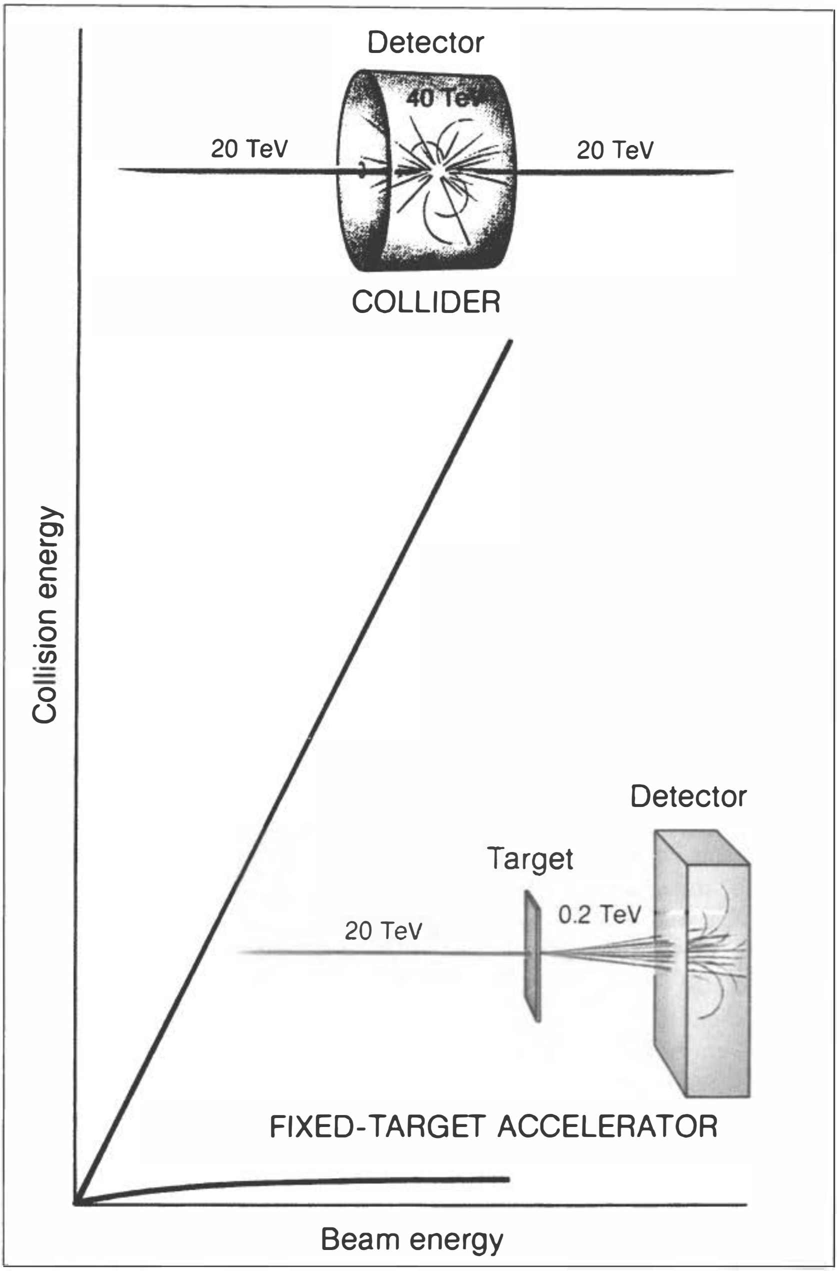


FIGURE 2 **The advantage of a collider.**

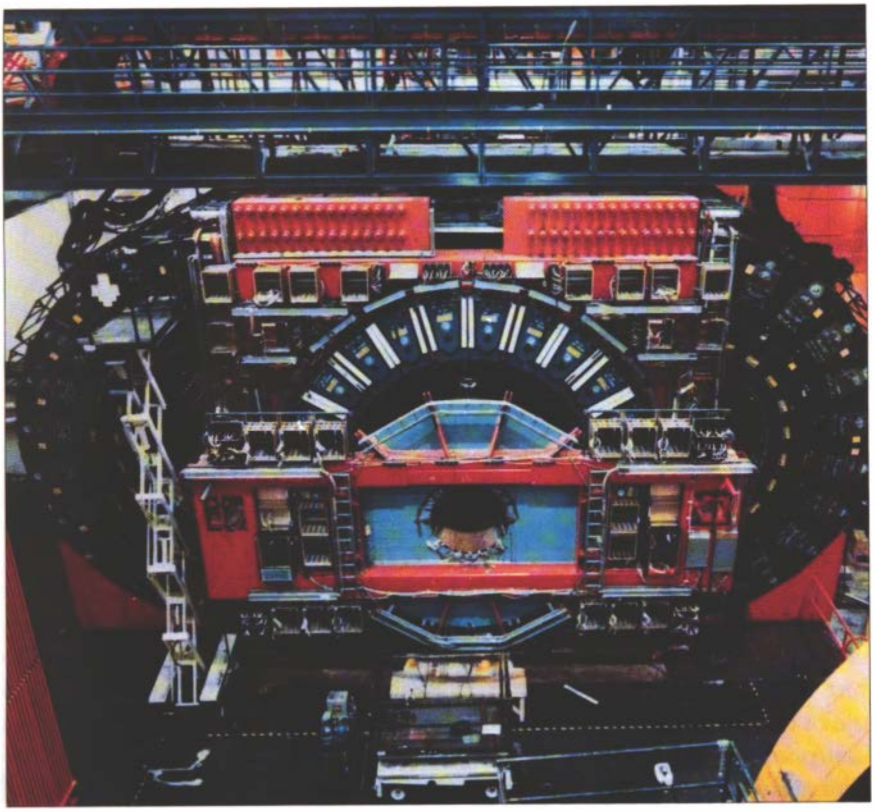


FIGURE 3 A collider detector during its assembly.

(see Figure 4). The ring will receive bunches of 1-TeV protons from the injector; the protons will be distributed around the ring and accelerated until they reach an energy of 20 TeV. When the protons are at the desired energy level, it will be possible to deflect the two beams so that they collide head-on with one another in the center of the particle detectors that surround the beams at the interaction points. After acceleration to full energy, the beams will continue to circulate for many hours while the experimental detectors record collision events. When the beam intensity falls, a new batch of protons will be introduced into the SSC and accelerated.

The main-ring bending and focusing magnets will use superconducting wire to carry the electric current that sets up the magnetic field. The costly and sophisticated superconducting cable as well as the great precision and quality control required in assembly will

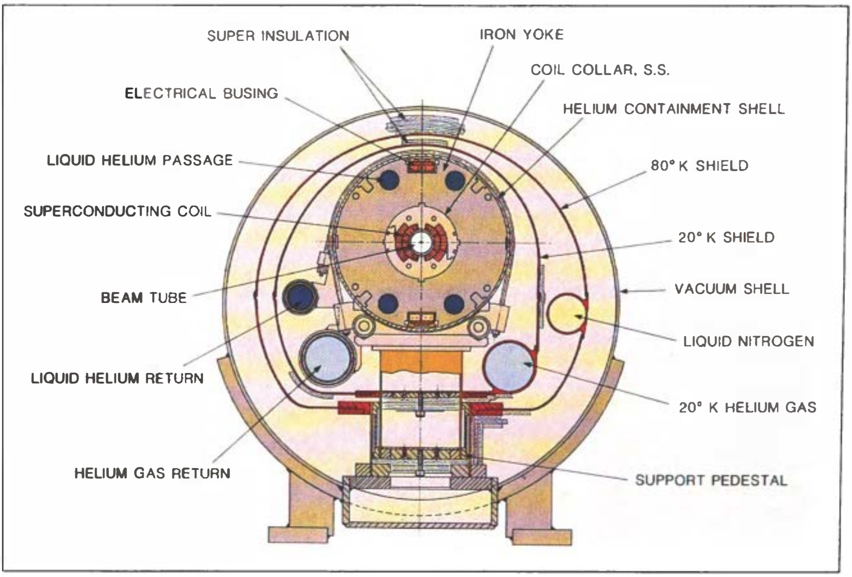


FIGURE 4 **Detail of magnet assembly.**

make the magnets expensive to build, although they will be relatively inexpensive to operate, because the superconducting coils have essentially no electrical resistance. In principle, a 20-TeV accelerator (of considerably larger circumference) could be built with conventional copper conductor electromagnets, but, because of the resistance of the wire, it would consume at least 4000 MW of power (as opposed to a total of 100 MW to be consumed by the entire SSC complex, much of which is necessary to cool the superconducting magnets to their required operating temperature) and lead to impractically high operating costs. Using superconducting magnets will reduce the total power consumption of the magnetic confinement system and permit the creation of magnetic fields several times stronger than any that could be achieved with conventional electromagnets. A stronger magnetic field will make it possible to confine protons of a given energy (say, 20 TeV) to an orbit of smaller radius and thus reduce the required length of the accelerator tunnel. The design circumference of the SSC—53 miles—is determined by the maximum intensity of its magnetic field—6.6 tesla—and the maximum energy of the protons—20 TeV.

The accelerator will also require hundreds of miles of cryogenic plumbing (at the boiling point of liquid helium, 4 K) to establish superconductivity. Such systems (though with a lower magnetic field) have been successfully constructed and used on a large scale in the Tevatron ring of the Fermi National Accelerator Laboratory, but the SSC cryogenic system will be some 13 times larger in scale than anything ever attempted.

THE SSC AS A CIVIL WORKS PROJECT

The proposed SSC will be the largest scientific instrument ever made. The tunnel, which will be the largest component of the facility, will be out of sight and covered by at least 35 feet of earth to ensure that no significant radiation ever reaches the surface. Approximately every 5 miles along the 53-mile tunnel, a cluster of surface buildings—housing cryogenic refrigerators, helium compressors, power supplies, and support facilities, and providing points of access—will be visible. Additional shafts allowing access to the collider tunnel will be located midway between adjacent service areas.

The campus—a focal point of the site—will be a science research center large enough to accommodate a staff of 3000, with a central office building, an auditorium, and various laboratory, support, and industrial buildings.

The SSC will consist of five major components: (1) an underground injector complex of cascaded accelerators to accelerate protons from rest to 1 TeV; (2) a main collider ring to accelerate, focus, and guide two beams of protons in opposite directions around the tunnel until they each reach an energy of 20 TeV, and then to "store" them in the ring until they are depleted through collisions; (3) collision/experimental areas containing the particle detectors; (4) campus/laboratory areas; and (5) a site infrastructure of roads and utilities.

The experimental areas containing the massive particle detectors will be located in two regions clustered diametrically opposite each other on the circumference of the collider ring. Each experimental area will have surface structures and underground collision and access halls. The dimensions of the collision halls will vary to allow a spectrum of possible experimental apparatus. The largest collision halls could be up to 160 feet long, 120 feet wide, and 130 feet high. Because the outside parts of the detectors are very likely to include large assemblies of thick steel plates—making the individual detector components enormously heavy—a thick concrete floor with steel plate capable of supporting loads of up to 9 tons/ft^2 will be used in the halls.

The campus area may have 15 or more buildings clustered in four major groups—a central laboratory building and auditorium, industrial buildings, warehouses, and auxiliary support buildings. The central laboratory building will provide office and laboratory space for administrative and technical personnel. One building might contain all the major offices of the facility and light laboratories for the development and testing of electronic components. Industrial buildings will house limited component assembly activities, various workshops, and associated offices. Warehouses will serve as receiving and storage facilities. The auxiliary support buildings—fire, rescue, site patrol, visitor services, waste management, and vehicle storage buildings—will provide services to the entire complex. The central laboratory facilities with their associated office and shop buildings, and assembly and staging areas, will be arranged like a small college campus.

Roads and utilities, adjacent to the campus, will include a main electrical substation consisting of incoming high-voltage electrical service, transformers, switch gear, and distribution systems. A second substation will be located on the far side of the ring. Water treatment facilities will process the cooling water used for the SSC. A road network will be needed in the campus, injector, and experimental areas, to connect the cluster regions, and to provide access to the service areas and access points located around the ring.

A significant part of the project's capital cost will go toward the 9500 superconducting magnets, whose design, construction, and testing will require advanced technologies and precision engineering of the highest order. In addition to the magnets, other advanced systems for the SSC will include the radiofrequency acceleration cavities, cryogenic facilities, particle detectors, supercomputers, and laboratory equipment.

The construction of conventional facilities, by contrast, will not require significant innovation as much as a scaling-up of existing methods. Construction of the tunnel and experimental halls, as well as the requisite infrastructure of utilities, transportation, housing, laboratories, offices, shops, maintenance, and so on, will be large in scope but straightforward in principle. It will be possible to excavate the 10-foot-diameter tunnel by cut-and-fill methods or tunnel-boring machines, or by a combination of both. The area enclosed by the ring will be left, for the most part, completely untouched.

THE SSC AS A HUMAN ENDEAVOR

An essential fact to keep in mind is that the initiation of an SSC is not simply "starting up a new large facility" but the creation of a new international basic research laboratory. This means that the efficient and prompt start-up of the new facility is only the first of several major tasks that will need to be undertaken. The second major effort is the creation of an infrastructure and environment to facilitate creative research through supporting the efforts of both inside and outside users. A third major task is the training of operating personnel to run and maintain the accelerator itself and the large ancillary complex required in support of experimental undertakings. A fourth item is the establishment of the administrative machinery to manage the SSC complex as well as to deal with the external constituencies: government, industry, the public, and the domestic and foreign participants in the work of the SSC.

The SSC will be a very large laboratory; its staff—scientists, engineers, technicians, skilled technical and mechanical laborers, and professional administrators—will number nearly 3000, including 500 visiting scientists (many on sabbatical leave from universities in the United States or abroad) and their students, who may participate in its work for periods of weeks to years throughout its operating period. Experience indicates that for each individual employed or working at a laboratory, several additional people (including families) are brought into the community in connection with schools, stores, maintenance, services, and other support facilities. Thus the SSC is likely to create additional employment in the community at large and could generate demand for additional housing, schools, and other services beyond what is required for the SSC staff itself.

3
Evaluating the Proposals

The 43 proposals originally received by the Department of Energy (of which 35 were eventually evaluated by the committee) were written in response to an April 1987 DOE document entitled *Invitation for Site Proposals for the Superconducting Super Collider (SSC)* (DOE/ER-0315). That document—the ISP—outlined the information that would be required in proposals and described the qualification criteria, technical evaluation criteria, and cost considerations that were to be used in the site selection process. (A list of the 43 proposals submitted to DOE appears in Appendix C.)

Proposals were required to show, first, that the site met a set of five qualification criteria before they could be forwarded to the committee by DOE. The qualification criteria, as stated by DOE (Section 3.2 of the ISP, p. 28), were:

> 1. Location entirely in the United States of America.
> 2. Land size and configuration to accommodate the SSC facility as specified in this Invitation. . . .
> 3. Absence of cost to the Government for land acquisition.
> 4. Capability of providing at least 250 MW of electrical power with at least 500 gpm of industrial water or 200 MW of power with 2,200 gpm of industrial water, or an appropriate interpolated combination.
> 5. Absence of known unacceptable environmental impacts from siting, constructing, operating, and decommissioning the SSC. Reasonable mitigation measures may be taken into consideration.

(Thirty-six proposals were deemed by DOE to have met the qualification criteria and were sent to the committee for evaluation. One of these was subsequently withdrawn from consideration by the State of New York.)

The ISP indicated that information in the proposals would be evaluated against a set of technical evaluation criteria and subcriteria in determining the best qualified list (BQL) and, eventually, in identifying the preferred site. As stated by DOE (Section 3.3 of the ISP, pages 28 to 29), the technical evaluation criteria were:

1. Geology and Tunneling
   - A. Suitability of the topography, geology, and associated geohydrology for efficient and timely construction of the proposed SSC underground structures.
   - B. Stability of the proposed geology against settlement and seismicity and other features that could adversely affect SSC operations.
   - C. Installation and operational efficiency resulting from minimal depths for the accelerator complex and experimental halls.
   - D. Risk of encountering major problems during construction.
2. Regional Resources
   - A. Proximity of communities within commuting distance of the proposed SSC facilities capable of supporting the SSC staff, their families, and visitors. Adequacy of community resources—e.g., housing, medical services, employment opportunities for family members, recreation, and cultural resources—all available on a non-discriminatory basis.
   - B. Accessibility to the site, e.g., major airport(s), railroads, and highway system serving the vicinity and site.
   - C. Availability of a regional industrial base and skilled labor pool to support construction and operation of the facility.
   - D. Extent and type of state, regional, and local administrative and institutional support that will be provided, e.g., assistance in obtaining permits and unifying codes and standards.
3. Environment
   - A. Significance of environmental impacts from siting, constructing, operating, and decommissioning the SSC.
   - B. Projected ability to comply with all applicable, relevant, and appropriate federal, state, and local environmental/safety requirements within reasonable bounds of time, cost, and litigation risk.
   - C. Ability of the proposer, the DOE, or both to reasonably mitigate adverse environmental impacts to minimal levels.
4. Setting
   - A. Ability of the proposer to deliver defendable title, in accordance with the schedule in [the ISP]. . . for land and estates in land that will adequately protect the Government's interest and the integrity of the SSC during construction and operation.

B. Flexibility to adjust the position of the SSC in the nearby vicinity of the proposed location.

C. Presence of natural and man-made features of the region that could adversely affect the siting, construction, and operation of the SSC.

5. Regional Conditions

A. Presence of man-made disturbances, such as vibration and noise, that could adversely impact the operation of the SSC.

B. Presence of climatic conditions that could adversely impact construction and operation of the SSC.

6. Utilities

A. Reliability and stability of the electric power generating and transmission grid systems. Flexibility for future expansion.

B. Reliability, quality, and quantity of water to meet the needs of the facility.

C. Availability of fuel, waste disposal, and sewage disposal.

In laying out the technical evaluation criteria, DOE noted in the ISP:

> In descending order of relative importance, the criteria are Geology and Tunneling, Regional Resources, Environment, Setting, Regional Conditions, and Utilities. Under each major criterion heading, the subcriteria are listed in descending order of relative importance. However, a serious deficiency in any one subcriterion may prevent the proposal from being included in the BQL.

DOE further stated that "cost considerations are important to the selection process and will be used in conjunction with the technical evaluation criteria in selecting the most desirable site." The department indicated that it would prepare a life cycle cost (LCC) estimate for each proposal and stated:

> Although cost considerations are significant, primary emphasis will be placed on the results from the evaluation of the technical evaluation criteria by the NAS/NAE in the development of their BQL recommendation to the DOE.

The process used by the committee was consistent with the instructions provided in the ISP. Early in its life, before any proposals had been received by DOE, the committee agreed on a set of procedures designed to permit the detailed and equitable evaluation of the voluminous set of proposals and supporting materials that it expected to receive and ultimately did.

The committee was faced with the task of evaluating the proposals using a multiplicity of technical criteria and subcriteria and costs. Because of the difficulty—perhaps impossibility—of directly comparing the various criteria and the extent to which individual proposals met or did not meet the criteria, the committee decided against adopting a rigid set of weights that would allow a mechanical means of scoring or grading proposals.

Seven working groups, focusing on each of the six criteria and costs, were established by the committee to assure careful, detailed examination of each proposal. Each working group was composed of members of the committee with particular expertise in its area of focus. The working groups were charged with identifying strengths and weaknesses of the proposals in their areas of concern and with providing an initial evaluation of proposals on a scale with three values (good, satisfactory, and questionable) as a basis for discussion by the full committee. The committee did not seek to verify independently and systematically information presented in the proposals; such verification may be necessary in subsequent stages of the site selection process. In its review of proposed plans for timely acquisition of the required land, the committee received assistance from the U.S. Army Corps of Engineers drawing upon that agency's long experience and substantial expertise for an analysis of the plans.

From the outset, the committee recognized the complexity of aggregating ratings for all the criteria and subcriteria. It noted that any single mechanical method (such as assignment of explicit numerical weights, explicit cutoff ranges for individual criteria or subcriteria, or preselected stepwise disqualification rules) would embody potential technical and practical flaws that would make its adoption by the committee unwarranted. Thus, although the committee asked its staff to try alternative aggregation methods and to note their sensitivity to basic assumptions, the committee used the ratings of individual members and working groups, and the staff analyses of sensitivity to different assumptions, only as guides to direct its discussions and deliberations.

At its final meeting, the committee discussed the strengths and weaknesses of the 35 proposals that remained for evaluation and for each site made an explicit determination of whether or not the site merited inclusion on the best qualified list. No explicit weighting or ranking was used to determine the list; thus the list itself is an unranked list of the best-qualified sites. At no point did the committee consider an "appropriate" length for the list. The best qualified list presented in this report is the result of 35 decisions made by the committee after careful consideration of the proposals, and the list includes all the sites on which a committee consensus for inclusion was reached. The list represents the best collective judgment of 21 individuals, carefully chosen for their expertise and impartiality, after a detailed assessment of the proposals using 19 technical subcriteria and DOE's life cycle cost estimates.

The committee recognized that it was dealing with proposals prepared by proponents of sites and that it was therefore likely that proposals would present sites in the best possible light. One way of obtaining additional information about some or all of the proposed sites might have been through visits to the sites. However, because the procedures for site selection presented in the ISP precluded site visits by the committee, and because the time constraints under which the committee was asked to work would have made any but the most superficial site visits difficult or impossible, the committee did not visit any sites as part of its evaluation. The committee is confident that the breadth of experience represented by its members and its detailed and comprehensive discussion of individual proposals were sufficient to assure that each proposal received adequate and equitable consideration and that the best qualified list reflects a judicious selection of those sites that best meet the selection criteria listed in the ISP. The committee does believe that site visits can provide a valuable means of confirming the information contained in the proposals and urges that, in further action by the Department of Energy on selection of a preferred location for the SSC, site visits and other confirmatory studies be used.

In the next chapter of this report, the committee presents an outline of some of the factors that weighed most heavily in its deliberations. This is followed by a chapter that briefly comments on the strengths and weaknesses of the sites that, in the judgment of the committee, were the best qualified of the proposed locations for the SSC.

4
Comments on the Evaluation of Site Proposals

The discussion of criteria for the evaluation of site proposals in the *Invitation for Site Proposals* is quite detailed and complete. Nonetheless, in its discussions and deliberations, the committee had occasion to elaborate and interpret several of the criteria in order to evaluate the adequacy of a given site proposal in terms of particular criteria and subcriteria.

The committee was asked by DOE to perform an evaluation of the site proposals ". . . developed in the light of past experience with large science research laboratories," and to "stress those items within the DOE-announced criteria and subcriteria and their relative importance, that are likely to be most critical in determining scientific productivity of the SSC laboratory. . . ."

GEOLOGY AND TUNNELING

Among the geological conditions for SSC construction that the committee considered to be favorable were groundwater table below the tunnel and experimental hall levels; rock or soil with low permeability; uniform rock and soil conditions for the entire tunnel or for long sections; rock or soil soft enough to allow for rapid excavation or tunnel advance rate; rock or soil strong enough to stand without support in the tunnel or in steep, high, open cuts; topography allowing efficient open-cut excavation or placement of the tunnel at relatively shallow depths; and geological conditions permitting minimal tunnel lining and support or no lining and support at all.

Among the unfavorable conditions for construction were: groundwater table at or near surface; high-permeability rock or soil; high hydraulic head because of an overall deep tunnel or mountainous topography; presence of surface water (swamps, lakes, rivers, or streams) that would complicate access or construction or provide recharge for inflows into the tunnel or open excavations; complex rock and soil types with many changes and wide variations in properties; low-strength rock and soil materials (such as loose sands or soft clays) that would require immediate support; hard or abrasive rock; particularly deep tunnels with shafts over a few hundred feet deep caused by topographical features; need for complicated, time-consuming, or highly specialized tunneling procedures to accommodate particular conditions; conditions necessitating slow tunnel advance or open-cut excavation rates; swelling or slaking soil or rock; and highly fractured rock that would require support.

The impact of geology on operational stability was also considered. Here, favorable sites were generally characterized by low soil or shale consolidation or heave; absence of active faults or zones of volcanic activity; low seismic exposure; absence of conditions for potential liquefaction or soil deformation; and formations not subject to adverse subsidence from subsurface fluid withdrawal, solution cavities, or mines.

Adverse site features for operational stability included the opposite of each of the favorable conditions listed above and, in addition, potential groundwater inflow leaking through construction joints; possibility of long-term sulfide attack on concrete and corrosion resulting from leakage into the tunnel; and potential toxic gas leakage into the tunnel.

The primary factors examined in considering the efficiency of installation and operation of the accelerator complex and experimental halls were depth, ease of excavation, and support requirements. In general, a site was found more suitable if it was characterized by shallow depth of cover at the experimental halls and conditions that would allow simple excavation and support procedures.

Construction risk, another of the geology subcriteria, was also examined. Here sites were judged positively if the geology was relatively simple or well understood and if the proposed method of excavation was shown to be compatible with the possible ground and water conditions that could be encountered. Sites were found to be risky or uncertain if they showed lack of geological information or unknown conditions; fault zones, shear zones, or hydrothermal alteration; mixed-face conditions; flowing ground (e.g., water-saturated sands); complex or highly variable geology making it difficult to predict conditions and requiring possible sudden changes in tunneling or excavation methods or water handling; existence of possible large volumes or sudden inflows of groundwater; cavities from rock solution or lava tubes; gas (methane or hydrogen sulfide) with potential for explosion or toxic effects requiring special lining of tunnel and enhanced ventilation systems; buried valleys; and stresses that could cause rock burst or squeezing ground.

REGIONAL RESOURCES

The various components of what are called in the ISP "regional resources" are less amenable to detailed technical analysis than are geological conditions. The committee was faced with the question of identifying which regional resources are most important to the efficient and effective construction, start-up, and operation of a major scientific facility and laboratory. The criteria and subcriteria listed by DOE in the ISP are, in general, comprehensive, but they provide little guidance as to which components will be most important to the eventual success of the SSC. In its deliberations, the committee found a number of components of regional resources to be of particular importance.

Because the SSC will be a very large national laboratory, its ability to attract and retain a first-class staff is of utmost importance to its scientific success. Scientists, engineers, skilled technicians, mechanical laborers, and professional administrators will number about 3000, including several hundred visiting scientists—many on sabbatical leave from U.S. or foreign universities—who may be in residence for periods of weeks to years. Although it may be the case that some high-energy physicists will be drawn to the SSC wherever it is located, this is not the case for most of those who will be involved in the enterprise. What is likely to attract a staff? Community proximity is one factor; other factors include housing, educational, and employment opportunities for staff, visitors, and their families. In this regard, the committee noted the very real and growing importance of employment opportunities for spouses of permanent and visiting staff members. A variety of cultural and recreational options, as well as an openness to various lifestyles, is highly desirable if the laboratory and the surrounding communities are to provide an hospitable environment for the diverse (and international) group of people who will be in residence. The quality of medical facilities and local schools is likely to be of great concern to the staff and visiting scientists. It should be noted that while it is not essential for cultural and educational resources (such as universities, museums, and theaters) or recreational opportunities to be immediately adjacent to the laboratory, they should be reasonably accessible. As might be expected, there was no detailed consensus among committee members about how close "close enough" is, though there was agreement on the general proposition that the closer the amenities the better.

Ease of access to the laboratory itself received considerable attention. Reasonable proximity to a well-serviced airport was seen to be quite crucial, although here again, no detailed definitions of "reasonable proximity" or "well-serviced" were developed. Access to the site by highway and railroad networks was also treated as an important factor.

Construction, start-up, and operation of the SSC will require the availability of an adequate local or regional labor pool of skilled engineers, technicians, administrators, and construction workers, the existence of heavy construction capability, and the availability of machine and electronics shops experienced in high-technology applications and vendors with sizeable stocks of small items (pumps, motors, tools, and the like).

The final subcriterion in this area, relating to local and regional cooperation, created considerable difficulty for the committee's deliberations on certain proposals. The material germane to this issue provided in individual proposals varied greatly in quality and completeness, although in almost all cases the proposals indicated that there would be active and effective administrative and institutional support. The result was that the committee was unable to use this subcriterion to discriminate effectively among the proposals. During the course of the committee's work, there have been numerous newspaper accounts of local opposition and support at a number of sites. In addition, members of the committee and staff received numerous letters, signed petitions, and other supplementary materials from individuals and organized groups, most of them attacking particular proposals. Because the committee was charged with reviewing the proposals themselves, because it had no reliable way to gauge the validity or representativeness of the letters or press reports, and because it was unable to evaluate the information received in these letters and reports, the committee agreed not to use this information in its deliberations. The committee strongly believes, however, that community acceptability, support, and cooperation will be important factors that must be considered carefully by DOE as it examines the best-qualified sites in the next stage of the site selection process.

ENVIRONMENT

Environmental impacts of construction and operation of the SSC were carefully considered. For purposes of analysis, each proposal was examined to determine effects on earth resources, water resources, air resources, ecological resources, health and safety, land use, socioeconomics, scenic and visual resources, and cultural and historical resources. Compliance with federal, state, and local laws and regulations and possible mitigative measures also received attention.

In its review, the committee found that no site proposal presented environmental problems that could not be prevented or minimized. However, some site proposals suggested environmental strengths or weaknesses that distinguished them from other proposals. A partial list of weaknesses found in some proposals will suffice to describe the kinds of environmental factors that were considered to be of importance by committee members (for the most part, environmental strengths were taken to be the converse of the weakness): critical environments and habitats likely to be disturbed or placed at risk; federally or state designated endangered, threatened, or special interest species significantly disturbed; managed fish or wildlife resources likely to be affected; impacts on surface water resources; impacts on groundwater resources; loss of prime agricultural land; impacts on federal or state recreational, wildlife refuge, fish and game management area, or wilderness area; impacts on historical or archaeological resources; impacts on local topography, stream courses, or scenic resources; impediments to access to gas, oil, coal, or mineral resources; impacts on air quality that could affect ability to attain air quality standards; noise or vibration likely to disturb sensitive human activity or animal populations; possible risks to health or safety from construction or operation of the SSC; and inadequate information about proposed mitigation actions.

OTHER TECHNICAL CRITERIA

The committee considered the other criteria listed in the *Invitation for Site Proposals*: setting (and principally the strengths and deficiencies of the various plans for timely acquisition of the required land), regional conditions, and utilities.

Among the regional conditions examined by the committee, noise, vibration, climate, weather conditions, and site-specific land use and activities that might affect construction and operation of the SSC received particular attention. There were some significant differences among the sites—such as major railroads crossing the proposed collider ring in a few cases, the presence of quarries and other noise and vibration sources at some sites, and severe climate conditions that might affect construction or operation in some locations—no site was characterized by such negative regional conditions that it could be eliminated on this basis alone. Thus, for example, at those few sites that had potential noise and vibration problems, it was felt that effective remedial actions were possible.

The last of the technical evaluation criteria—utilities—provided little discrimination among the sites; all but one of the proposals demonstrated the ability to provide reliable and stable electric power, water, and fuel, and to handle the wastes generated in the construction and operation of the SSC.

COST

As noted earlier, costs were to be considered in the evaluation of site proposals, although the precise mechanism for their inclusion in the evaluation was not specified in the *Invitation for Site Proposals*.

Working with a contractor, DOE devoted extensive effort to the calculation of the absolute and relative costs of construction and operation of the SSC at each of the various sites proposed. DOE provided the results of the calculations to the committee during the course of its deliberations. The basic calculations were carried out using procedures that committee members felt were reasonably consistent with currently accepted economic practice. The calculations themselves were painstaking and extensive, but they were unavoidably based, in part, on estimates of future outlays about which there was considerable uncertainty. Social benefits and costs, such as contributions to local employment and environmental damage problems, were considered separately and, because of a paucity of definitive data, more or less informally.

Cost calculations did play a role in the final evaluation process, but that role was more minor than might have been anticipated. The reason was not lack of concern by members of the committee over the costs. The reason was, rather, the remarkably narrow range within which cost estimates for the different sites fell. The cost of the most expensive sites was only a few percent above the average for the group, and that of the most economical site was only a few percent below the average. Since the range of uncertainty was no doubt at least comparable in magnitude, this obviously weakened considerably the committee's ability to distinguish among the site proposals in terms of the costs each could be expected to entail.

The narrowness of the range of calculated cost results in part from imperfect ability to foresee future costs, particularly as they would be affected by unforeseeable contingencies. But the uncertainty is clearly an unavoidable attribute of the nature of the task.

5
The Best Qualified List

In agreeing on a best qualified list, the committee took as its goal precisely that articulated by DOE in the *Invitation for Site Proposals*: ". . . to select [sites] that will permit the highest level of research productivity and overall effectiveness of the SSC facility at a reasonable cost of construction and operation and with minimal adverse impact on the environment." The committee is confident that the list that follows meets that goal in the sense that a productive and effective SSC could be built and operated at any of the sites on the list.

In alphabetical order, the sites on the best qualified list are:

ARIZONA/MARICOPA

The Maricopa site is located about 35 miles southwest of Phoenix in an area of desert plains bisected by a mountain range.

The SSC would be located in an area whose geology is quite favorable for construction using a combination of cut-and-fill and tunneling methods. Much of the planned ring would be in fanglomerate (a lightly cemented sedimentary rock resulting from coalescing alluvial fans), which allows rapid advance rates by either method. The remainder of the tunnel would pass through a mixture of fanglomerate, granitic rocks, and interbedded volcanic and sedimentary rocks; here, too, tunneling is easily accomplished. Water problems are unlikely since the ring would pass through unsaturated materials and lie above the water table.

Although the geology is generally quite good, there are a few comparative weaknesses of the site in this regard, most notably the need for considerable mixed-face tunneling, the interception of possible faults and shear zones (particularly in the granitic segments), and the uncertainty arising from the limited availability of information on the moderately complex mountainous terrain. Some deep shafts would be required in parts of the ring that would pass through the mountainous area.

The regional resources necessary for the construction and operation of the SSC are present at or near the site. The area has a strong technical and labor base whose effects can already be seen in the growing electronic and semiconductor industry and scientific laboratories in the region. Convenient access and housing, and employment and educational opportunities are all available, although some upgrading of roads and highways in the immediate vicinity of the proposed site would be needed.

The SSC would be unlikely to cause major environmental impacts at the site; indeed, the proposal demonstrates the possibility that the project could actually enhance a somewhat degraded environment by salvaging and replanting desert vegetation. The Arizona proposal was particularly strong in its response to the environmental criterion of the ISP.

A relatively small number of property owners would be affected by the land acquisition plan. Much of the land required for the site is federal land under the administration of the Bureau of Land Management of the Department of Interior.

A main and busy branch of the Southern Pacific Railroad would cross directly over the SSC ring; the proposal states that vibration problems from the railroad, if they exist, could be mitigated. Otherwise, no serious deleterious regional conditions were noted by the committee.

According to the life cycle cost estimates provided by DOE, construction and operating costs for a super collider located at the Maricopa site would be slightly higher than the mean costs for all proposed sites, although the difference from the mean is smaller than the likely accuracy of the estimates themselves.

COLORADO

The Colorado site is in an area of slightly hilly topography in a region of grasslands some 60 to 70 miles northeast of Denver.

The SSC would be located in an area whose geology is very simple and predictable (100 percent Pierre shale) and would enable rapid construction—advance rates consistent with estimates in the proposal—using routine tunnel boring machines. The shafts and other experimental facilities would be surface excavated, and they are moderately shallow, the average depth to the ring being about 100 feet. Groundwater problems would be minimal in this impermeable rock.

Although the geology is highly favorable, there are a few comparative weaknesses involving construction. The shale would need immediate sealing to prevent slaking—i.e., the breaking up of shale upon exposure to air—and some routine dewatering would be required for shafts and interaction chambers in the near-surface soils. Deep foundations would be required for surface structures, but this is a routine construction method in the area.

The proposed site would draw on the strong regional resources of the somewhat distant Denver and Boulder areas, although the distance would make easy commuting or ready access to the employment, housing, and cultural resources difficult. A comparative weakness is the current virtual absence of communities in close proximity to the proposed facility. The location of the newly planned airport and the outward growth of Denver are likely to help this situation. The transportation systems are good, and Colorado proposes to improve access by constructing a new highway to the site.

Major environmental impacts from construction are unlikely, as the tunnel would be bored with modest habitat disturbance. For the surface excavations and structures, any impacts resulting from the construction could be readily minimized.

Relatively few property owners would be affected by the land acquisition plan, and few relocations would be necessary; the appropriate legislation is in place. Although regional conditions at the site are good in general, some attention must be paid to possible vibration due to nearby oil well pumping.

According to the life cycle cost estimates provided by DOE, construction and operating costs for a super collider located at the Colorado site would be slightly less than the mean costs for all proposed sites, although the difference from the mean is smaller than the likely accuracy of the estimates themselves.

ILLINOIS

The Illinois site is located about 40 miles west of Chicago, directly west of the Fermi National Accelerator Laboratory in Batavia.

The SSC would be located in a flat to gently rolling area, and the tunnel would be excavated in uniform dolomite. There is extensive tunneling experience in the area, and the rock can easily be excavated by machine with excellent advance rates and minimal required support. The experimental halls would be mined excavations with minimal roof supports of rock bolts and reinforced shotcrete.

A weakness of this site would be the depth of excavation (generally between 270 and 430 feet) and routine groundwater control required for shafts.

The Chicago area is a major urban center offering a wide array of excellent regional resources, including universities and diverse cultural and recreational activities. An extensive transportation infrastructure, including highway, air, rail, and water, is in place. Also in plentiful supply are machine tool and fabrication companies, as well as a skilled labor force experienced in high-technology applications. Ample housing is available in the numerous neighboring communities.

An additional strength of the site is an existing infrastructure built upon on almost two decades of experience in operating an outstanding high-energy physics research laboratory.

Tunneling would be done by boring machine, thus reducing effects on the surface. The site has no developed oil, gas, or coal deposits; impacts on surface and ground waters would probably be modest; no highly sensitive animal or human population is likely to be affected by SSC operational noise; and no federally endangered or threatened species or Illinois species of interest is at risk.

Weaknesses include air quality attainment problems in the Chicago area with respect to ozone; loss of some prime farmland and wetland habitat; and a risk of increased siltation of streams during construction. These negative impacts can probably be satisfactorily minimized by such steps as lease back and creation of new wetlands.

A rather large, complex acquisition and relocation program would be involved in conveying the land, but the state has already enacted the Superconducting Super Collider Act of Illinois, granting quick-take land acquisition authority.

The presence of quarries and gravel pits at the site requires some study but does not appear to present a fundamental difficulty. Climate conditions are not as favorable as at some other sites.

According to the life cycle cost estimates provided by DOE, construction and operating costs for a super collider located at the Illinois site would be slightly higher than the mean costs for all proposed sites; if credit is allowed for the use of components of the existing Tevatron, however, the site becomes one of the less costly.*

MICHIGAN/STOCKBRIDGE

The Stockbridge site is located in a relatively flat, predominantly rural farming and recreational area in the south central portion of Michigan, approximately 35 miles from Ann Arbor and equidistant from East Lansing.

The geology of the proposed site is on the whole favorable for construction of a tunnel driven through shales, limestone, dolomites, and sandstone. A tunnel through such formations is likely to include long unlined sections and relatively high advance rates. There are, however, a few comparative weaknesses, including the need for significant groundwater control in certain tunnel sections. Groundwater is found near the surface, and dewatering of shafts as well as slurry walls for experimental halls would be necessary. In addition, there is a risk of encountering a buried valley during tunneling.

Regional resources essential for construction and operation of the SSC are present at or near the site. The area is close to two major research universities, and it offers diversified housing, recreational

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*In the course of its evaluation of the Illinois proposal, the committee was given the report of a DOE-sponsored study on the technical feasibility and estimated costs that would be involved in using the Fermilab Tevatron complex as an injector for the SSC. (*Analysis of the Fermilab Tevatron as an Injector for the SSC*, RTK, October 1987.) The report concludes that, with certain modifications and improvements, it is reasonable to expect that the existing Fermilab accelerators could meet SSC design requirements. Cost estimates for the alterations are given, although they show a wide range because of uncertainty about whether or not the existing main ring would have to be replaced to meet SSC performance specifications. (Further measurements at Fermilab would be necessary to determine the need for replacement of the main ring.) Although the committee did not question the report's conclusions, it did note that the report does not discuss whether the Tevatron would meet reliability criteria for the SSC. Given the importance of the reliability of the injector to the SSC and the age of the Tevatron magnets and components, some members of the committee felt that some or all of the aging components might have to be replaced. If this were necessary, there would, of course, be cost implications that are not discussed in the report.

and employment opportunities, and reasonable access to the Detroit International Airport. It has an excellent industrial base including large numbers of machine shops and a major concentration of advanced technology manufacturers.

An SSC would be likely to cause relatively limited environmental effects at the site. There are no threatened or endangered species or habitats at risk in the area, and there would be little likelihood of significant impacts on scenic aspects of the area because tunneling detritus would be disposed of in nearby gravel pits. An SSC is unlikely to add significantly to environmental air pollution in this nonattainment area for ozone, but several historical and archaeological sites may require attention. Some abundant stream courses will need protection during construction in order to preserve wetland habitats.

Michigan has proposed a complex, time-sensitive plan for acquisition of the site. There are some 700 landowners whose parcels must be purchased and 221 homes and residences whose occupants must be relocated under reasonable state acquisition laws and procedures.

The proposal states that a number of roads and railroads would cross directly over the SSC ring; it is expected that vibration problems either would not be severe or could be minimized. Winters in the area are somewhat cold and snowy.

According to the life cycle cost estimates provided by DOE, construction and operating costs for a super collider located at the Stockbridge site would be very close to the average for all proposed sites.

NEW YORK/ROCHESTER

New York proposes a site for the SSC in a moderately hilly location between the cities of Rochester and Syracuse on the shore of Lake Ontario in the central portion of the state. The site is currently about two-fifths in forest and brush and three-fifths in agriculture. The major SSC facilities would be located about 18 miles east of Rochester.

The site's geology, which is favorable for construction of a tunnel at medium depth, is marked by surficial glacial drumlins (oval hills caused by glacial drift) underlain by interbedded sedimentary rocks. Its specific strengths include good tunneling conditions in sedimentary rocks with well-understood and predictable geology leading to rapid advance rates and minimal required support. Cut-and-fill construction techniques could be used for the near cluster experimental halls and underground excavations for the far cluster. Comparative site weaknesses are the presence of hydrogen sulfide and methane gas requiring continual ventilation or other controls, corrosive sulfate water requiring special concrete tunnel lining, local artesian groundwater conditions, and high in-situ stresses that might cause localized spalling in the shaly materials.

Regional resources necessary for construction and operation of the SSC are present at or near the site. The area allows access to several colleges and research universities, with a good range of living, educational, employment, and recreational opportunities. A particular strength of the area is its advanced technology industrial production and research base. The site is less readily accessible than several others.

Construction and operation of the SSC are likely to have relatively limited environmental effects in the region. No rare habitats are threatened, and no long-term impacts would be expected on surface and ground waters. In addition, the area's air quality attainment is likely to remain within federal standards, and tunneling and construction spoils could be disposed of in local quarries. Construction would be expected to remove prime farmland from production, although the amount could be reduced by lease back, and the loss of some wetlands would require examination. Several historical and archaeological sites might need special consideration.

A number of roads and railroads would cross directly over the SSC ring; the proposal anticipates that vibration problems at the interaction points either would not be severe or could be mitigated. Winters in the area are cold and very snowy, and they could affect a construction schedule for surface facilities.

According to the life cycle cost estimates provided by DOE, construction and operating costs for a super collider located at the Rochester site would be slightly lower than the mean costs for all proposed sites, although the difference from the mean is smaller than the likely accuracy of the estimates themselves.

The Rochester site was one of those about which committee members and staff received a large number of letters and supplementary materials from residents of the area. Almost all the letters opposed the site. As noted earlier, the committee was unable to use the letters in its evaluation of the site; but it feels strongly that DOE must, in the next stage of the site selection process, look closely at the extent to which the vocal opposition represents a true absence of local support.

NORTH CAROLINA

North Carolina proposes a site near its northern border with Virginia. Located in rolling terrain in a rural, mostly forested area near the cities of Durham and Raleigh, the site's campus would be about 20 miles from Research Triangle Park.

The tunnel would be bored in interlayered metamorphosed volcanic and sedimentary rocks. The average depth below the surface would be about 175 feet, and the site's experimental halls would be in excavated caverns. The geological advantages of the site include favorable tunneling characteristics that promise rapid excavation and little need for supports. Site weaknesses include a major shear zone, localized areas of potential instabilities, and probable modest water inflow in some areas.

The North Carolina site is generally quite strong in local attributes that would attract and support the scientific and technical staff of the SSC. The immediate proximity of several major research universities, the presence of urban amenities including those of Research Triangle Park, and employment prospects for family members of staff are notable. Accessibility to transportation is adequate but less strong than for some other sites, although Raleigh-Durham Airport serves as a hub for a major air carrier and is currently undergoing significant expansion.

The site is generally favorable on environmental grounds, with no major risk to identified species or critical habitats and very little long-term impact on wetlands or water quality, but the discussion of this last matter in the proposal was not very extensive. The environmental disadvantages that exist are generally associated with effects of urbanization on an area that is now largely forested. However, some prime farmland would be lost, and about 100 relocations would be required, including several facilities of the North Carolina National Guard.

Regional conditions for this site are quite good, with only seasonal rains creating slight problems for year-round construction.

According to the life cycle cost estimates provided by DOE, construction and operating costs for a super collider located at the

North Carolina site would be slightly below the average for all proposed sites, although the difference from the mean is smaller than the likely accuracy of the cost estimates.

TENNESSEE

Tennessee proposes a site in the central part of the state, near the city of Murfreesboro and about 30 miles southeast of Nashville. The area is one of generally rolling to hilly terrain, and the site mainly occupies undeveloped rural lands.

Geological conditions are generally favorable. The collider tunnel would be bored through a bed of homogeneous Ordovician limestone at an average depth of about 400 feet below the surface. The tunnel would be placed below the zone in which groundwater would present an impediment. Strengths of the site include favorable prospects for rapid machine excavation with minimal support and lining. The experimental halls would be mined excavations requiring minimal roof supports. Comparative drawbacks include the tunnel depth and karst solution features in the upper 200 feet, which would require groundwater control during shaft construction.

The site is near the requisite regional resources, as is reflected in recent decisions by General Motors and Nissan Motor Company to locate new plants in the area. The site is easily accessible through the Nashville Metropolitan Airport, which serves as a hub for a major air carrier and is currently undergoing significant expansion. There are other important local resources, including the nearby city of Nashville and Vanderbilt University.

The depth of the facility would minimize environmental impacts. There would be neither significant loss of prime farmland, nor significant risk to wetlands, surface waters, or groundwater, and the placement of the project's surface features is such that it would avoid impacts on the cedar glade and limestone cave habitats present in the area. However, the presence of several threatened and endangered species and the presence of historic structures would require special attention.

Regional conditions at the site are good, with the only drawback of note being seasonal rains that could slightly affect the construction schedule.

According to the DOE estimates, the Tennessee site ranks among the lowest in construction costs and labor rates. Its overall life cycle costs are estimated at slightly below the mean for all sites.

TEXAS/DALLAS-FORT WORTH

The Dallas-Fort Worth site is in an area of gently rolling prairie about 30 miles south of Dallas.

The SSC would be located in an area whose geology is excellent for construction. The planned ring would be in chalk and marl, which allow for very high advance rates using tunnel boring machines (based on tunneling experience elsewhere in the same formations) and are at the same time of high strength, permitting a minimum of support and lining. The shafts and other experimental facilities would be surface-excavated and of moderate depth. A few of the experimental halls would range from 165 to 220 feet below the surface; the strength of the rocks would permit stable, unsupported, near-vertical cuts.

Although the geology is quite favorable for SSC construction, there are a few comparative weaknesses. Several of the experimental halls that bottom in shale have a potential bottom heave; there are plans to relocate these halls to avoid the shale. Within the marl there are local slickensided blocky ground and slaking (breaking up of the marl upon exposure to air); the marl in surface excavations would need to be sealed fairly soon after exposure. Excavations in weathered marl would need to be supported.

The regional resources and technological base of the region offer most of the advantages of a major urban center. The Dallas-Fort Worth airport is one of the nation's leading air hubs and a major international point of entry. In addition, the transportation network of highways and railroads is excellent. There is a diversity of attractive housing in the region, and cultural, recreational, educational, and employment opportunities are plentiful. The SSC is unlikely to have major environmental impacts on the site because the tunnel would be bored with modest habitat disruption. One of the comparative weaknesses is that a substantial acreage of prime farmland would be lost, but lease-back opportunities might diminish much of this.

There are a moderate number of property owners (420), and a number of residences and businesses would be affected (224) by site acquisition. Slightly less than one-half of the land would be in stratified fee. The acquisition plan is well conceived and could easily be executed.

Regional conditions at the site appear quite good, with only a few possible vibration sources requiring some attention.

According to the life cycle cost estimates provided by DOE, construction and operating costs for a super collider located at the Dallas-Fort Worth site would be slightly less than the mean costs for all proposed sites, but the difference from the mean is smaller than the likely accuracy of the estimates themselves.

SITES NOT ON THE BEST QUALIFIED LIST

As noted earlier, the committee used a procedure for examination of the proposals that it developed before receipt of any proposals from DOE. The procedure involved careful examination of each proposal by working groups that paid particular attention to criteria in their areas of expertise. The working groups reported to the full committee on the results of their examinations, including an initial evaluation of each proposal using the categories good, satisfactory, and questionable. The reports formed part of the basis for the committee's discussions and final deliberations. Those deliberations involved the review and synthesis of a vast amount of information by a group with broad and varied experience, perspectives, and expertise. The very nature of this process does not permit determination of the extent to which any specific factor or combination of factors influenced how individual judgments were formed or a group consensus achieved. Nonetheless, some general comments are possible and warranted.

Among the remaining sites, a number displayed unfavorable geological conditions. Some sites were likely to be subject to excessive water inflow during tunneling; others could be expected to demonstrate uneven subsidence from subsurface fluid withdrawal. A small number were characterized by seismicity or zones of volcanic activity that could present problems in the operation of the SSC. Finally, some sites demonstrated complex or uncertain geological characteristics that suggested possible substantial delays in construction.

Other proposed sites, including some with quite favorable geological characteristics, were less successful in meeting the regional resources criteria than were those included on the best qualified list. Several lacked existing communities near the site; others were not particularly accessible because of their distance from a major, well-serviced airport. In some cases, there was no evidence of a strong infrastructure of machine and electronics shops, vendors, or labor force experience in high-technology endeavors. A few sites were quite distant from universities and medical centers; others did not offer opportunities for professional employment of spouses of SSC staff.

No site presented insurmountable environmental problems, or unsolvable problems of site acquisition or regional conditions, although, as might be expected, some sites would have posed more serious difficulties than others.

It should be noted, again, that the committee chose not to adopt any arbitrary set of scores or weights to reach its decision about the inclusion or exclusion of any particular site on the best qualified list. The list, then, is the outcome of committee judgment about which sites most effectively demonstrated in their proposals that they met or could meet the set of criteria established by DOE at the start of the site selection process.

Appendix A: Statement of Work for the Committee

The National Academies of Sciences and Engineering (Academies) shall assist the Department of Energy (DOE) in the Superconducting Super Collider (SSC) site evaluation process by evaluating the suitability of proposed sites for the SSC facility. Time is of the essence. The Presidents of the Academies will jointly appoint a Site Evaluation Committee (Committee) reporting directly to the Academies' Governing Board of the National Research Council. The Committee shall consist of about 15 distinguished scientists, engineers, and other individuals and will be appointed giving due consideration to potential real or apparent conflicts of interest and geographical distribution.

The Academies shall:

1. Consult with DOE officials as those officials determine the evaluation criteria, subcriteria, and considerations to be announced in the DOE Invitation for Site Proposals as well as broad indications of the relative importance of those criteria, subcriteria, and considerations. (In the absence of Committee members, Academies' officials shall carry out the consultation.) The Committee shall establish (prior to receipt of proposals) techniques, processes, and special analyses to be employed in evaluating proposals using the DOE-announced criteria and subcriteria and their relative importance. The Committee's evaluation, to be developed in the light of past

experience with large science research laboratories, will stress those items within the DOE-announced criteria and subcriteria and their relative importance, that are likely to be most critical in determining scientific productivity of the SSC laboratory.

2. Restrict its attention to those sites referred to it by DOE for consideration and evaluation.

3. Perform, or cause to be performed, special analyses, as deemed appropriate, of required site characteristics.

4. Develop a process that will assure expeditious evaluations resulting in the identification of a small number of best qualified sites from among those considered, i.e., a Best Qualified List (BQL).

5. Obtain clarifications, if determined to be appropriate, from any site proposer. Proposers may not modify their proposals during, or as a result of, any such clarifications. Further, designated DOE personnel will be invited to be present during the Committee's meetings with proposers.

6. Prepare a final report to the DOE Director of Energy Research no later than three (3) months after the DOE formally provides the Academies with the proposals to be evaluated. The report shall describe the evaluation process; the rationale employed, including emphasis, in the development of the BQL; and assessments of those sites included in the BQL. The BQL shall not be prioritized.

7. Until release of the Academies' final report after the DOE announces the preferred site, maintain the confidentiality of DOE provided sensitive material which has not been made public by the Government, as well as the Academies' proceedings and results, from all but DOE officials designated by the Director of Energy Research. If DOE has given the Academies access to proprietary information (labeled as such) owned by or in the possession of DOE, the Academies will protect such information from unauthorized disclosure to the extent permitted by law so long as the information remains proprietary. (The term "proprietary information" means trade secrets and commercial or financial information obtained from a person and privileged or confidential.)

8. At their option, release their recommended list of best qualified sites, after the list is determined and provided to DOE and release is coordinated with DOE. The report of the Academies shall include a discussion of the strengths and weaknesses of the proposals included in the recommended BQL. To insure the integrity of the DOE competitive selections process and prevent the details of proposals still under consideration from being made public during the

process, the report shall not be made public until DOE announces the preferred site.

9. Be prepared to respond to DOE regarding substantive questions about its recommendations; after release of the Academies' report to the public, the Committee shall be prepared and respond to substantive questions from others.

10. Interact closely with DOE without compromising the real or perceived independence of the Academies' evaluation effort. The Academies will routinely inform DOE in advance of all Committee meetings. DOE designated personnel will be invited to all Committee meetings, except Executive Sessions deemed necessary by the Academies. DOE shall provide information and analyses to the Committee when necessary.

Appendix B
Meetings of the Committee and Its Subgroups

June 30-July 1	Committee	National Academy of Sciences, Washington, D.C.
July 15	Regional Resources Subgroup	Telephone Conference
July 28	Costs Subgroup	New York University; 269 Mercer Street, N.Y., N.Y.
August 31	Regional Resources Subgroup	National Academy of Sciences, Washington, D.C.
September 21-22	Geology and Tunneling Subgroup	Sheraton Airport Hotel, Denver, Colorado
October 5-7	Geology and Tunneling Subgroup	Pacific Gas and Electric, San Francisco, California

October 6	Utilities Subgroup	Southern California Edison Rosemead, California
October 8	Environment Subgroup	Scripps Institution of Oceanography, La Jolla, California
October 8	Regional Resources Subgroup	Scripps Institution of Oceanography, La Jolla, California
October 8	Settings Subgroup	Scripps Institution of Oceanography, La Jolla, California
October 8-10	Committee	Scripps Institution of Oceanography, La Jolla, California
October 9	Regional Conditions Subgroup	Scripps Institution of Oceanography, La Jolla, California
November 13-14	Committee	National Academy of Sciences, Washington, D.C.

Appendix C
September 17 Letter from James F. Decker to Edward A. Frieman

Department of Energy
Washington, DC 20585

September 17, 1987

Dr. Edward Frieman
Chairman
Super Collider Site Evaluation Committee
National Academy of Sciences/National Academy of Engineering
2101 Constitution Avenue, NW
Washington, DC 20418

Dear Dr. Frieman:

The Department of Energy (DOE) has completed its review of the Superconducting Super Collider (SSC) site proposals against the qualification criteria included in the Invitation for Site Proposals for the SSC (Invitation). The Invitation required that proposals either not meeting the qualification criteria or which are so grossly or obviously deficient as to be totally unacceptable will not be evaluated.

Proposers were asked to demonstrate, certify, or both that the following criteria are met in the proposal:

1. Location entirely in the United States of America.

2. Land size and configuration to accommodate the SSC facility as specified in this Invitation, including Figure 1-2 and Table B-1.

3. Absence of cost to the Government for land acquisition.

4. Capability of providing at least 250 MW of electrical power with at least 500 gpm of industrial water or 200 MW of power with 2,200 gpm of industrial water, or an appropriate interpolated combination.

5. Absence of known unacceptable environmental impacts from siting, constructing, operating, and decommissioning the SSC. Reasonable mitigation measures may be taken into consideration.

Forty-three (43) proposals were submitted by the 2:00 p.m. deadline September 2, 1987. The DOE has determined that the thirty-six (36) proposals identified in Attachment 1 are qualified and are referred to the National Academy of Sciences/National Academy of Engineering (NAS/NAE) for evaluation. Seven (7) proposals listed in Attachment 2 are disqualified.

Celebrating the U.S. Constitution Bicentennial — 1787-1987

We recognize and sincerely appreciate the NAS/NAE's assistance in the evaluation of the SSC site proposals. Please remind your committee and staff of the sensitive nature of the evaluation process and the need to keep your deliberations confidential.

Sincerely,

James F. Decker
Acting Director
Office of Energy Research

cc:

R. Kasper, NAS/NAE
W. Spindel, NAS/NAE
SSEC Members

SUPERCONDUCTING SUPER COLLIDER SITE PROPOSALS THAT MEET THE QUALIFICATION CRITERIA

Site No.	State	Site Name	Proposer
3	New Mexico	Estancia Basin	State of New Mexico
4	South Dakota	Northern Great Plains	State of South Dakota
6	Montana	Montana Site	State of Montana
7	Nevada	Nevada Site	State of Nevada
8	New Mexico	Dona Ana County	West Texas Council of Govts. & Dona Ana County
9	Wyoming	Cheyenne	State of Wyoming
10	Texas	Far West Texas Site	West Texas Council of Govts.
11	Utah	Ripple Valley	State of Utah
12	Utah	Cedar Mountains Site	State of Utah
13	Florida	Jacksonville	State of Florida
14	Kansas	Topeka	State of Kansas
15	Tennessee	Tennessee Site	State of Tennessee
16	New York	St. Regis Valley Site	State of New York
17	Louisiana	Louisiana Site	State of Louisiana
18	Oregon	Columbia River Site	State of Oregon
19	Arizona	Maricopa	State of Arizona
20	Texas	Amarillo	State of Texas
21	Colorado	Denver Site	State of Colorado
22	Mississippi	Mississippi Site	State of Mississippi
23	Illinois	Fermilab	State of Illinois
24	Oklahoma	Oklahoma Site	State of Oklahoma
25	New York	Wallkill Valley Site	State of New York
26	Texas	Dallas/Fort Worth Site	State of Texas
27	Ohio	Ohio Site	State of Ohio
28	Arizona	Sierrita Site	State of Arizona
29	New York	Rochester Site	State of New York
30	Washington	Lincoln County Site	State of Washington
31	Oregon	University Site	State of Oregon
32	North Carolina	Raleigh/Durham	State of North Carolina
33	Michigan	Stockbridge Site	State of Michigan
34	Alaska	Denali Site	State of Alaska
35	Michigan	Dundee Site	State of Michigan
36	Texas	Garden City Site	Garden City SSC Commission
38	Idaho	Idaho National Engineering Laboratory	State of Idaho
40	California	Davis Site	State of California
41	California	Stockton Site	State of California

ATTACHMENT 1

SUPERCONDUCTING SUPER COLLIDER SITE PROPOSALS THAT DO NOT MEET ONE OR MORE QUALIFICATION CRITERIA

Site No.	State	Site Name	Proposer
1	Texas	Liberty County Site	Terrell G. Lara
2	N/A	Jablonka	Paul Jablonka
5	Washington	Mattawa	A-Enterprises
37	Utah	Delta Area Site	Larsen Institute of Technological Evolution
39	New York	International Site	State of New York
42	Texas	Dever Site 1	O.R. Amy
43	Texas	Devers Site 2	Bill Leatherwood

ATTACHMENT 2

Appendix D
October 26 Letter from Wilmot N. Hess to Edward A. Frieman

October 26, 1987
Dr. Edward A. Frieman
Chairman
Super Collider Site Evaluation
Committee
National Academy of Sciences/
National Academy of Engineering
La Jolla, CA 92093

Dear Dr. Frieman:
On September 18, 1987, we transmitted a listing of SSC site proposals which met the qualification criteria set forth in the Invitation for Site Proposals for the SSC. The purpose of this letter is to inform you that proposal #25 for the Wallkill Valley site has been withdrawn from further consideration by the State of New York. I have enclosed a copy of Governor Cuomo's letter for your information.

Please destroy the copies of the Wallkill Valley proposal that we have sent to you. A complete distribution list of these copies to the SSEC committee and staff is enclosed. We would appreciate your confirmation to us that all of the copies for the Wallkill Valley site have been destroyed.

Thanks so much for your continuing assistance in evaluating SSC site proposals.

Sincerely,

Wilmot N. Hess
Chairman
SSC Site Task Force

Appendix E
Biographical Sketches of Committee Members

EDWARD A. FRIEMAN (Chairman) is director of Scripps Institution of Oceanography and vice chancellor of marine science at the University of California, San Diego.

Dr. Frieman began his career in 1951 as an instructor at Polytechnic Institute of Brooklyn. From 1952 to 1979, he was a professor of astrophysical sciences and deputy director of the Plasma Physics Laboratory at Princeton University. He was with the U.S. Department of Energy as director of energy research from 1979 to 1981. Prior to his appointment at Scripps in 1986, he was executive vice president at the Science Applications International Corporation from 1981. Concurrently, he was an adjunct professor of physics at the University of California, San Diego. Dr. Frieman held a National Science Foundation Postdoctoral Fellowship in 1964 and a John Simon Guggenheim Fellowship in 1970. He has served on numerous government and private sector panels and boards. He is a member of the National Academy of Sciences and the American Association for the Advancement of Science and a fellow of the American Physics Society. His research interests are in plasma physics, hydromagnetics, hydrodynamics, and astrophysics. Dr. Frieman received a B.A in engineering from Columbia University (1946) and an M.A. (1948) and Ph.D. (1953) in physics from Polytechnic Institute of Brooklyn, New York.

ROBERT McCORMICK ADAMS is secretary of the Smithsonian Institution, Washington, D.C.

Dr. Adams was an educator and administrator with the University of Chicago from 1955 to 1984. He was the Howard H. Swift Distinguished Service Professor of Anthropology (1975-1984); director of the university's Oriental Institute (1962-1968 and 1981-1983); dean of the Division of Social Sciences (1970-1974 and 1979-1980); and provost of the university (1983-1984). He also held appointments to the Department of Anthropology and Near Eastern Languages and Civilizations, and the Committee on Public Policy Studies. Dr. Adams assumed the Smithsonian post in 1984. He has lectured at U.S. and foreign institutions and continues to teach, serving as a research associate with the University of Chicago's Department of Anthropology (from 1984) and as adjunct professor with the Departments of Anthropology and Near Eastern Studies at The Johns Hopkins University (from 1984). Dr. Adams is a member of numerous associations and organizations, including the National Academy of Sciences, the American Association for the Advancement of Science, the American Oriental Society, and the Middle East Institute. He is a fellow of the American Academy of Arts and Sciences, the American Anthropological Association, and the Middle East Studies Association. His research interests are in the agricultural and urban history of the Near and Middle East, geographical and archaeological study of settlement patterns, comparative economic and social history of pre-modern societies, and institutions and policies for the support of research. Dr. Adams received a Ph.B. (1947), an A.M. (1952), and a Ph.D. (1956), all from the University of Chicago.

WILLIAM J. BAUMOL is professor of economics at Princeton University, New Jersey, and New York University, New York City.

Dr. Baumol began his career at the U.S. Department of Agriculture (1942-1943, 1946). He was an assistant lecturer at the London School of Economics (1947-1949). He moved to Princeton University, where he advanced from assistant professor (1949) to professor (1954). In 1971 he also became professor at New York University, commencing a joint appointment with both institutions. He is the director of the C.V. Starr Center for Applied Economics at New York University (from 1984). Dr. Baumol is the author of numerous books and publications on economic theory and processes. He is the recipient of the Townsend Harris Medal awarded by the City University of New York; a Guggenheim fellow (1957-1958); and Ford Faculty Fellowship recipient (1965-1966). He is a member of the American

Economics Association, the American Academy of Arts and Sciences, the Atlantic Economic Society, and the American Philosophical Society and a fellow of the Econometric Society. He is a member of the National Academy of Sciences and has honorary degrees and fellowships from U.S. and foreign colleges and universities. He received a B.S.S. from the City College of New York (1942) and a Ph.D. from London University (1949).

JOHN E. CANTLON is vice president at the Michigan State University, East Lansing.

Dr. Cantlon began his career at the George Washington University advancing from assistant professor in botany to associate professor (1950-1953). From 1953 to 1954 he served as senior ecologist at the Physics Research Laboratory of Boston University. In 1954 he moved to Michigan State University and served as associate professor of botany (1954-1958), and professor (1958-1969). In 1969 he was appointed provost, a post he held until 1975, when he moved to his current position. Dr. Cantlon has served on many advisory panels and committees with the National Academy of Sciences, the National Science Foundation, the American Institute of Biological Sciences, the Department of Defense, the Oak Ridge National Laboratory, the Department of Energy, and the Environmental Protection Agency. He is a member of the American Association for the Advancement of Science, the American Institute of Science, the Ecological Society of America, the Botany Society of America, and the American Society of Naturalists. His research interests are in physiological ecology, patterns in communities, Alaskan tundra vegetation, and research and academic administration. Dr. Cantlon received a B.S. from the University of Nevada (1947) and a Ph.D. in botany from Rutgers University (1950).

LLOYD S. CLUFF is manager of the Geosciences Department, Pacific Gas and Electric Company (PG&E), San Francisco, California.

Mr. Cluff began his career with El Paso Natural Gas Company as junior geologist (1957-1959), then with the firm of Lottridge Thomas & Associates (1960). He joined Woodward-Clyde Consultants in 1960, advancing from staff geologist to associate and chief engineering geologist, vice president, principal and director. He joined PG&E in 1985. Mr. Cluff has served on numerous international and national consulting boards and advisory panels, including those of the National Academy of Sciences, the U.S. Geological Survey, National Academy of Sciences, the U.S. Geological Survey, the National Science Foundation, the International Atomic Energy Agency, the California Seismic Safety Commission and Governor's Earthquake Council, and others, advising on the siting of critical facilities from the standpoint of engineering geology and seismic safety. In 1965, he was presented the Hogentogler Award by the American Society of Testing and Materials. Mr. Cluff is a member of the National Academy of Engineering, Association of Engineering Geologists (president, 1968-1969), Earthquake Engineering Research Institute (director, 1976-1980), International Association of Engineering Geologists, Seismological Society of America (president, 1982-1983), Structural Engineers Association of Northern California, and Geological Society of America. His research interests are in active faults, earthquake and geologic hazards, seismic safety, and engineering geology. Mr. Cluff received a B.S. in geology from the University of Utah (1960).

ERNEST D. COURANT is a senior physicist at Brookhaven National Laboratory in Upton, New York.

Dr. Courant was a graduate student at the University of Rochester from 1940 to 1943; he left to take a position as scientist at the Atomic Energy Project of the National Research Council of Canada (1943-1946). He was a research associate in physics at Cornell University (1946-1948), and joined the Brookhaven National Laboratory when the laboratory was founded in 1947. He has remained there since, rising to the rank of senior physicist in 1960. He has held concurrent university appointments at Princeton University as assistant professor (1950-1951); Yale University as Brookhaven professor of physics (1962-1967); SUNY-Stony Brook as professor of physics and engineering (1967-1985). He served as a consultant to the General Dynamics Corporation (1958-1959) and as a visiting physicist at the National Accelerator Laboratory (1968-1969). Dr. Courant is a co-originator of strong-focusing particle accelerators. He is a fellow of the American Physical Society and the AAAS, and a member of the National Academy of Sciences and the New York Academy of Sciences, from which he received the Boris Pregel Prize in 1979. He received the Fermi Prize (1986) and the R. R. Wilson Prize (American Physical Society, 1987). His research interests include particle accelerators, nonlinear dynamics, and nuclear reactions. Dr. Courant received a B.A. from Swarthmore College (1940), and an M.S. (1942) and Ph.D. (1943) in physics from the University of Rochester.

DON U. DEERE is an international consultant in engineering geology and rock mechanics from Gainesville, Florida, and an adjunct professor of civil engineering at the University of Florida.

Dr. Deere began his career in mining engineering, first with Phelps Dodge Corporation in Arizona (1943-1944) and then with Potash Company of America in New Mexico (1944-1946). He became assistant professor and then associate professor of civil engineering at the University of Puerto Rico (1946-1950) and became head of the Department of Civil Engineering (1950-1951). He was co-founder and partner of the Foundation Engineering Company of Puerto Rico (1951-1955). He returned to teaching at the University of Illinois at Champaign-Urbana, where he had a joint appointment in the departments of civil engineering and of geology, and where he advanced from associate professor to professor (1955-1972). In 1972 he moved to Gainesville, Florida, and became a full-time consultant on dams, tunnels, and landslides, mostly overseas. He also is an adjunct professor in civil engineering at the University of Florida. Dr. Deere is a member of the National Academy of Engineering, National Academy of Sciences, República Argentina *Academia Nacional Ciencias Exactas, Fisicas, y Naturales (Académico Correspondiente)*, American Society of Civil Engineers, Geological Society of America, and Association of Engineering Geologists. He received the MOLES Award in 1983 for Outstanding Achievement in Construction. Dr. Deere received a B.S. in mining engineering from Iowa State College (1943), an M.S. in geology from the University of Colorado (1949), and a Ph.D. in civil engineering from the University of Illinois (1955).

THOMAS E. EVERHART is president of California Institute of Technology, Pasadena.

Dr. Everhart began his career at the Research and Development Laboratories at Hughes Aircraft Company (1953-1955). He was a member of the Department of Electrical Engineering and Computer Science at the University of California, Berkeley, from 1958 to 1978. He was department chairman from 1972 to 1977. Dr. Everhart was dean of the College of Engineering and professor of electrical engineering at Cornell University (1979-1984), and chancellor and professor of electrical and computer engineering at the University of Illinois at Urbana-Champaign (1985-1987). He has served on numerous advisory boards and as a consultant. Dr. Everhart was a Marshall Scholar at Cambridge University (1955-1958); held a National Science Foundation Senior Post-doctoral Fellowship (1966-1967); was a Miller Research Professor at the University of California, Berkeley

(1969-1970); and held a John Simon Guggenheim Fellowship (1974-1975). He is a member of the National Academy of Engineering, Institute of Electrical and Electronic Engineers, and American Association for the Advancement of Science. Dr. Everhart received an A.B. in physics from Harvard (1953), an M.Sc. in applied physics from the University of California, Los Angeles (1955), and a Ph.D. in engineering from Cambridge University, England (1958).

MARVIN L. GOLDBERGER is director, Institute for Advanced Study, Princeton, New Jersey.

Dr. Goldberger began his career as a physicist at the Radiation Laboratory at the University of California (1948-1949). He was a research associate in physics at Massachusetts Institute of Technology (1949-1950), and at the University of Chicago he advanced from assistant professor to professor of physics (1950-1957). He moved to Princeton University, where he was appointed the Higgins Professor of Mathematical Physics (1957-1977); chairman of the Physics Department (1970-1976); and the Joseph Henry Professor of Physics (1977-1978). He was president of the California Institute of Technology from 1978 to 1987. Concurrently, he served as the Higgins Visiting Associate Professor (1953-1954); member, President's Science Advisory Committee (1965-1969); and member, Council on Foreign Relations. In 1961 he was awarded the Dannie Heineman Prize. Dr. Goldberger is a member of the National Academy of Sciences, American Physical Society, American Academy of Arts and Sciences, American Philosophical Society, and Federation of American Scientists. He is a director of General Motors. His research interest is in theoretical high-energy physics. Dr. Goldberger received a B.S. from the Carnegie Institute of Technology (1943) and a Ph.D. in physics from the University of Chicago (1948).

WILLIAM R. GOULD is the chairman emeritus of Southern California Edison Company in Rosemead.

After seven years of service as an engineer officer in the U.S. Navy, Mr. Gould continued his engineering career in the electric utility industry. In 1948 he joined the Southern California Edison Company as a mechanical engineer and advanced through the ranks until becoming president of the company in 1978. In 1980 he was elected chairman of the board and chief executive officer, from which position he is now retired. He served the industry in many committee and association assignments, including several years as chairman and CEO of The Electric Power Research Institute and chairman and

CEO of the Atomic Industrial Forum. He has served as a fellow and chairman, Institute of Advanced Engineering; member and president (U.S.), International Conference on Large High Voltage Electrical Systems; member, U.S. Energy Research and Development Administration general advisory committee. He is the recipient of the Power-Life Award of the Institute of Electrical and Electronics Engineers (1978), the George Westinghouse Gold Medal of the American Society of Mechanical Engineers (1979), and the Oliver Townsend Medal of the Atomic Industrial Forum (1985). He is a member of the National Academy of Engineering and a fellow of the American Society of Mechanical Engineers. His research interests include mechanical engineering, electrical engineering, nuclear engineering, and electric power generation, transmission, and distribution. Mr. Gould received a B.S. from the University of Utah (1942) and was awarded a Naval Architecture Diploma from MIT in the U.S. Navy postgraduate program.

LTG ELVIN R. HEIBERG, III, is chief of engineers, U.S. Army Corps of Engineers, Washington, D.C.

General "Vald" Heiberg was commissioned a 2nd lieutenant in the U.S. Army in 1953 and advanced to lieutenant general in 1984. He served with the Corps of Engineers in New Orleans (1974-1975) and in Cincinnati (Ohio River Division (1975-1978)). He then was engineer, U.S. Army, Europe (1978-1979); director of civil works, Washington, D.C. (1979-1981); deputy chief of engineers (1981-1983); and program manager, Ballistic Missile Defense Program (1983-1984). He was on the faculty of the U.S. Military Academy from 1965 to 1968. Active duty assignments earlier included service in Korea, Germany, and Viet Nam. General Heiberg has been awarded the Distinguished Service Medal, Silver Star, and a number of other U.S. and foreign decorations. He is a member of the American Society of Civil Engineers and national president of the Society of American Military Engineers. LTG Heiberg received a B.S. from the U.S. Military Academy (1953), an M.S. in civil engineering from Massachusetts Institute of Technology (1958), an M.A. in government (1961), and an M.S. in administration (1971) from George Washington University. He became the 46th Chief of Engineers in 1984, a four-year assignment, after Senate confirmation of President Reagan's nomination.

EDWARD G. JEFFERSON, chairman and chief executive officer (retired); member, Board of Directors, and chairman, Finance Committee, of the Du Pont Company, Wilmington, Delaware.

Dr. Jefferson joined Du Pont in 1951 and advanced through a series of supervisory positions. In 1973 he was appointed a director, senior vice president, and member of the Executive Committee. In 1978 he was given responsibility for the direction and coordination of all research and development activities for the company. He was named president and chief operating officer in 1980, and became chairman and chief executive officer in 1981. Dr. Jefferson was awarded the Samuel Smiles Prize for Chemistry from King's College, University of London. He is a member of the National Academy of Engineering and the American Philosophical Society and a fellow of King's College. He holds a doctoral degree from King's College, University of London.

HERMAN B. LEONARD is the George F. Baker, Jr., Professor of Public Sector Financial Management, John F. Kennedy School of Government, Harvard University.

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