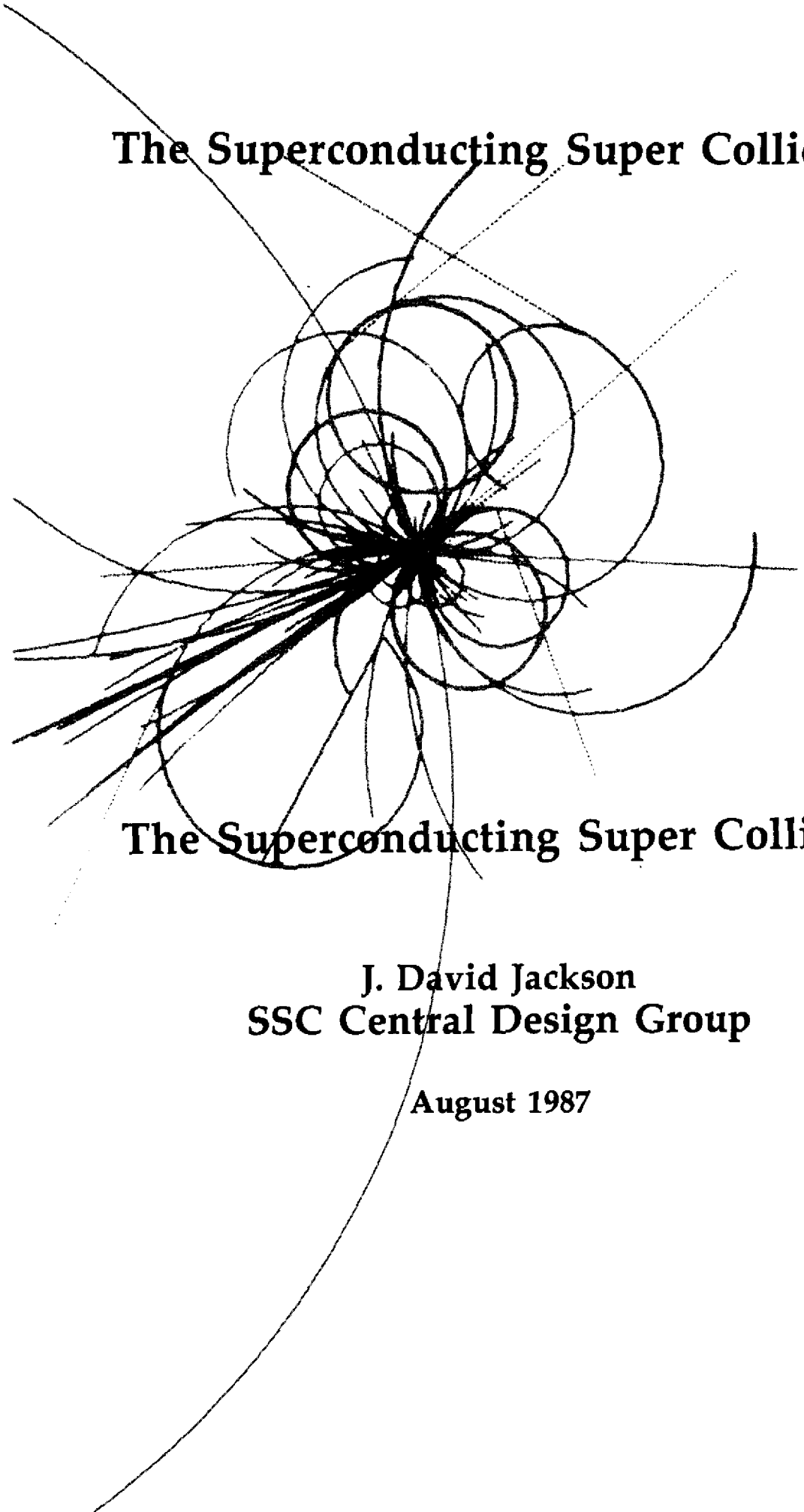
SSC-136

The Superconducting Super Collider



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J. David Jackson
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1. CHRONOLOGY AND BRIEF DESCRIPTION

The SSC can be said to have its origins in the ICFA Workshops on Future Accelerators held at CERN and Fermilab in 1978 and 1979, where a number of concepts for higher energy facilities were discussed. The actual birth of the idea can be identified with the Summer Study at Snowmass, Colorado in 1982. At that meeting it became simultaneously clear that to go beyond the Standard Model required access to sub-energies for hard collisions in excess of 1 TeV,and that the means to achieve such energies was available. A multi-TeV hadron collider was needed for the physics and could be built using the newly won superconducting accelerator magnet technology of the Tevatron.

During 1983, a number of workshops were held at LBL, Cornell, and elsewhere on accelerator questions and physics and detector issues. In that year, the High Energy Physics Advisory Panel (HEPAP) recommended unanimously to the U.S. Department of Energy (DOE) and the National Science Foundation (NSF) that research and development begin immediately with the goal of achieving multi-TeV hadron collisions at high luminosity at the earliest possible date. In response to the recommendation, the DOE reprogrammed FY 1984 funds into SSC magnet R&D.

In the first half of 1984 an ad hoc group prepared the Reference Designs Study, in which three possible designs for the SSC were developed and compared. At that same time the DOE moved to contract the SSC R&D program with the Universities Research Association (URA), a consortium of 56 American and Canadian research universities. URA established the SSC Central Design Group (CDG) and appointed Maury Tigner of Cornell as Director. Dr. Tigner accepted the hospitality of the Lawrence Berkeley Laboratory (LBL). In October 1984 the CDG officially began its work of coordination and guidance of a national R&D effort at Brookhaven National Laboratory (BNL), Fermilab, LBL, the Texas Accelerator Center (TAC), and universities.

The evolution and accomplishments of the R&D program are described in more detail in Section 2, but Table 1 lists the major milestones of the SSC program to date.

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Table 1. Major Milestones of SSC Program

Oct 1984	Central Design Group begins
Apr 1985	Preliminary Siting Parameters Document
Sep 1985	Selection of Magnet Type
Mar 1986	Conceptual Design Report (CDR)
Apr - May 1986	DOE Reviews of CDR
Jan 1987	Presidential Approval of SSC
Apr 1987	Invitation for Site Proposals (ISP) issued by DOE

The SSC is conceived as a proton-proton collider with 20 TeV protons in each beam and a luminosity of 10^{33} $cm^{-2}s^{-1}$. The magnetic bending field of 6.6 teslas is provided by magnets 16.5 meters long, with niobium-titanium superconducting coils. The layout of the SSC is shown in Fig. 1. The circumference is approximately 84 km, with major facilities located in two clusters.

The so-called near cluster (on the left in Fig. 1) is the location of two low-beta interaction regions and two straight sections that accommodate the injection and abort equipment and the rf acceleration. The cascade of accelerators comprising the injector (1 TeV injection into the main ring) is located next to the straight sections. The central laboratory campus is planned nearby.

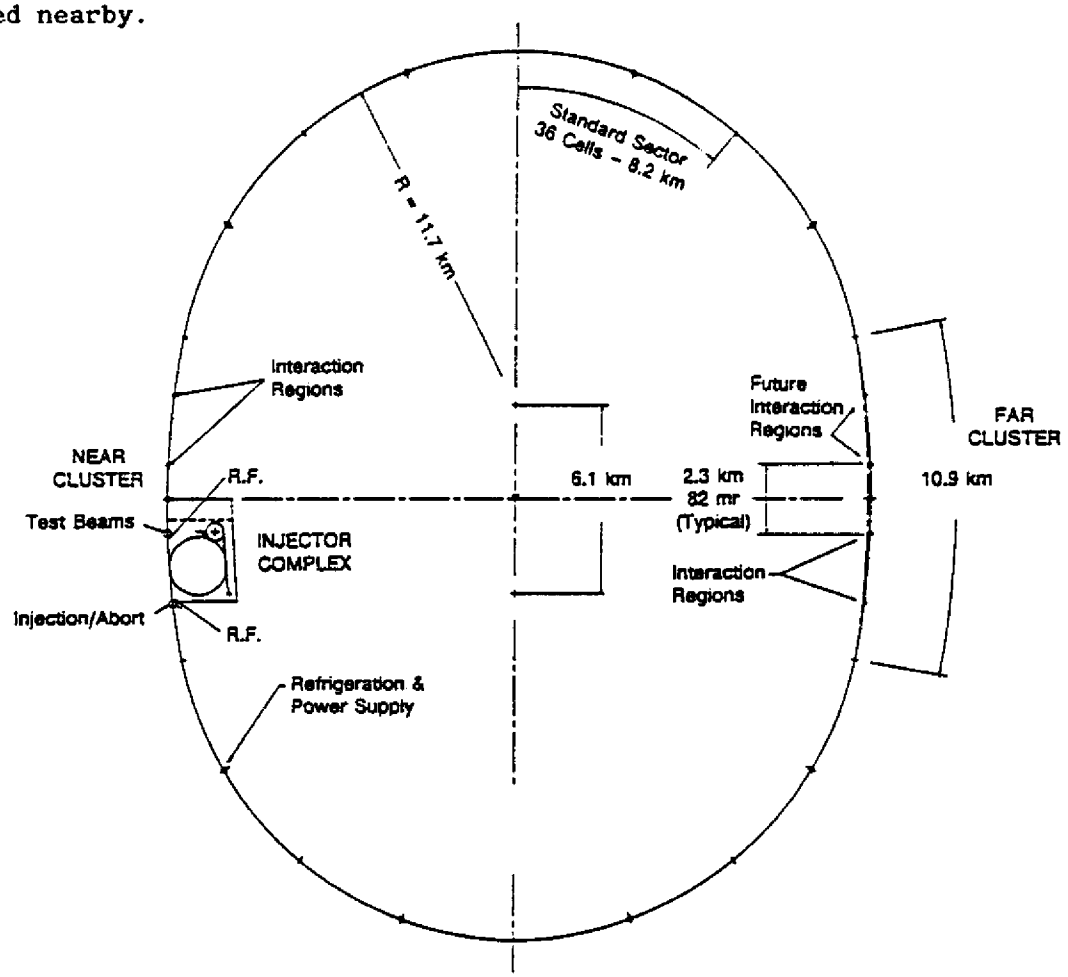

Figure 1. Schematic diagram of the SSC. The circumference is 84 km.

The far cluster (right side in Fig. 1) comprises four interaction regions spaced 2.3 km apart and with the beams at a relative angle of 83 mr from one IR to the next to reduce interference backgrounds. Only two of the four IRs will be developed initially (with medium beta). The cryogenic system is divided into 10 sectors, each of length 8.4 km. A refrigeration plant in the center of each sector (black diamonds in Fig. 1) circulates liquid helium and nitrogen 4 km in each direction in a continuous path through the magnets, out and back, and is also connected to the systems on either side so that backup can be provided in the event of a refrigerator malfunction.

Since the tunnel (3 m inside diameter) is 10 meters or more underground, around most of the circumference the only evidence of the facility will be the refrigeration/power service units every 8.4 km and much smaller ventilation and emergency personnel egress units halfway between.

The land areas specified for the SSC laboratory in the DOE's Invitation for Site Proposals are shown in Fig. 2. The annulus is 300 m wide for the most part, with wider extent in the clusters. The wings on the near cluster are needed for the below ground beam dumps, with multi-TeV muons penetrating several kilometers in the soil beyond the structure that contains the hadronic cascade.

The Conceptual Design Report (SSC-SR-2020) and its four Attachments contain a complete conceptual design and a detailed cost estimate, as of March 1986. Since then the design has changed from a phase advance of 60 degrees per cell to 90 degrees. The low-beta IRs have $\beta^* = 0.5$ m with ± 20 m free space, while the medium-beta IRs have $\beta^* = 10$ m and ± 120 m free space. Other details can be found in the CDR and SSC reports since then.

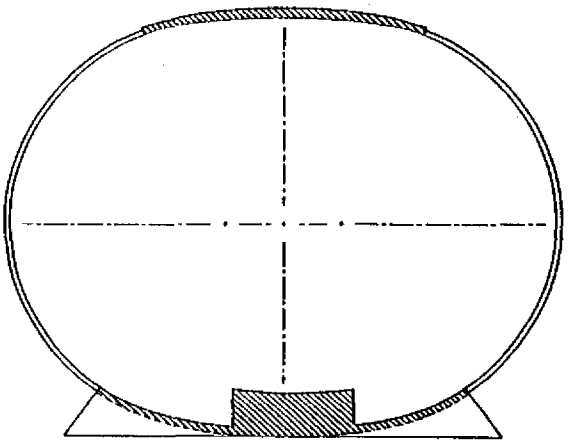

Figure 2. Schematic land area diagram from the DOE Invitation for Site Proposals. Shaded portions are reserved to the SSC laboratory. Unshaded portions may have shared use on the surface. The central area is not part of the laboratory.

2. SUMMARY OF THE R&D ACTIVITIES

The totality of research and development activities of the SSC concerns all aspects of the project - technical systems (magnets, cryogenics, power supplies, controls, injection and abort, the injector itself, beam dynamics, interaction regions, etc.) and conventional systems (tunnels, service facilities, cluster regions, interaction region halls, the central laboratory, power, water, roads, safety, etc.). The following paragraphs highlight the major R&D activities during the past four fiscal years (1 October 1983 - 30 September 1987).

FY 1984 (1 October 1983 - 30 September 1984) might be described as "getting started". The HEPAP recommendation of July 1983 was implemented by the DOE by requesting permission from the U.S. Congress in the fall of 1983 to reprogram (redirect) funds for a modest effort at the national laboratories on SSC magnet design. The basic parameters of 20 TeV per beam and a luminosity of 10^{33} $cm^{-2}s^{-1}$ were set and the directors of the national high-energy physics laboratories initiated the Reference Designs Study. During the first 4 or 5 months of 1984, a group of accelerator experts, headed by M. Tigner, studied three basic designs of a possible SSC and prepared a detailed report, the Reference Designs Study, for the DOE. The report contained preliminary cost estimates for the designs, with $3 billion dollars as the approximate cost of the accelerator and associated laboratory.

During that same time period, the DOE negotiated with URA to hold the contract for R&D to establish the feasibility and then prepare a detailed design and cost estimate for the SSC. URA formed the SSC Central Design Group and chose M. Tigner as Director.

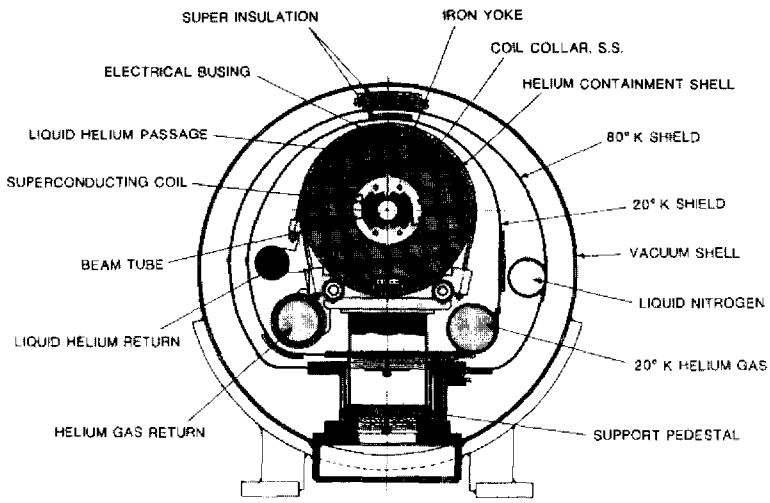

Figure 3. Cross section of SSC dipole magnet showing the cold mass, cryostat, and support post. Outer diameter is approximately 60 cm.

FY 1985, a year of R&D along parallel paths for the magnet design, began with the CDG located at LBL and different magnet concepts being pursued at BNL and LBL (jointly), Fermilab, and TAC. In addition to the basic dipole magnet work, R&D was pursued on cryogenics, quench protection, correction elements, superconductor strand and cable, accelerator physics, and conventional facilities. Both short and long model magnets were built, some high-field, conductor-dominated, others low-field, iron-dominated. Some were one dipole and beam tube in one cryostat (1-in-1) and others were two dipoles and beam tube in one cryostat (2-in-1). The aim of the magnet program during FY 1985 was to do enough R&D to narrow the options and pick one type for future development into the SSC magnet. In September 1985, the high-field, conductor-dominated, 1-in-1 type was chosen. The cross section of the SSC magnet type is shown in Fig. 3. The beam tube, two-layered coils, collars and iron yoke can be seen in the interior, above center, surrounded by the 20 K shield, then the 80 K shield, and the outer stainless steel jacket. The iron yoke is approximately 27 cm in outer diameter, while the shell of the cryostat is 61 cm in diameter. The re-entrant support post is specially designed to minimize the heat leak into the system.

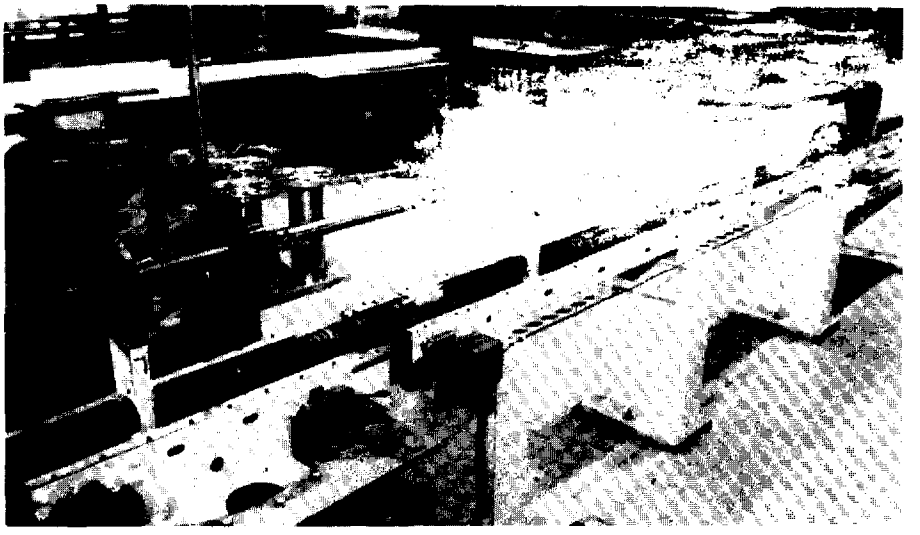

Figure 4. Coil winding machine at BNL. Cable spool can be seen at left. The long mandrel is moved past the spool to lay down the successive turns of the 16.5 m coil.

The work in FY 1986 focussed on the chosen magnet type and on preparation of a conceptual design of the whole SSC. The laboratories began specialized tasks, with BNL preparing to build full-scale "cold masses" (beam tube, collared coil assembly and iron yoke - see Fig. 4), Fermilab beginning to build cryostats (see Fig. 5) install the cold masses from BNL, and prepare a facility to test the completed assemblies (see Fig. 6). LBL continued work on short model magnets to test out design changes and on developing superconductor and winding cable for the magnet program. TAC worked on quench protection diodes and lumped correction coils. The major effort on accelerator physics was done by the CDG, which also conducted experiments at BNL on the photodesorption of gases from the beam tube by synchrotron light (a potential problem for the vacuum in the SSC). A major effort by the CDG and the laboratories was the preparation of a complete conceptual design and detailed cost estimate. This report (over 700 p.) and its four Attachments (totalling another 2000 p.) were submitted to the DOE on March 31, 1986. The report was reviewed extensively by the DOE, found credible, and formed the basis for further DOE deliberations and the decision to proceed within the Administration.

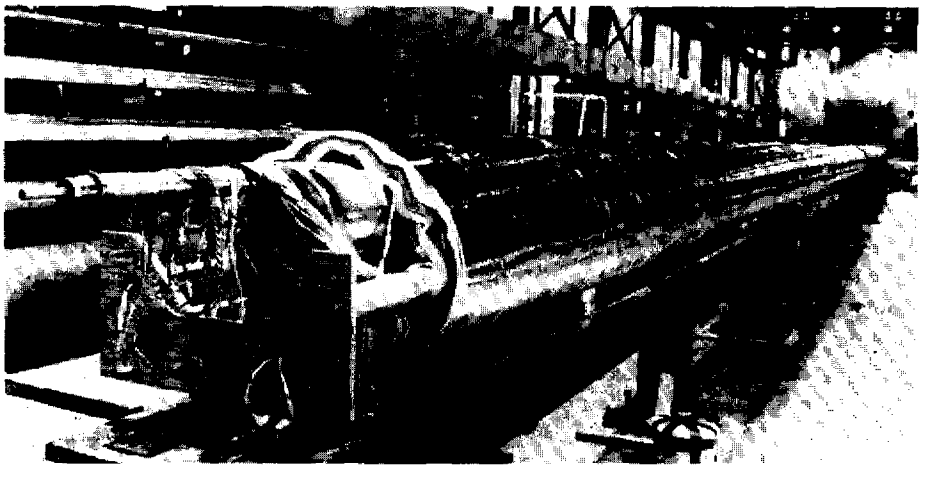

Figure 5. Partially completed SSC dipole cryostat at Fermilab. Layers of superinsulation (aluminized mylar and fiberglass) can be seen. Compare Figure 3.

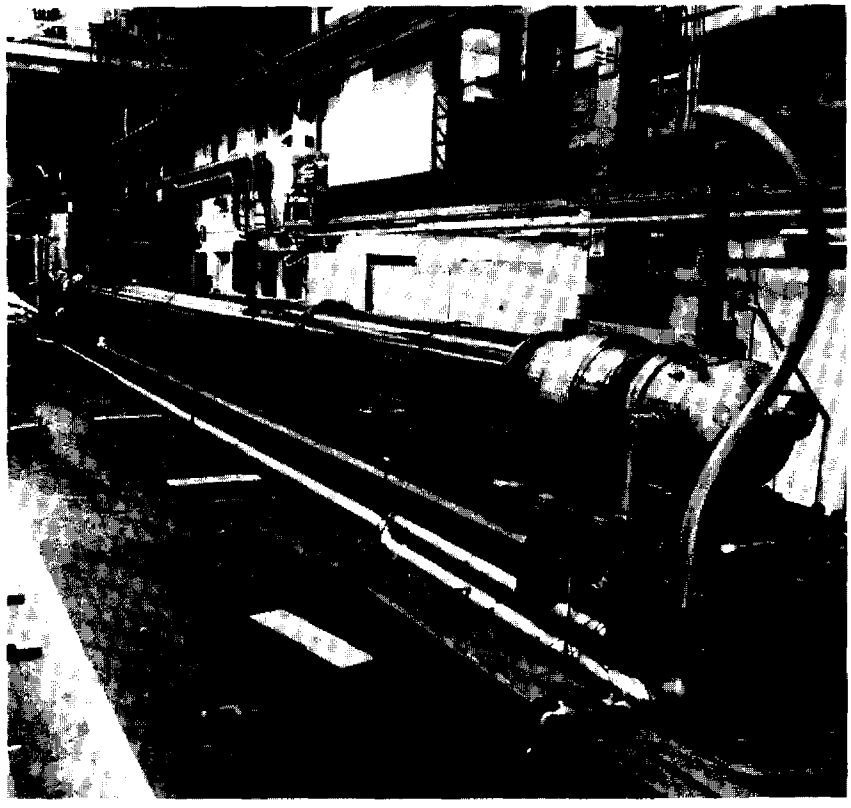

Figure 6. Completed full-scale SSC dipole model on the test stand at Fermilab. The cryogenic feed can is at the far end.

The current fiscal year (FY 1987, 1 October 1986 - 30 September 1987) has seen continued emphasis on the magnet program, with both long and short models (1 m at LBL, 1.8 m and 17 m at BNL) being made to test out design improvements. The first full-scale model magnets have been tested at Fermilab, with test results providing feedback for design and assembly modifications. Improvement of the cold-mass support system within the cryostat and the detailed design of the cryogenic system are other major efforts. Experiments have continued at BNL on the photodesorption of gases from the beam tube wall by synchrotron radiation, at Fermilab on the backgrounds of neutrons and other radiation in the tunnel, and at TAC on the effects of radiation on quench protection diodes. In accelerator physics, experiments were performed with the Tevatron to validate some of the aperture concepts of the Conceptual Design Report. In other accelerator physics areas, further work on the dynamics of the beam led to a decision to change from the 60° phase advance per cell of the CDR to 90°, with an accompanying revision of the lattice. Improvements are being made in the design of the IR optics; changes in the lattice to allow construction of bypasses are also being investigated.

The impact of the evolving detector requirements on the scale and design of the interaction halls has been pursued vigorously, as has the creation of a mechanism for encouraging, approving, and funding relevant detector R&D in a timely fashion.

The CDG has also been involved heavily in the run-up to the DOE's Invitation for Site Proposals in April 1987 and in related subsequent activities.

3. DETECTOR R&D EFFORTS

The detector R&D plans deserve more elaboration. A scheme has been worked out that preserves the diversity and independence of university and laboratory groups to pursue particular ideas, while providing guidance and a sense of direction toward goals necessary for the success of the SSC. A coordinating office has been established at the CDG, with M. Gilchriese as interim coordinator. An international advisory committee has been established - see Table 2. Proposals for detector R&D germane to the SSC are submitted to the usual funding agencies. The agencies send such proposals to the coordinating office for appraisal and recommendation by the advisory committee.

Table 2. International Advisory Committee on Generic Detector R&D for the SSC

D. Bryman (TRIUMF)	D. Nygren (LBL)
C. Fabjan (CERN)	L. Price (ANL)
J. Jaros (SLAC)	V. Radeka (BNL)
R. Kephart (FNAL)	P. Rancoita (INFN-Milano)
R. Klanner (DESY)	R. Ruchti (Notre Dame)
T. Kondo (KEK)	M. Shaevitz (Columbia)
S. Mori (Tsukuba)	*H. H. Williams (Pennsylvania)

*(Chairman)

The advisory committee met for the first time in April 1987 and again in July. At the April meeting the committee recommended approximately $0.5M of expenditures for the remainder of FY 1987 for work on

- Basic detector technologies
- Signal processing for drift chambers and calorimetry
- Scintillating fibers
- Pixel detectors
- Integrated circuit development for drift chambers, calorimeters and silicon strip devices
- Radiation damage
- Simulation techniques

Continuation of these efforts in FY 1988 will require $2.5M. In addition, other areas would need $1.5M.

The advisory committee projects a growth from $4M in FY 1988 to $8M (FY 1989) and $12M (FY 1990). It expects to meet on a regular basis to evaluate new proposals and to hear of progress on those already funded.

4. SCHEDULE FOR SITE SELECTION AND CONSTRUCTION FUNDING

At the same time as the R&D program of the CDG proceeds, the DOE is moving ahead with site selection and the congressional budget process. The site selection program was initiated on 1 April 1987 with publication of an Invitation for Site Proposals. The schedule published at that time is shown in Fig. 7. The proposal preparation phase has been extended by a month, with the due date now 4 September. Other dates remain unchanged at this writing. The "blue ribbon" panel appointed by the National Academy of

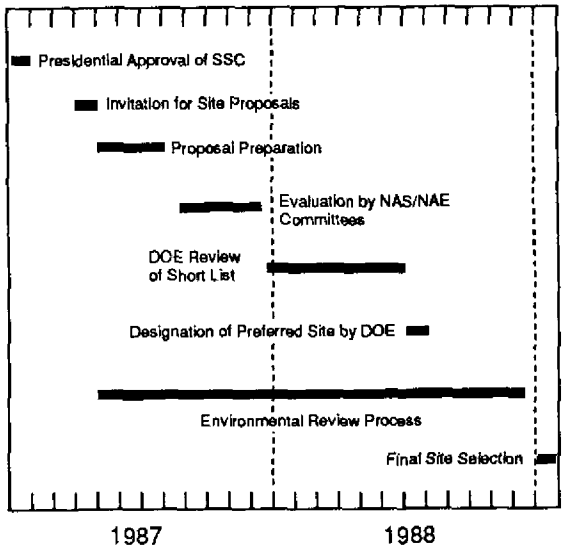

Figure 7. DOE Schedule for Site Selection for the SSC. Dashed vertical lines mark calendar year boundaries.

Science and of Engineering is scheduled to evaluate the proposed sites in the fall of 1987 and to recommend a short, unranked list of acceptable/ superior sites. The calendar year 1988 is consumed by DOE reviews, naming of the preferred site, environmental review hearings, and (one hopes) announcement of the vetted and approved site in January 1989. Site preparations would begin soon after, with some parts of the project at the site within six months.

At the time of the President's endorsement and the inclusion of the SSC in the Administration's FY 1988 budget request to Congress, the DOE submitted an overall funding profile for the whole project, as shown in Fig. 8. The solid histogram represents the annual projected funding in FY 1988 dollars for all aspects - R&D, civil and technical construction, pre-operating costs, detector and large computer costs. The dashed lines indicate the amounts for the civil and technical construction of the accelerator and its laboratory. The total cost of the machine and laboratory is $3.2G, while all the other items come to $1.2G over the 8 year period shown.

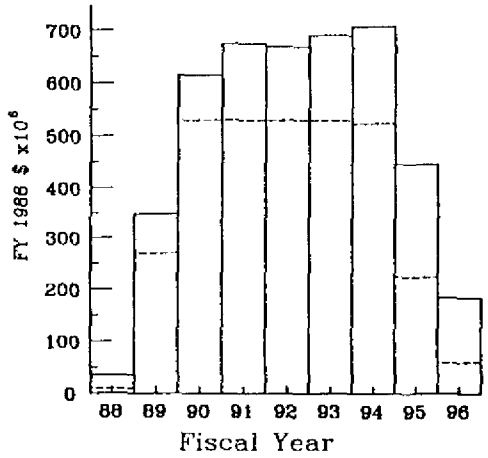

Figure 8. Proposed SSC funding profile submitted by DOE to the U.S. Congress in February 1987. The overall amounts include R&D, pre-operations, detector and computer costs, as well as the construction costs of the SSC and associated conventional facilities. The dashed lines show construction costs of the laboratory and machine alone.

Accompanying this DOE funding profile are many very detailed schedules. One rather high-level schedule is shown in Fig. 9. At the top is a list of milestones, while the bottom half shows the design and fabrication, conventional construction, technical installation, and testing phases of the injector and of the main collider rings, as well as for the ancillary site facilities.

As of this writing, the FY 1988 funding request is before Congress. Appropriation is expected in September 1987 for the fiscal year beginning on 1 October 1987.

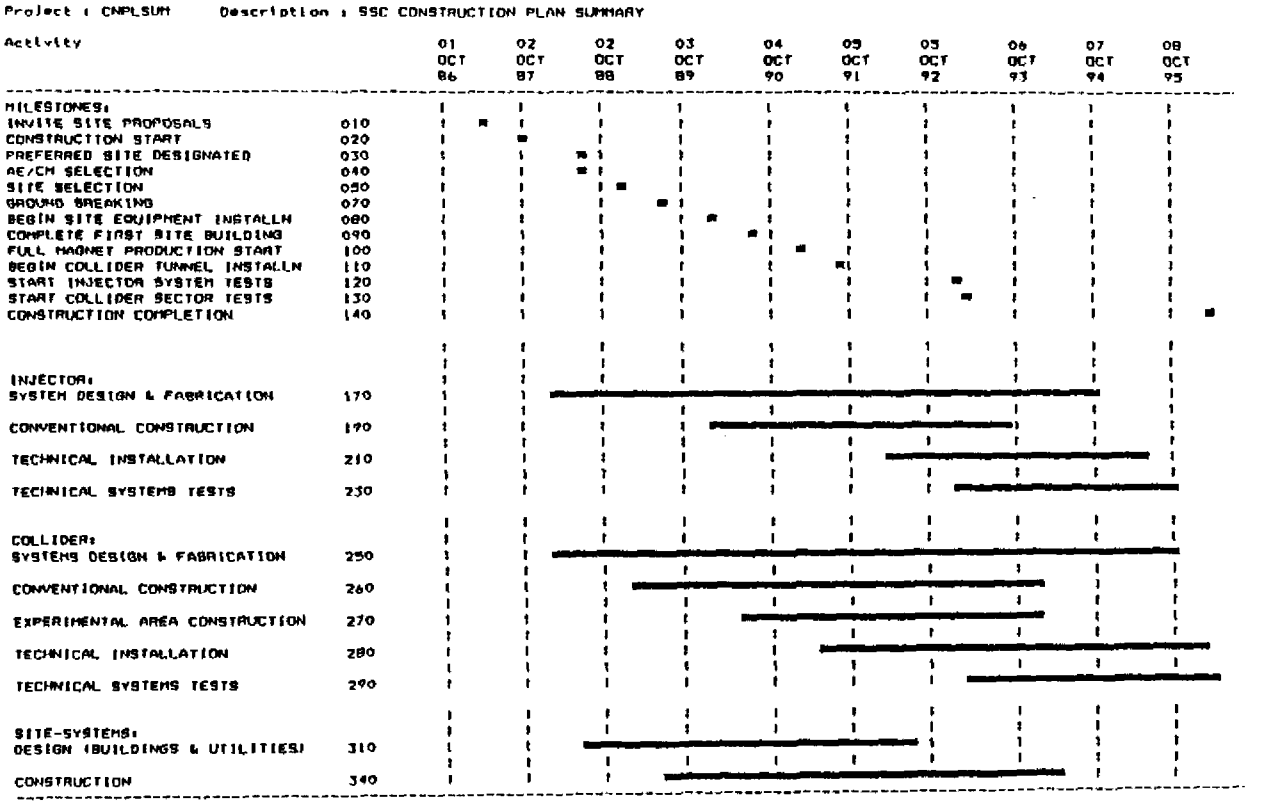

Figure 9. Overall SSC construction schedule conforming to the funding profile of Fig. 8.