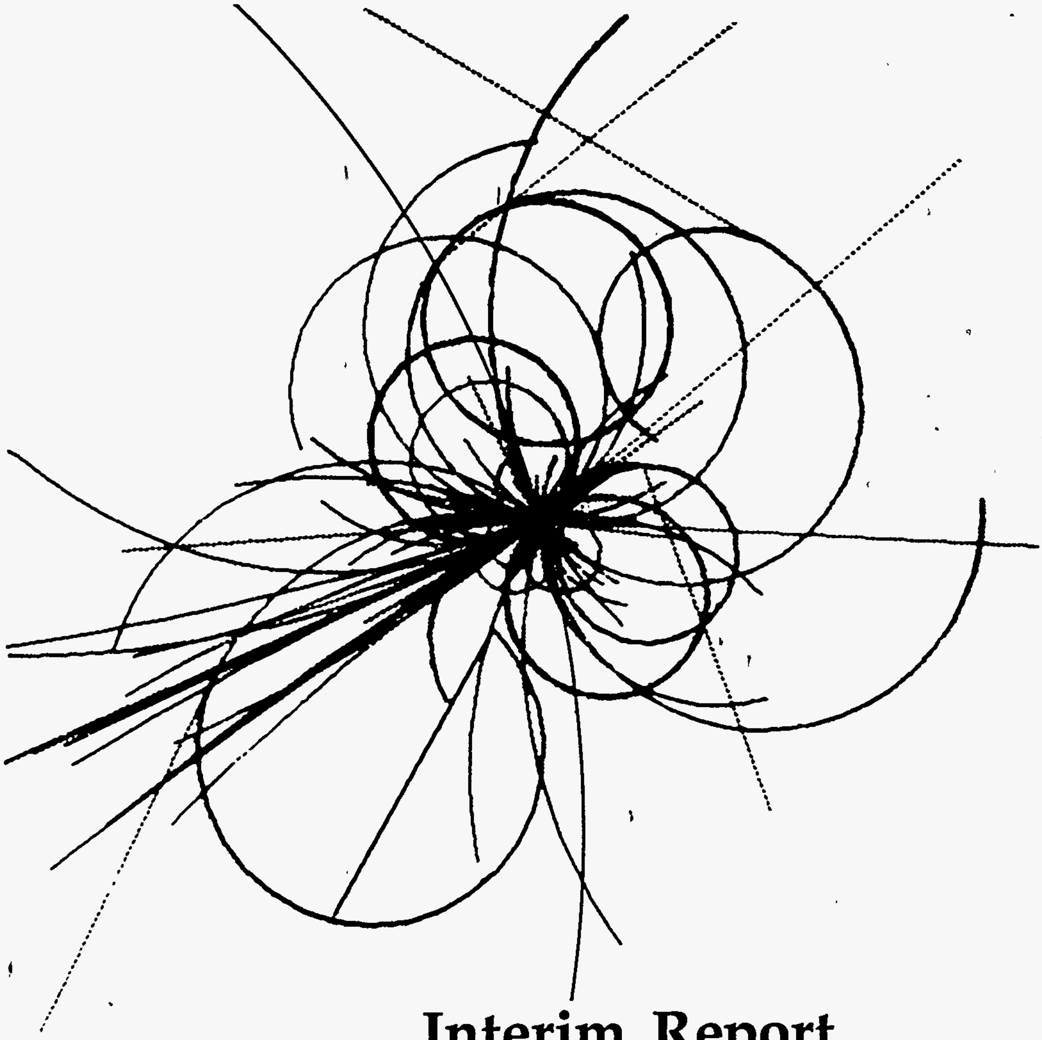
SSC–SR–1011

The Superconducting Super Collider



Interim Report

SSC Central Design Group

June 1985

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SSC-SR-1011

INTERIM REPORT

SSC CENTRAL DESIGN GROUP*

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SSC INTERIM REPORT - June 1985

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PREFACE

This Interim Report summarizes the research and development activities of the Superconducting Super Collider project carried out from the completion of the Reference Designs Study (May 1984) to June 1985. It was prepared by the SSC Central Design Group in draft form on the occasion of the DOE Annual Review, June 19-21, 1985. This final version contains essentially the same material as the draft, but in a different format.

Now largely organized by CDG Divisions, the bulk of each chapter documents the progress and accomplishments to date, while the final section(s) describe plans for future work. Chapter 1, Introduction, provides a basic brief description of the SSC, its physics justification, its origins, and the R&D organization set up to carry out the work. Chapter 2 gives a summary of the main results of the R&D program, the tasks assigned to the four magnet R&D centers, and an overview of the future plans. The reader wishing a quick look at the SSC Phase I effort can skim Chapter 1 and read Chapter 2.

Subsequent chapters discuss in more detail the activities on accelerator physics, accelerator systems, magnets and cryostats, injector, detector R&D, conventional facilities, and project planning and management. The magnet chapter (5) documents in text and photographs the impressive progress in successful construction of many model magnets, the development of cryostats with low heat leaks, and the improvement in current-carrying capacity of superconducting strand. Chapter 9 contains the budgets and schedules of the CDG Divisions, the overall R&D program, including the laboratories, and also preliminary projections for construction.

Appendices provide information on the various panels, task forces and workshops held by the CDG in FY 1985, a bibliography of CDG and Laboratory reports on SSC and SSC-related work, and on private industrial involvement in the project.

The early version of the report was prepared by the CDG staff, J.R. Sanford responsible. J.D. Jackson edited the final version.

M. Tigner
Director

CHAPTER 1. INTRODUCTION

This is a report of progress since the completion of the Reference Designs Study (RDS) of May 1984.[1] Since that time the major focus of activity has been on the most costly systems identified in the RDS, the bending magnet and tunnel systems. Cost analyses, engineering studies, and component R&D have continued. Work to date has supported the RDS conclusions that the SSC is technically feasible and that the accelerator facility itself (exclusive of land acquisition, R&D and pre-operating costs, and the initial complement of detectors) can be built for less than 3 billion dollars (1984).

This chapter presents a brief description of the project and its scientific maturation and history, as well as the objectives for Phase I and the organization created to carry it out.

1.1 SSC Facility Description

The SSC facility is a unique high energy physics laboratory whose major research instrument is a high-luminosity multi-TeV hadron collider. The collider will provide effective access to particle-particle collisional energies at least an order of magnitude greater than are available at existing facilities. The major design objectives for the collider are given in Table 1-1.

Table 1-1. Primary SSC Design Objectives.

Maximum proton beam energy (TeV/beam)	20
Maximum luminosity ($cm^{-2}s^{-1}$)	10^{33}
Number of interaction regions	6

Different magnetic field strengths for bending the proton beams are being explored in the Phase I R&D program. The low field (3T) would result in a main ring of magnets approximately 100 miles in circumference, while the high field (6T) would yield a ring circumference of roughly 60 miles.

The complete SSC facility is comprised of the 20 TeV per beam collider, an injector complex, interaction halls and associated support buildings, and a central complex of office and laboratory buildings. The injector complex consists of a cascade of accelerators that successively boost the particles to higher and higher energies for ultimate injection into the main ring, where they receive their final acceleration to 20 TeV. The interaction halls (underground, with extensions on the surface) are located at the interaction regions where the counter-rotating beams are made to collide. Staging halls are adjacent to the interaction areas for convenient assembly and testing of detectors before installation at the interaction point. The central complex provides the control center of accelerator operations, laboratory and office space for scientists, support services, and administration.

1.2 Scientific Motivation

Since the 1930's the development of accelerators has largely set the pace of discovery in particle physics, specially since the 1940's and 1950's with the development of powerful synchrocyclotrons and synchrotrons. These post-war machines were able to convert energy into new forms of matter, hitherto seen only in very low abundance in the cosmic rays. The controlled and flexible conditions of the laboratory provided the basis for rapid and impressive progress far beyond the cosmic rays, from Lawrence's first cyclotron in 1931 (5 inches in diameter and 100 keV in proton energy) to Fermilab's Tevatron (1-1/4 miles in diameter and 900 GeV in proton energy).

The inexorable upward thrust in energy is a consequence of two basic laws of nature. The first is that to "see" an object of a certain size it is necessary to use radiation (either sound or light or particles) of a wavelength smaller than the object to be studied. If we wish to probe deeper and deeper into the heart of matter, we must use shorter and shorter wavelengths. The second natural law is that the wavelength of a particle or of light is inversely proportional to its energy (strictly speaking to its momentum, but at high energies the difference is negligible). Shorter and shorter wavelengths therefore require higher and higher energies. To begin to probe the nucleus requires protons of several MeV; to probe the proton itself, several GeV; and to probe deep inside the proton and explore its basic constituents requires energies of many TeV.

The physics need for the SSC has been discussed in a number of places.[2-8] Only a brief sketch is presented here. The tremendous progress of the last 25 years, in experimental discovery and in theoretical synthesis, has given physicists a remarkably successful description of the fundamental laws of nature, called the Standard Model. It is based on quarks and leptons as the elementary building blocks of all matter, interacting by forces carried by gauge bosons (the photon of electromagnetism being the most familiar). While the Standard Model encompasses and relates almost all observations to date, it is not complete and self-contained. There are a large number (~20) empirical parameters in the model. These are a reflection of its failure to explain a number of fundamental questions -- for example, the origin and pattern of particle masses, the reason for the observed groupings of quarks and leptons, the reason for handedness in the weak interactions.

Other questions beyond its reach abound: Are quarks and leptons really basic, or are they composites of more basic entities? Are there unifications of forces beyond the electroweak unification of the Standard Model? Can gravity be incorporated into particle physics? Are other, grander symmetries like "supersymmetry", a unification of particles of integral and half-integral spin, realized approximately in nature? Figure 1-1 indicates the progress since Newton's time toward an ultimate unification of all the forces of nature.

The list of questions and issues beyond the scope of the Standard Model is long, but its domain of proven validity is also extensive -- sufficient, in fact, to provide a firm basis for judging where experiments must go in order to answer many of the pressing questions of today. Very general arguments lead to the conclusion that study of the mass or energy range of 1 TeV and beyond must reveal new phenomena. The nature of the new phenomena is not known -- different theoretical extensions of the Standard Model make different predictions -- but behavior beyond or different from what is known at 100 GeV and below must occur.

For example, the so-called Higgs particle, seemingly necessary for the spontaneously broken symmetry of electroweak dynamics, may be a low-energy approximation to a rich and complex dynamics of bound states of a type of super-quark and super-strong force. Experiments that probe masses of 1 TeV should reveal these new systems. On the other hand, perhaps the Higgs particle is a basic constituent. If its mass is less than 1 TeV, the strong and electroweak dynamics will continue to be separately recognizable in the 1 TeV energy range and well beyond. But if the Higgs mass is large compared to 1 TeV, all the forces must become strong, and complex new phenomena, not

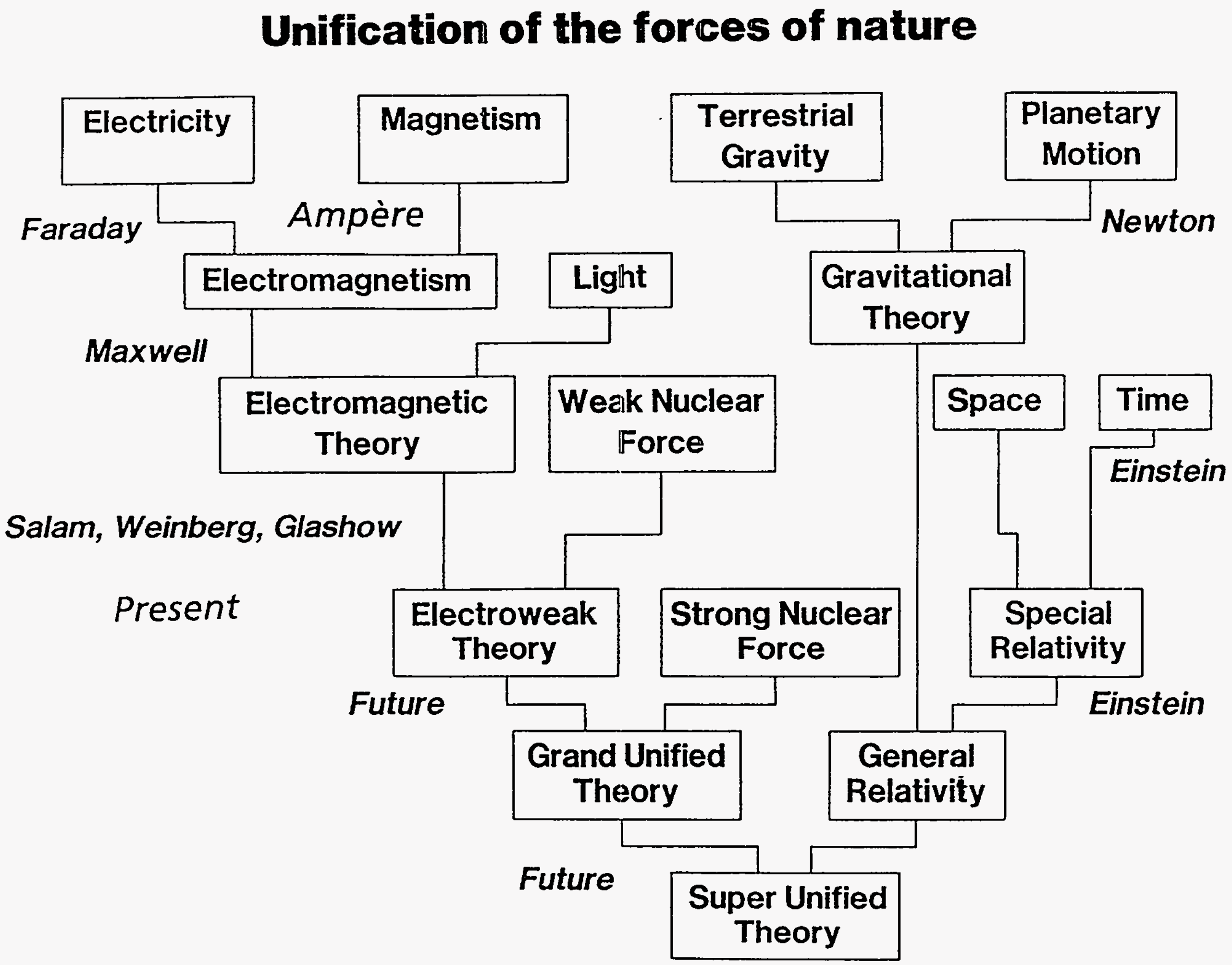

Fig. 1-1. History of unification of our understanding of the basic forces and speculation as to its possible future course. At present, the Electroweak Theory and the Strong Nuclear Force (called QCD) form the basis of the Standard Model.

known today, will result. In any of these eventualities (and others not described), something new must be seen as the 1 TeV mass domain is explored.

The need for multi-TeV hadron beams to explore masses of 1-4 TeV stems from the compositeness of hadrons. The proton and other hadrons consist of quarks and gluons sharing the energy of motion. When hadrons collide at very high energies, the hard collisions that correspond to distances much smaller than the size of a hadron occur between constituents, rather than between the hadrons as a whole. Since the constituents each carry less than the total energy of the hadron, the energy available for the hard collision (and potentially convertible into mass) is generally much less than twice the beam energy of the hadrons. To study the short distances corresponding to masses from 1 to 4 TeV requires proton beam energies up to 20 TeV.[9]

The desirability of a next step in accelerator energy toward 20 TeV/beam is one thing, its realization another. Fortunately, the 20-year program of development of superconducting accelerator magnet technology provides a proven base on which to build. There now exist sophisticated industrial techniques for the production of highly stable, multifilament, superconducting strand (NbTi in a copper matrix) of very high current-carrying capacity and its fabrication into magnet cable of carefully controlled dimensions. Fermilab's Tevatron, with its one thousand large superconducting magnets (and another thousand smaller ones), is an "existence proof" of this still developing technology. One can therefore conceive of constructing larger accelerators based on this technology, exploiting the higher magnetic fields without the inordinately high electric power costs associated with conventional copper and iron magnets. Superconductivity is the key to the feasibility of the SSC.

1.3 Recent Chronology

The concept of a multi-TeV accelerator was first discussed in public about ten years ago. Two workshops sponsored by the International Committee on Future Accelerators (ICFA), one at Fermilab in 1978 and one at CERN in 1979, discussed various possibilities for very high energy machines, including proton-proton colliders in the 20 TeV per beam range. The SSC itself can be said to have had its origins in the 1982 Snowmass Summer Study, sponsored by the Division of Particles and Fields of the American Physical Society, and the recommendation a year later by the High Energy Physics Advisory Panel (HEPAP) to the Department of Energy (DOE) for the construction of a multi-TeV, high-luminosity hadron collider at the earliest possible date. The recent chronology is summarized below.

Summer 1982: A Summer Study of the American Physical Society's Division of Particles and Fields was held at Snowmass, Colorado. An in-depth examination of the idea of a 20-TeV/beam proton-proton collider resulted from this meeting. Strong and widespread support for the physics goals of such a collider emerged.

February 1983: A week-long workshop was held at the Lawrence Berkeley Laboratory (LBL) to consider detector problems for high-energy, high-luminosity hadron-hadron colliders.

March 1983: A workshop was held at Cornell University to consider technical and cost questions associated with construction of a multi-TeV hadron-hadron collider.

July 1983: A subpanel of the High Energy Physics Advisory Panel (HEPAP), convened early in 1983 to consider future high energy facilities in the United States, recommended immediate initiation of a project aimed at the construction of a new high-energy, high-luminosity, hadron collider. This recommendation, "unanimously . . .and enthusiastically endorsed by HEPAP with the highest priority" for high energy physics, was transmitted to DOE.

Fall 1983: DOE initiated preliminary R&D for the SSC. Hearings were held before the House Science and Technology Committee concerning redirection of resources toward the SSC R&D.

December 1983: The Reference Designs Study was chartered by the directors of the U.S high-energy accelerator laboratories with the energy and luminosity goals defined.

March 1984: DOE assigned responsibility for oversight of the national SSC effort during the R&D preconstruction phase to the Universities Research Association (URA).

Spring 1984: The Reference Designs Study drew upon the expertise of about 150 accelerator physicists and engineers from across the nation. It concluded that a 20 TeV on 20 TeV proton-proton collider is technically feasible. The Study, also containing cost estimates, was extensively reviewed by DOE personnel and their consultants.

Summer 1984: A Summer Study of the American Physical Society's Division of Particles and Fields was held at Snowmass, Colorado, to examine the design and utilization of the SSC. It reaffirmed the parameters of Table 1-1 as important for the physics goals.

Summer 1984: Initiation of the Phase I R&D program for the SSC was approved by the Secretary of Energy. Extensive work on model magnets for the SSC was already underway at Brookhaven National Laboratory (BNL), Fermi National Accelerator Laboratory (FNAL), Lawrence Berkeley Laboratory (LBL), and the Texas Accelerator Center (TAC).

Fall 1984: The Central Design Group (CDG) was formed, with headquarters at LBL. The CDG has been charged with directing and coordinating the SSC R&D work.

1.4 Phase I Objectives

The purpose of the SSC Phase I effort is to carry out a comprehensive research and development program sufficient to determine a cost- and performance-optimized design, and to demonstrate that the key technical features of the accelerator-collider system are achievable within the estimated cost and schedule. The R&D effort is also to include assessment of the requirements of the initial complement of detectors for the projected SSC experimental physics research. Phase I is envisioned by the CDG to be of about three years' duration (FY 1985-1987).

In more detail, the overall objectives of Phase I are:

(a) To develop the performance specifications for the Superconducting Super Collider consistent with the recommendations of HEPAP and its 1983 Subpanel on New Facilities, with consideration of the results of subsequent pertinent studies and deliberations.

(b) To conduct SSC design and R&D activities, making use of the skills, experience, and facilities of National Laboratories, universities and the industrial sector.

(c) To select an optimum superconducting magnet design style for the SSC based upon technical, economic and operational criteria.

(d) To develop, as required for timely consideration in the FY88 budget process, an SSC Conceptual Design Report including costs, schedule, staffing plan, and other elements showing how the SSC can be realized in a practical, environmentally sensitive and safe manner.

(e) To evaluate site parameter requirements and to provide site information specification documents.

(f) To develop and demonstrate cost-effective techniques for fabrication of magnets.

(g) To conduct systems tests to evaluate performance and reliability of magnets and other components.

(h) To develop a site-specific plan and critical-path schedules following site selection.

(i) To develop a catalog of operating needs for the SSC, including utilities, cryogens, maintenance supplies, and manpower levels.

(j) To conduct or coordinate appropriate R&D activities for the development of advanced particle detectors.

1.5 Organization to Carry out Technical Objectives

In the spring of 1984 the Department of Energy selected the Universities Research Association, a consortium of 56 leading research universities, as to carry out Phase I of the SSC program. URA formed an SSC Board of Overseers to assure that the SSC efforts were carried out responsibly and independently of the URA-managed program at Fermilab. The Board of Overseers consists of academic, laboratory, and industrial scientists and engineers. Its current composition is James W. Cronin, University of Chicago; John M. Deutch, Massachusetts Institute of Technology; Harold P. Furth, Princeton University; John K. Hulm, Westinghouse Electric Corporation; Edward Knapp, Los Alamos National Laboratory; Boyce D. McDaniel, Cornell University, Chairman; George E. Pake, Xerox Corporation; Wolfgang K.H. Panofsky, Stanford University; Martin Perl, Stanford Linear Accelerator Center; Chris Quigg, Fermi National Accelerator Laboratory; Sam B. Treiman, Princeton University; George H. Trilling, Lawrence Berkeley Laboratory; and Steven Weinberg, University of Texas. The SSC Board of Overseers formed the SSC Central Design Group, appointed Dr. Maury Tigner of Cornell University as Director, and, upon his recommendation, approved the siting of the CDG at the LBL.

The relationship of the Central Design Group to URA, DOE, and the various R&D centers is indicated in Fig. 1-2. The CDG acts as the coordinating and management group for the SSC research and development being carried out at the

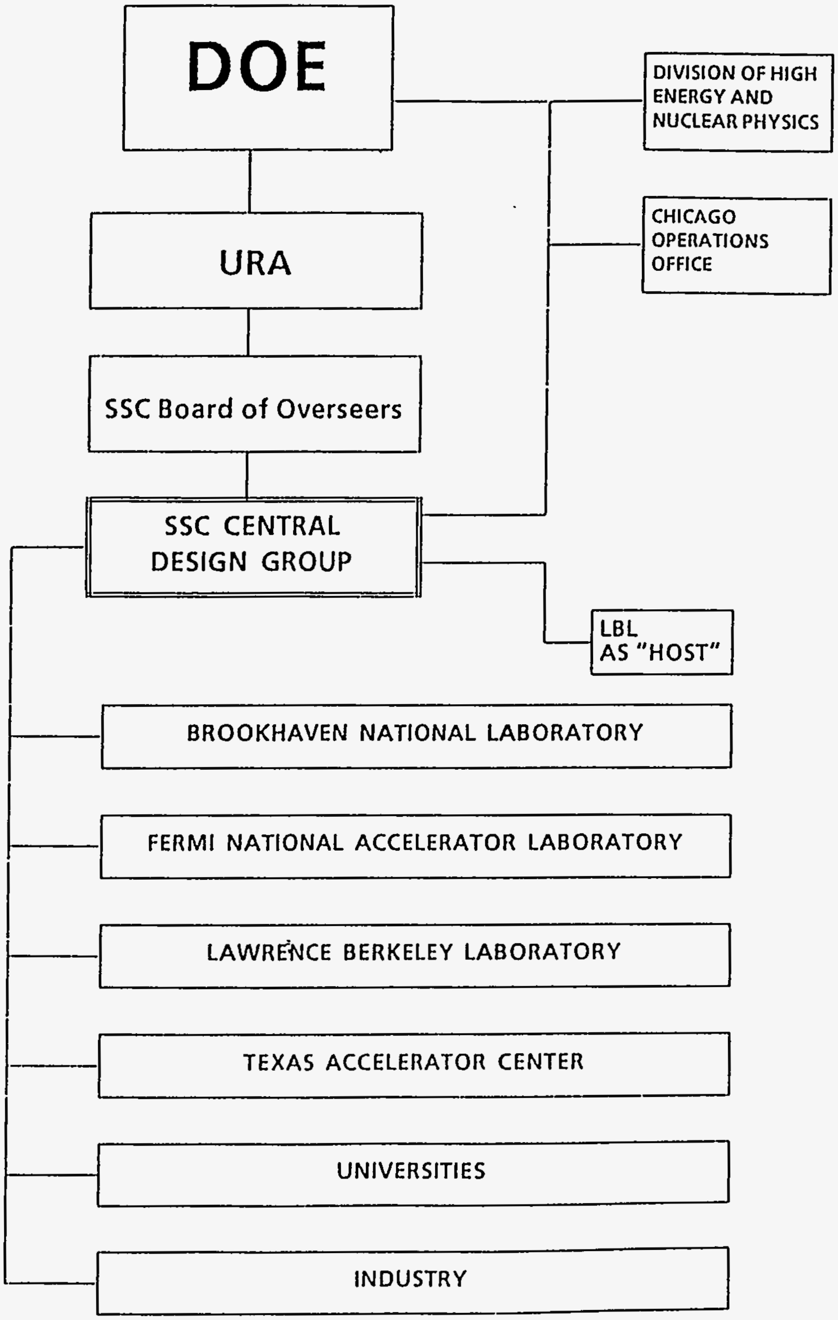

Figure 1-2. Organization chart showing the relationship of the Central Design Group to URA, DOE, and the various R&D centers. The DOE has additional direct lines of communication to the laboratories and other R&D centers.

four magnet R&D centers, in the universities, and in industry, as well as within the CDG itself. To accomplish its goals, the Central Design Group is organized into a number of Divisions, as shown in Fig. 1-3.

The major technical objective of the Accelerator Physics Division is to obtain a detailed understanding of the beam dynamics of high-current stored beams as envisioned in the SSC. These studies provide basic specifications on such crucial issues as magnet aperture, necessary field quality, and alignment tolerances over the operating ranges of the various accelerator systems.

The R&D efforts of the Accelerator Systems Division are aimed at the development of a workable, cost-effective, and reliable system of accelerators consisting of magnets and cryostats, associated refrigeration, quench protection, power supplies, vacuum, rf acceleration, instrumentation and controls, abort systems, etc. This will require integration and reliability studies for development of system and system-interface specifications, system testing and specification of needs for component development. Modeling and prototyping of system components as well as system tests are an important part of Division activities. Principal among the system tests are those demonstrating integrated performance of the complete magnet system.

The Conventional Systems Division has as its technical R&D objectives to determine SSC site requirements, to prepare a site-parameter document that will be used by the DOE as technical advice in its site-selection process, and to explore ways to minimize the cost of conventional construction. To this end it will develop a site master plan and conventional system design that meets the scientific needs of the facility in a cost- and schedule-optimized fashion.

The Magnet Division is responsible for the selection of the basic magnet type and for the development of the design, specification and prototyping of that selected magnet. It directs and coordinates R&D work carried out at the magnet R&D centers (BNL, FNAL, LBL, TAC) and in the universities and industry. The main Phase I technical objective is to develop a magnet that meets the field-quality requirements of the SSC. Associated objectives are to optimize technical performance and reduce costs of the final design, to develop tooling and demonstrate manufacturability of SSC magnets in a reliable and cost-effective manner.

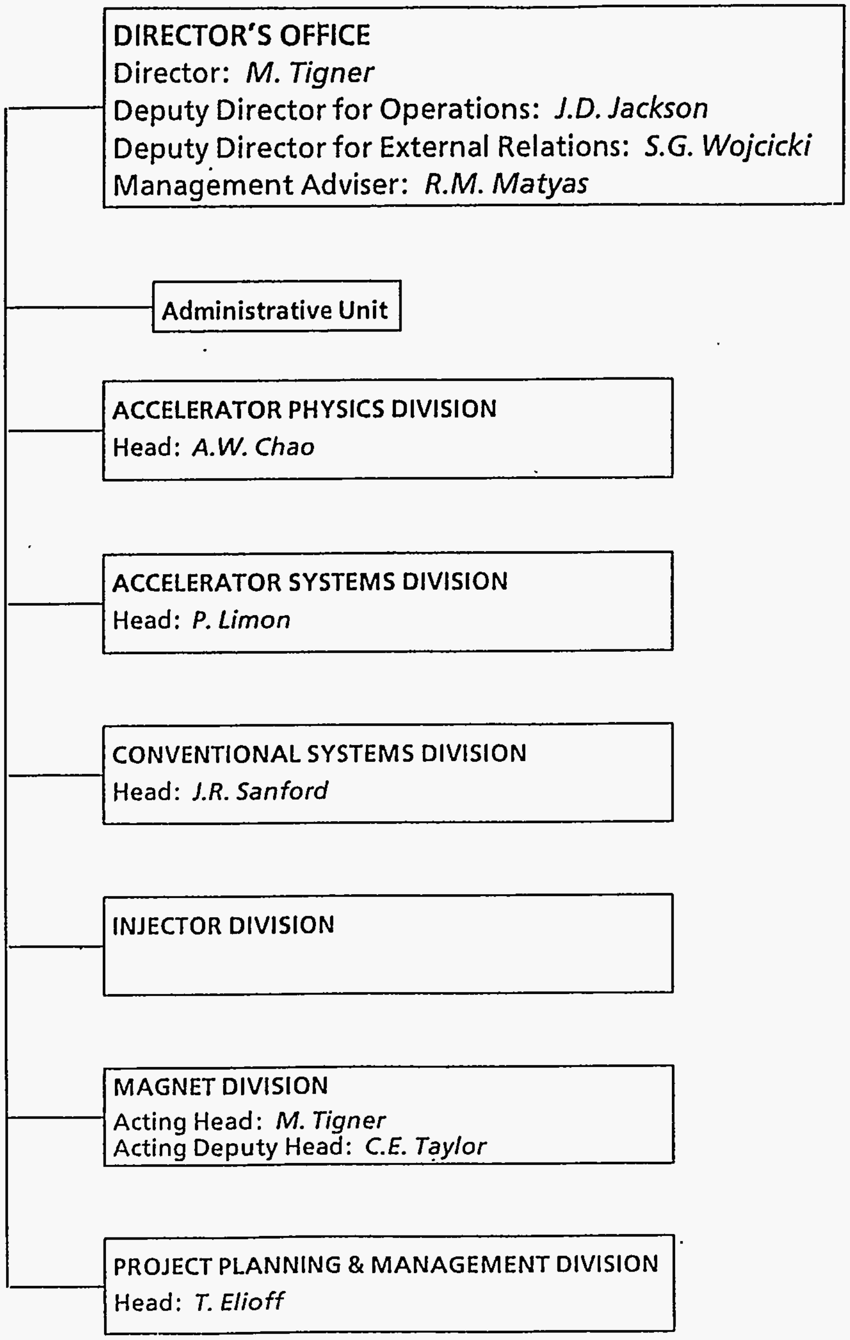

Figure 1-3. SSC Central Design Group Organization

The Project Planning and Management Division is responsible for integrated planning of the R&D work and for formulation of a project plan that includes the schedule and resource profiles that will be needed to realize the SSC. Other duties of this Division include devising a quality-control plan, and also the responsibility for monitoring and reporting both technical and financial aspects of the R&D program.

Overall coordination and management is provided by the Director's Office.

The four magnet R&D centers have played a crucial role in accomplishing the Phase I program to date. Their work is coordinated through formal agreements with each of the centers. These agreements describe the tasks to be undertaken, the schedule, and the SSC funds allocated for the work. The responsible individuals at the four centers are P.J. Reardon, Brookhaven National Laboratory; R.A. Lundy, Fermi National Accelerator Laboratory; K.H. Berkner, Lawrence Berkeley Laboratory; and F.R. Huson, Texas Accelerator Center. Monthly financial and technical reports are submitted by these groups to the CDG and are integrated into a CDG Monthly Report to the DOE. The primary tasks to be performed by each institution are outlined in the next chapter (Section 2.2).

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3. "To The Heart of Matter -- The Superconducting Super Collider," an informational booklet published by the Universities Research Association, March 1985.
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5. Proceedings of 1982 DPF Summer Study on Elementary Particle Physics and Future Facilities (Division of Particles and Fields of the American Physical Society, 1983), Snowmass, Colorado.

6. Proceedings of the 1984 DPF Summer Study on the Design and Utilization of the SSC (Division of Particles and Fields of the American Physical Society, 1985), Snowmass, Colorado.
7. C. Quigg, "Elementary Particles and Forces," Scientific American, April 1985, p. 84.
8. S.L. Glashow and L.M. Lederman, "The SSC: A Machine for the Nineties," Physics Today, March 1985, p. 28.
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CHAPTER 2. SUMMARY OF R&D PROGRAM

2.1 Results in FY 1985

The major milestones foreseen for Phase I are displayed in Table 2-1. The major focus of activity since completion of the RDS, as can be seen from the milestones, has been on the primary technical parameters of the SSC, i.e., the scientific specification, selection of the optimum superconducting magnet technology to be used for the collider accelerator, and continuing assessment of costs for constructing the SSC. In addition, attention has been given to describing the siting requirements for the facility. Planning for completion of Phase I work has also been a central effort.

The Summer Study on Design and Utilization of the SSC, conducted by the Division of Particles and Fields of the American Physical Society in June and July, 1984, reaffirmed the scientific design goals of 20 TeV per beam, high luminosity (10^{33}cm^{-2}sec^{-1}), and potential for six interaction regions.

Even prior to the formation of the CDG, considerable model work on superconducting magnets for SSC service had been carried out. At the beginning of FY 1985 an extensive review of the existing magnet program was carried out by a CDG-appointed panel of experts. This Technical Magnet Review Panel not only reviewed the status of the various magnet development efforts but also made suggestions on how the on-going program could be strengthened and refocused to permit an early selection of the Basic Magnet Type to be pushed forward to full-scale prototyping. A selection process has been devised which is based on the results of the engineering and modeling studies now proceeding, upon cost estimates for complete collider systems based on the five magnet types now under study, and upon system considerations having to do with commissioning and operation of the collider. The five magnet types under consideration* span the range of technical approaches that the previous

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* The following nomenclature for the Basic Magnet Types is used:

Basic Magnet Type	Description
A	2-1, high field, cold iron
B	1-1, high field, warm iron
C	2-1, low field, cold iron
C'	1-1, low field, cold iron
D	1-1, high field, cold iron

Table 2-1. Phase I Program Milestones.

Date	Item
Oct 1984	Define Selection Criteria and Technical Information needed for Magnet Selection
Nov 1984	Establish Primary SSC Design Features and SSC Phase I Program Plan Objectives
Apr 1985	Site Parameters Document[a]
Apr 1985	Review Magnet Development Program
Jul 1985[b]	Magnet Design Type Selection[a]
Dec 1985	Preliminary Conceptual Design
Feb 1986	Start Pre-Production Prototype Magnets
Mar 1986	Conceptual Design Report (non-site specific) and Other Documentation[a]
Oct 1986	Magnet Half Cell Test Begins
Dec 1986	Site Selection by DOE[a]
Apr 1987	Report on Half Cell Test
Aug 1987	Recommended SSC Phase II Management and Procurement Plans Partial Title I Design Report
Oct 1987	SSC Construction Start (NTP)[a]

[a] Denotes Primary Milestone

[b] Selection to be made during the last quarter of FY 1985.

studies have indicated could meet the scientific objectives and be economically competitive. The five are variants of two basic approaches, the iron-shaped field approach and the conductor-shaped field approach. Each of these is applied to a version in which the two beam channels of the collider are mechanically and cryogenically independent (1-1) and a version in which the two channels are mechanically linked within a common cryogenic envelope (2-1). These four employ magnet iron held at coil operating temperature. The fifth variant has a conductor-shaped field with the shielding iron held at room temperature. The iron-shaped field versions are limited in field to 3 Tesla or less by the properties of iron. The conductor shaped field versions are limited in field by the properties of superconducting materials. The economic optimum for this type at 4.5K appears to be at 6 Tesla or somewhat higher.

Figure 2-1 displays the various activities aimed at the final selection process, as well as the integration of the technical inputs into a selection decision. This process will be carried out in three steps. The Technical Magnet Review Panel will evaluate the technical status of design and development work on the magnets and specify the R&D remaining before each of the types under consideration is ready for final prototyping. The report of this panel, along with the cost information and information resulting from accelerator systems considerations, will be presented to a Magnet Selection Advisory Panel which will produce an ordered preference list, with justification, of the basic magnet types under consideration. Criteria to be used by the Advisory Panel include relative capital cost, operating cost, workability of designs, relative complexity of the magnet systems and of their operation, relative flexibility of SSC design employing the various magnets, impact of the magnet types on the construction schedule, remaining R&D and accelerator physics considerations. The detailed charges to the panels are contained in Appendix A.

Substantial technical progress in assessing the viability and engineering features of the various types has already been made. Of the iron-shaped types, 1-meter and 7-meter models have been tested for a cumulative total of 20 meters of beam channel. Of the conductor-shaped types, 1-meter and 4.5-meter models have been tested for a cumulative total of 45 meters of beam channel. In all cases the magnetic field achieved was a few per cent greater than that predicted from short-sample measurements of the superconducting

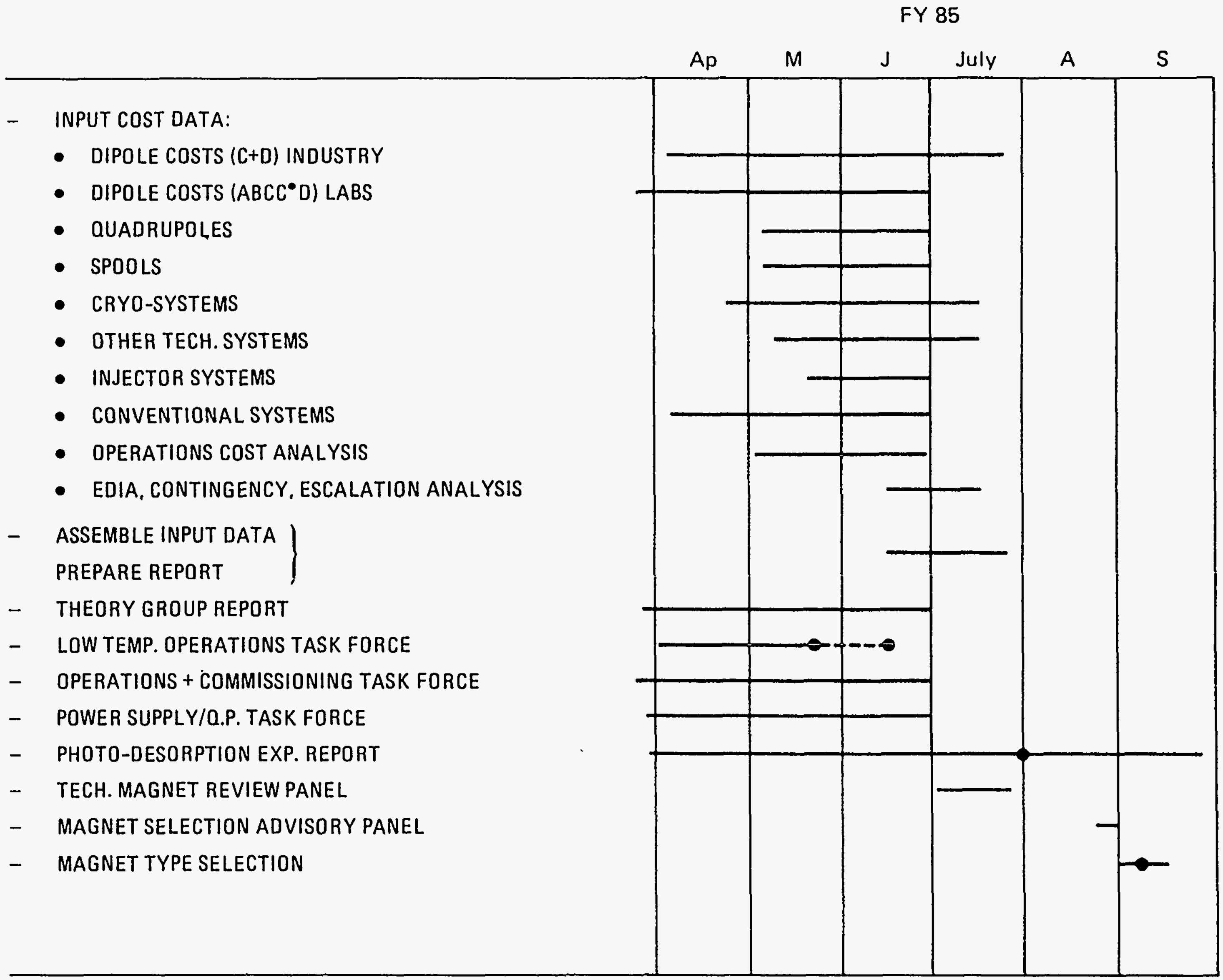

Fig. 2-1. Plan for magnet type selection.

strand used, taking into account the expected degradation from cabling and winding. Very little training is observed. Model production now in train is expected to produce an additional 70 meters of iron-dominated magnet beam channel and an additional 35 meters of high-field, conductor-dominated magnet beam channel by the end of FY 1985. In the iron-shaped types, maximum field is limited by iron properties to about 3T, and this has been achieved. In the conductor-shaped types, the current-carrying capacity of the conductor limits the field. This capacity increases as the temperature is lowered. The presently planned operating temperature for the SSC is about 4.5K, and the conductor-shaped types are tested at both that temperature and at 2K. In every instance the achieved field rises about 2T with this decrease in temperature, so that models made with the most recently produced, improved, superconductor achieve a field of 8T. A Low Temperature Operations Task Force is investigating the economics and systems implications of exploiting this improvement in the SSC design.

The basic mechanical and electrical arrangements employed in the magnet types under study are thus demonstrated to be sound. Remaining are questions about the relative difficulty of achieving the needed field quality in the various types and their economics, matters that are the objectives of the studies which will be well advanced by selection time.

The cost effectiveness of the magnets is heavily dependent on the performance of the superconductor used. At 5T and 4.5K, the commercially available cable used in the Tevatron magnets had a critical current of 1800 A/mm^2 in the superconducting filaments. The RDS cost estimate was based on the assumption that this level could be increased to $2400A/mm^2$ by the time SSC construction might be underway. As a result of cooperative R&D sponsored by the DOE and carried out by a collaboration of interested laboratories, universities,* and industry, this expectation has been shown to be too modest. The most recent batches of strand that will soon be incorporated in models achieve $2700A/mm^2$, and laboratory results indicate that further improvement is to be

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* It is to be noted that major contributors to the development of the processes resulting in improved performance are the Teledyne Wah Chang Corporation in producing high homogeneity NbTi alloy, and Prof. D. Larbalestier and colleagues at the University of Wisconsin in devising improved wire-production techniques which have been successfully transfered to industry.

expected. The strategy for exploiting these gains in the most cost-effective way is still being mapped out. In any event, some cost decrease will result.

Another area of potential concern highlighted in the RDS was the achievement of low heat leaks in the magnet system. Calculation showed that the average heat leak into the helium-cooled parts could be reduced from those measured in the FNAL Energy Saver (ES) Magnet System by about a factor of five through design changes giving more space for thermal shielding. The average loss to the low-temperature portion of the ES magnets is about 1.5 W/m. Recent measurements on a 12 m model of an SSC-style cryostat system complete with cold mass and prototype supports connecting the cold mass to the room-temperature outer vessel showed the combined heat leak to 10K and 4K portions to be less than 0.25 W/m. This then is a substantial step towards experimental verification of the refrigeration loads to be expected in the SSC.

The magnet system is the most costly of the technical systems, and verification and reduction of that cost is a continuing priority. Similarly the tunnel system is the most costly of the conventional systems, and attention to predicting its cost accurately is also a continuing priority. Without a site, specific work to improve accuracy is impossible. However, since the RDS we have continued to widen and deepen an analysis of tunnels built in the recent past. While the analysis is not yet complete, the evidence gathered so far points to the soundness of the tunnel cost conclusions in the RDS.

Securing a good site that meets the scientific and technical needs of the facility and permits use of economical construction methods is crucial. To this end considerable effort has been put into a technical advisory, the Site Parameters Document (SSC-15, June 15, 1985), to aid the DOE in the site-selection process. Upon completion of magnet type selection, the Site Parameters Document will be revised to reflect the actual magnetic field value selected.

In addition to these highlights, much other work in support of magnet type selection, superconductor development, and planning for the completion of Phase I R&D, including the conceptual design, has been carried out and is reported in more detail below.

2.2 Agreements on R&D Tasks, Budgets, Costs in FY 1985

The planned program for the SSC in FY 1985 involves primarily the CDG and BNL, FNAL, LBL, TAC, and some industrial contracts. The CDG has the responsibility for organizing, planning, and coordinating all R&D for the SSC Phase I program (See Chapter I). Efforts for the magnet program in FY 1985 involve coordination of laboratory programs and also the planning and analysis required for the selection of a magnet style. In the area of accelerator physics studies, the CDG staff, with assistance of personnel from other institutions, plays a central role. Specific details of these activi- ties and accomplishments are given in the following sections of this report under Accelerator Physics, Accelerator Systems, Conventional Systems, and Magnet Systems. The planned CDG budget for FY 1985 follows these categories and is summarized in Table 2-2 below.

Table 2-2 SSC Central Design Group Budget Plan (M$).

	FY85
Administration and Support	2.01
Project Planning and Management	0.40
Accelerator Physics	0.68
Magnet Program	0.50
Accelerator Technical Systems	0.50
Injection Systems	0.05
Conventional Systems[a]	1.18
Total	5.32

[a] Includes engineering study contracts.

The primary tasks to be performed by each of the participating institutions, as set forth in the performance agreements with the CDG, are outlined below.

Brookhaven National Laboratory

The primary tasks to be performed by BNL in FY 1985 are:

1. Completion of field-quality measurements on 3.2-cm bore, 2-in-1, NbTi magnets.
2. Construction and test, in collaboration with others, of at least four 4-cm bore, single-channel, cold-iron magnets of length sufficient to demonstrate basic mechanical and thermal properties.
3. Study of quench-propagation characteristics of various coil assemblies.

4. Study of cold diodes suitable for passive quench protection.
5. Continue, in collaboration with others, studies of fine-filament NbTi superconductor production.
6. Provide detailed design information, by Feb. 15, 1985, for 2-in-1 and 1-in-1 cosine-theta magnets sufficient for cost estimating and reliability analysis purposes. A magnetic design for a 2-in-1 quadrupole is to be included.
7. Carry out 4-cm bore-tube development, including high-conductivity inner coatings, special cooling for synchrotron radiation load, and bore-tube-attached correction-coil packages.
8. Provide facilities for and participate in photodesorption experiments relevant to SSC vacuum requirements.
9. Carry out preliminary planning of and make preliminary arrangements for carrying out the Long String Test and Short String Test as defined in SSC-SR-1001.
10. Participate in accelerator physics studies in support of aperture determination and preliminary conceptual design.

Fermi National Accelerator Laboratory

The primary tasks to be performed by FNAL in FY 1985 are:

1. Provide design support for the national cosine-theta magnet effort.
2. Design and develop a "dry-wound" coil-insulation system and test with appropriate 1-meter models. Provide wet-wound coils as required for cryostat tests.
3. Design and develop cryostat for 1-in-1 type cosine-theta magnets.
4. Provide design information needed for cost and reliability analysis of 1-in-1 "ironless" and cold-iron magnets of cosine-theta type.
5. Continue, in collaboration with others, development of high-current-density superconductor.
6. Carry out preliminary planning of and make preliminary arrangements for carrying out a Magnet Half Cell Test.
7. Provide support of CDG Aperture Task Force and preliminary conceptual design activities.
8. Provide support of CDG Photodesorption Task Force.
9. Conduct studies of modifications and additions to Tevatron which would be required in the event it is needed for SSC injector service.

Lawrence Berkeley Laboratory

The primary tasks to be performed by LBL in FY 1985 are:

1. Fabricate and test eight 3-foot superconducting accelerator magnet models per specified schedule.
2. Develop neutral coil-end designs.
3. Direct work of industrial consultants in cryostat design for cosine-theta magnets.
4. Continue superconductor and cable studies to improve annealing procedures; the goal is to produce fine-filament NbTi with J_c above 2400A/mm^2. LBL will also supply the strands and cable for both the LBL and BNL programs.
5. Assist CDG in magnet-design and cost-estimating activities.
6. Accelerator theory support to the CDG including participation in the National Magnet Aperture Task Force directed by the CDG. This effort will supply at least six FTE accelerator physicists to work on the general lattice, aperture, and machine-design problems for an SSC.

Texas Accelerator Center

The primary tasks to be performed by TAC FY 1985 are:

1. Fabricate and test superferric accelerator magnet models per specified schedule.
   (a) Ten or more 30-inch one-channel segments either coupled or uncoupled.
   (b) Four or more 25-foot 2-in-1 models.
   (c) Three approximately 92-foot 2-in-1 models (subject to accomplishment of a successful arrangement for assembly by others).
2. Accomplishment by February 15, 1985, of detailed designs and specifications for:
   (a) 2-in-1, 1"V x 1.3"H aperture dipoles
   (b) 2-in-1, 1" x 1.6" aperture dipoles
   (c) 1-in-1, 1" x 1.3" aperture dipoles
   (d) 2-in-1 quadrupoles with computations of $B(r,\theta)$ as a function of excitation currents equivalent to 1 TeV, 10 TeV, and 20 TeV operation.

   In this context 1-in-1 means magnetic, electrical and quench independence of the beam channels.
3. Accelerator theory support in the form of participation in the National Magnet Aperture Task Force directed by the CDG. This effort will supply at least two FTE accelerator physicists to work on the general aperture problems for an SSC.

The above tasks were developed at the beginning of FY 1985 with particular reference to Magnet Designs A, B, and C and modifications thereof. In December 1985, Magnet Design D, a 1-in-1 design incorporating B coil design into cold iron of A, was proposed with a collaborative arrangement between BNL, FNAL, and LBL. The plan for Magnet Design D and the specific Laboratory responsibilities are summarized below.

BNL-FNAL-LBL Magnet Design D

The short-range program plan for each Laboratory is as follows:

BNL

(a) Build four to six 1-in-1 4.0-cm-aperture magnets on same schedule as former 2-in-1 plan.

(b) Continue development of bore tube including coatings, special cooling for synchrotron-radiation effects, correction coils, etc.

(c) Develop magnet-measuring hardware.

FNAL

(a) Develop and design a "dry-wound" coil-insulation system and test with appropriate models.

(b) Develop and design the cryostat for the "long" [and possibly short (4.5 meter)] magnets.

LBL

(a) Continue fabrication of 1-meter models to confirm coil cross section and collaring approach.

(b) Develop appropriate end shape for NbTi coils (non-dog bone).

(c) Continue development of improved wire and cable.

The longer range program for Design D, while dependent on available funding, would be expected to include the following plan:

(a) Joint development of "long" magnets.

(b) Magnets will use more optimized NbTi, optimized iron, optimized ends, collars to accommodate "dry" and "wet" coils.

(c) Jointly developed high-current-density fine-filament NbTi wire.

(d) FNAL will build cryostats (at least 4).

(e) BNL will build collared "wet" coils with LBL ends (at least 4).

(f) FNAL will build "dry" collared coils (at least 4) using BNL collars.

(g) Parts for 10 more "long" magnets will be procured for fabrication in FY 1986.

The budget and reporting categories for each of the participating institutions were reviewed by the Fiscal and Managerial Task Force in November 1984. The resulting established budget categories for each institution are found in Table 9-5, p. 120.

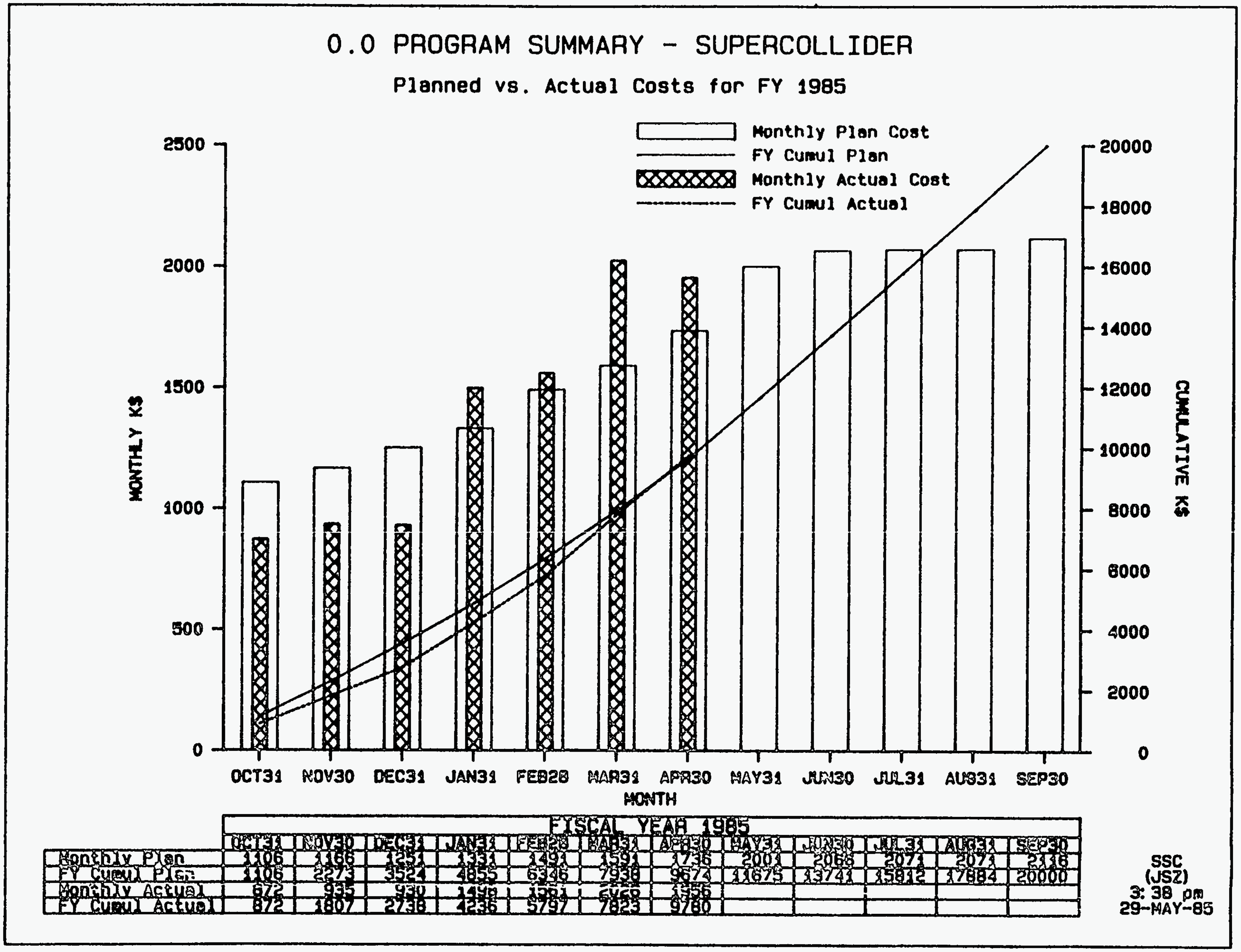
A summary of the R&D costs by institution is shown for the SSC program and for related Laboratory accelerator programs in Tables 2-3 and 2-4. The cumulative costs and the monthly costs are graphically displayed in Figs. 2-2 and 2-3. The projected SSC funding level for the first seven months of operation was $9.67M. The actual costs were $9.78M as shown in the table at the bottom of Fig. 2-2.

Table 2-3. Program Summary - SuperCollider.
April 1985 Cost Report (K$)

	Program Element	Year to Date	Annual Budget
1.	CDG Program	2068	5325
2.	BNL SSC Program	3085	4980
3.	FNAL SSC Program	2519.9	3905
4.	LBL SSC Program	464	790
5.	TAC SSC Program	1640.6	5000
	Total SSC Program	9777.5	20000

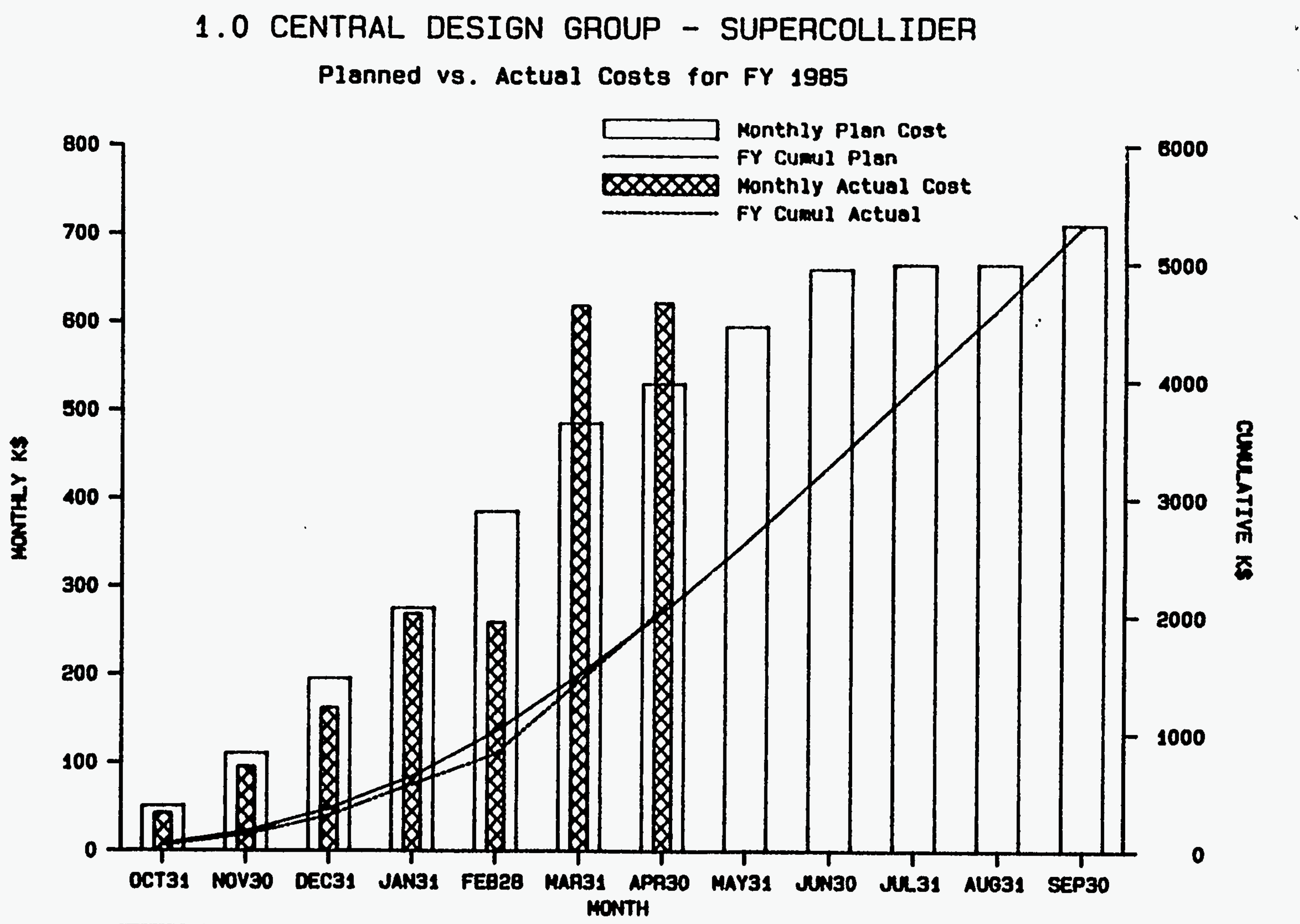
Table 2-4. SSC-Related Accelerator Program Summary.
April 1985 Cost Report (K$)

	Program Element	Year to Date	Annual Budget
1.	BNL	910	1670
2.	FNAL	1628.7	2120
3.	LBL	708	1210
	Total SSC Related	3246.7	5000



	FISCAL YEAR 1985											
	OCT31	NOV30	DEC31	JAN31	FEB28	MAR31	APR30	MAY31	JUN30	JUL31	AUG31	SEP30
Monthly Plan	1106	1166	1251	1331	1491	1591	1736	2001	2066	2071	2071	2116
FY Cumul Plan	1106	2273	3524	4855	6346	7938	9674	11675	13741	15812	17884	20000
Monthly Actual	872	935	930	1498	1561	2026	1956					
FY Cumul Actual	872	1807	2738	4236	5797	7823	9780					

Fig. 2-2



1.0 CENTRAL DESIGN GROUP - SUPERCOLLIDER

Planned vs. Actual Costs for FY 1985

	FISCAL YEAR 1985											
	OCT31	NOV30	DEC31	JAN31	FEB28	MAR31	APR30	MAY31	JUN30	JUL31	AUG31	SEP30
Monthly Plan	50	110	195	275	385	485	530	595	660	665	665	710
FY Cumul Plan	50	160	355	630	1015	1500	2030	2625	3285	3950	4615	5325
Monthly Actual	42	95	162	269	259	619	622					
FY Cumul Actual	42	137	299	568	827	1446	2068					

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Fig. 2-3

2.3 Overview of Planned Future Program

The beginning of FY 1986 will mark an important transition in SSC R&D work. With the selection of the basic magnet type, design of the overall system can become particular and effort can focus on the major cost items of the SSC, the magnet and tunnel systems. An integrated conceptual design will be ready by mid-FY 1986, and a significant number of full-scale magnet prototypes will be tested individually by the end of FY 1986 with magnet system testing (Half Cell Test) to begin in early FY 1987.

Magnet work to date has been on a broad front, examining several magnet technologies in parallel, largely at DOE Laboratories. After selection, work will concentrate on the chosen type. While primary responsibility for the first full-scale prototypes of the selected type will be with laboratories now involved in magnet development, FY 1986 should see the beginning of a strong industrial involvement in SSC magnet technology. By 1987, magnet prototype production in industry should be established so that serious production could begin in 1988.

In FY 1984 and FY 1985 sketch designs encompassing various magnet technical possibilities were made and studied. From these and from engineering and hardware studies of the several magnet possibilities, a magnet selection will be made. In FY 1986 the emphasis will be on further technical development of the dipole magnet for purposes of cost and design verification. Intense accelerator physics and engineering design work will flesh out the technical systems conceptual design based on the selected magnet. Engineering studies and modeling of less costly but technically critical components of the magnet system, such as focusing and correction magnets, will also begin in FY 1986.

Increased resources for beginning industrial involvement in SSC magnets in FY 1986 are requested. In FY 1987 a significant boost in resources is needed for industrial production of dipole prototypes, system testing of dipoles, production of focusing and correction magnets, and other accelerator system development and prototyping.

Through concentration of resources on a single magnet type, it will be possible in FY 1986 to construct and individually test enough SSC prototype magnets for one half cell. These magnets will be assembled into an array for the Half Cell Test beginning in FY 1987. By this means, the engineering viability of the magnet design will be explored and material quantities firmly established. The initial prototyping experience at the laboratories, coupled with the growing industrial involvement and its associated manufacturing studies, will serve to establish tooling and labor costs.

Accelerator systems and accelerator physics work in FY 1986 will focus on the production of a viable, technical conceptual design from which a detailed cost estimate can be made. In the latter part of FY 1986 and through 1987, work in these areas will emphasize certain critical-component R&D, system testing of the magnets and associated instrumentation, and developing detailed systems and systems-interface specifications to provide a very detailed picture of the SSC technical systems.

Owing to their considerable cost impact, conventional systems will also receive further attention. A non-site-specific integrated design will be worked out to identify all principal structures; a general site master plan for optimized adaptation of conventional structures to the scientific and technical needs of the facility will be devised; cost sensitivities to geology, topography, and construction method will be investigated.

To round out the picture of what the full SSC project would entail, considerable planning of engineering development, fabrication, installation, and sequencing is needed. This activity, including the study of critical-path networks and quality-control plans, will be an important effort of the Project Planning and Management Division. From these efforts possible schedules and resource-need profiles will be developed, showing how the R&D program could interface with the beginning of construction.

Milestones and goals are shown in Fig. 2-4. Detailed projected time lines for these activities are displayed in Figs. 9-1 through 9-5 at the end of Section 9.2.

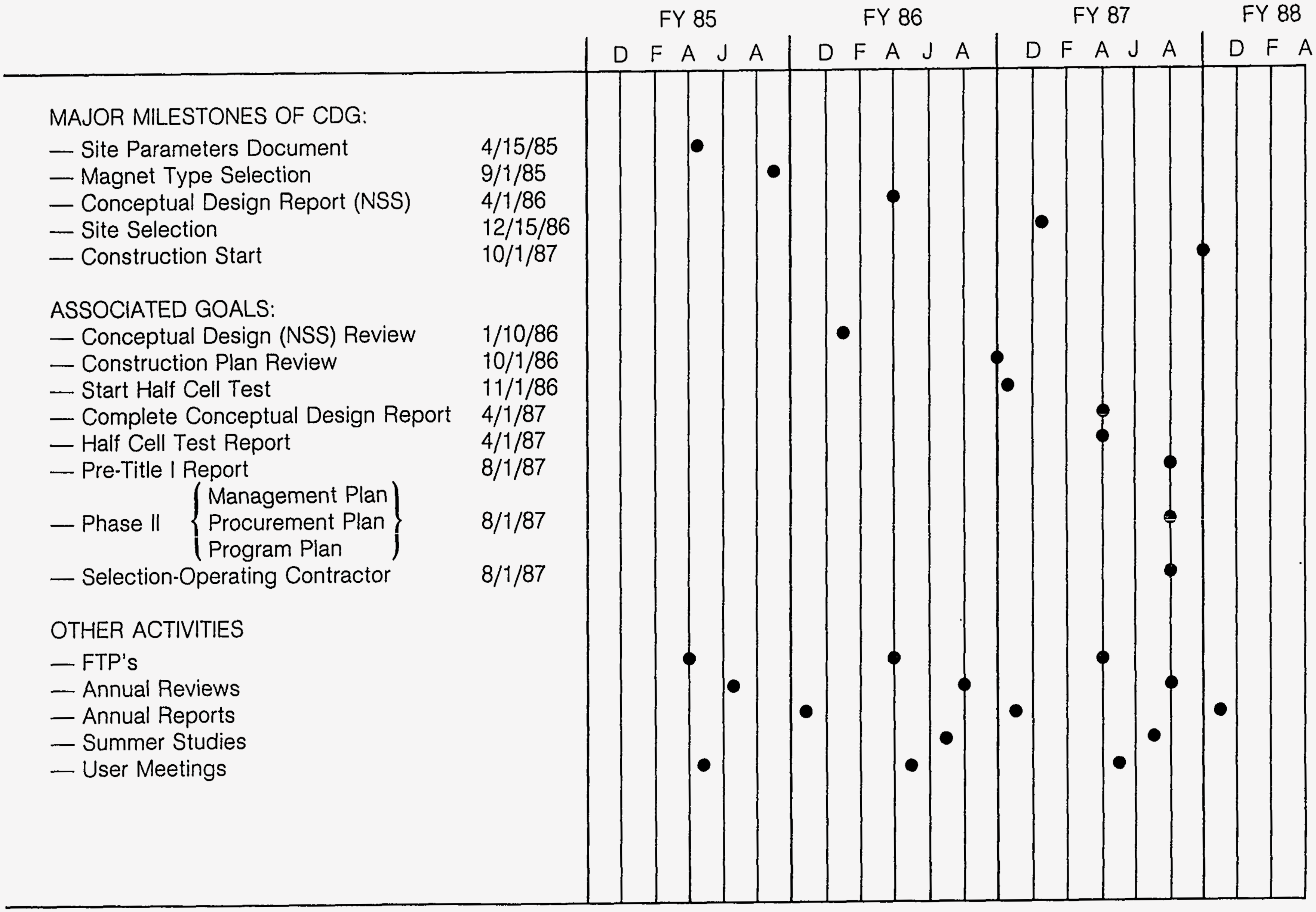

Fig. 2-4. SSC Milestones and Goals

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CHAPTER 3. ACCELERATOR PHYSICS

3.1 Accomplishments Since RDS

The accelerator physics efforts during this period have been a continuation of the work started with the RDS. It was observed in the RDS that one of the most urgent accelerator physics tasks is the aperture evaluation. The aperture required by the beam imposes an important tolerance constraint on the magnet field quality, which translates directly into the cost of the magnets. An Aperture Workshop was therefore held at Berkeley shortly after the formation of the Central Design Group in order to launch a systematic attack on the aperture question. The workshop was organized into seven groups, each responsible for one of the identified tasks. After the workshop, an Aperture Task Force (ATF) was formed to coordinate and carry out the assigned tasks. A series of meetings by the working groups and ATF meetings by the working group coordinators (see Appendix A) were held to monitor the progress and to make new task assignments.

The aperture evaluation program outlined in the workshop included the following:

(a) Setting up a data base at the CDG with network connections to the various laboratories and universities;

(b) Defining the required aperture for beam stability and operating conditions;

(c) Designing test lattices for efficient aperture-evaluation purposes;

(d) Defining the magnet field errors of the various magnet designs for aperture studies;

(e) Developing the particle-tracking as well as the analytical programing tools;

(f) Actual tracking studies;

(g) Experiments on existing accelerators.

The main objective has been to provide information for the magnet type selection, scheduled for September 1985. In addition, the tools and techniques developed will provide a best possible estimate on the final aperture for the selected magnet style at a later time.

Since the workshop, the data base has been established, test lattices have been created and stored in the data base, and a set of magnetic field errors appropriate to a range of apertures and magnet types has been derived. These errors are estimated by scaling from the FNAL Tevatron and BNL CBA magnets and have been checked against early model measurements. The field descriptions include both systematic and random multipoles. For conductor-dominated magnets, the persistent current contribution at low fields is included also. Improved programs for tracking studies which can incorporate realistic error distributions in full-size lattices of the scope of the SSC are being developed at Stanford, Argonne National Laboratory (ANL) and the University of Maryland, as well as at the CDG.

Much of the aperture study is still in train, and detailed reporting is thus premature. Assessments needed for comparisons of magnet types will be complete by the end of July. A rough feeling for the nature of the results can be found in SSC-24 and SSC-25, which will appear in the Proceedings of the 1985 Particle Accelerator Conference recently held in Vancouver. Figure 3-1 shows the dynamic aperture computed by tracking for a typical test lattice with and without higher order multipoles added to the dipole field. The ideal

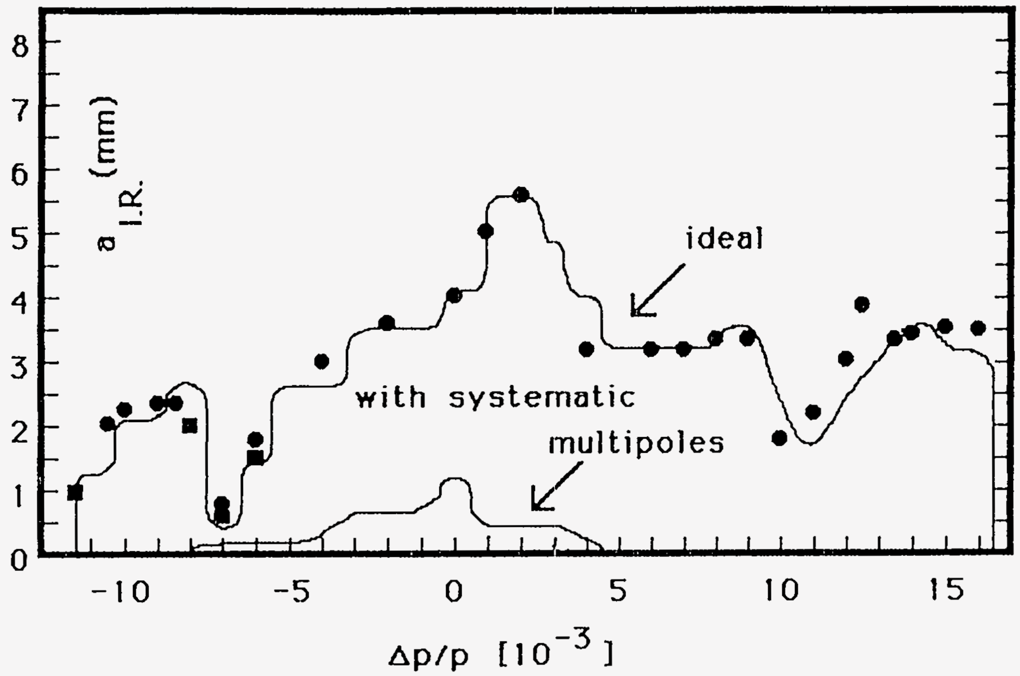

Fig. 3-1. Chromatic aperture of TLA1 lattice at interaction point. DIMAT data are given by solid lines, PATRICIA data by circles, and MARYLIE data by squares. Lower curve shows the influence of systematic multipoles on dynamic aperture in the case of 4-cm bore, conductor-dominated magnet. Cell length is 200 m in these calculations.

case incorporated ideal dipoles, quadrupoles, and chromaticity-correcting sextupoles. The stable oscillation amplitude is recorded at the crossing points. The corresponding stable amplitude in the bending dipoles is obtained by multiplying by 17.3. In the case shown, the potential dynamic aperture of the ideal machine is considerably larger than the physical aperture. When the multipole content of the dipoles is included, the dynamic aperture shrinks substantially but is still sufficient to meet SSC requirements. Further study using shorter cell lengths is indicated. It appears that stable amplitudes up to about 1 cm in the arcs can result if $\Delta B/B$ of less than a few parts in 10^4 is achieved at 1 cm radius.

For assessing the physical aperture requirements of the magnets, the concept of "linear aperture" is useful. The linear aperture is defined by those amplitudes for which beam response is essentially linear, i.e., smearing of amplitudes from turn-to-turn is small (less that 10%) and betatron tune deviates by no more than 0.005 from the infinitesimal amplitude frequency, all for fractional momentum deviations less than 10^{-3}. Efficient operation demands that this aperture be larger than the natural beam size at injection to allow control of injection and beam gymnastics by reasonable feedback techniques and minimal operator intervention. For example, with a one micrometer invariant emittance and a 200 m cell length ($\hat{\beta}\simeq300$m), the full beam occupies a transverse extent of about 3 mm. A full linear admittance of 1 to 1.5 cm under these circumstances would appear adequate. While the result is very preliminary, it appears that for economically reasonable cell lengths and for approximately $\sqrt{\hat{\beta}}$ scaling of the needed linear admittance, coil inner diameters of 4 to 5 cm will be adequate. This conclusion could be modified by further tracking studies or by the results of the photodesorption studies. Relevant also are the results of collective-effect studies, which, as reported in SSC-25, indicate that adequate stability can be achieved in the range of cell lengths, bore sizes, and circumferences now being considered.

It should be noted that the tracking work has depended crucially on use of the Livermore Magnetic Fusion Energy (MFE) supercomputer time made available by the DOE. A total of 806 hours of CRAY time has been allocated for SSC design computations for FY 1985. So far, 412 hours have been consumed. The remaining hours are expected to be used up by the end of the fiscal year.

During this period, it has been necessary to develop quickly the design programs at the beginning of the year and then to use the allocations carefully, minimizing the number of runs while trying to obtain sufficient information. Computing has been concentrated mainly on the aperture evaluation needed for magnet selection.

As the design studies proceed, computation of other effects will consume more time, while the aperture computations will continue. For the next fiscal year, it is not expected that the present CRAY allocation will be adequate. At the peak of SSC design efforts, the needed CRAY time will be more than 2000 XMP hours per year, as estimated by the DOE subpanel on computing needs for high energy physics.*

A major purpose of accelerator experiments addressing the aperture issue is to supplement and check tracking codes and their computations. In the past, such studies have also revealed phenomena not predicted in the numerical simulations. To this end, experimental efforts are now underway at SPEAR and the Tevatron and initial results are at hand.**

In the initial Tevatron experiment, the beam positions are measured by two nearby position monitors to give the information on (x, x') for successive revolutions. The horizontal tune is moved to the value of 19.333 with a set of sextupoles powered to drive the third integer resonance. The results, shown in Fig. 3-2, agree quite well with what is expected from a first order resonance theory. More experiments to confirm second order theory, as well as detailed tracking studies are planned in the near future.

In addition to the aperture-related studies, the SSC accelerator physics studies have included collective effects, beam-beam interaction effects, intrabeam scattering effects, and lattice designs. In these studies, the parameters suggested in the RDS are reviewed and found to be basically optimized with several relatively minor adjustments.

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*A. Dragt et al., "Computing Requirements for the SSC Accelerator Design and Studies," Proceedings of the 1984 DPF Summer Study on the Design and Utilization of the SSC (Division of Particles and Fields of the American Physical Society, 1985), Snowmass, Colorado, p. 395.

**(a) D.A. Edwards, R.P. Johnson and F. Willeke, Fermilab-PUB-85/59 (1985) "Tests of Orbital Dynamics Using the Tevatron". (b) F. Willeke, TM-1309 (1985), FNAL internal note, "Using the Tevatron Beam Position Monitor System to Investigate Transverse Phase Space". (c) P.L. Morton et al, SPEAR group, SLAC-PUB-3627 (1985) "A Diagnostic For Dynamic Aperture".

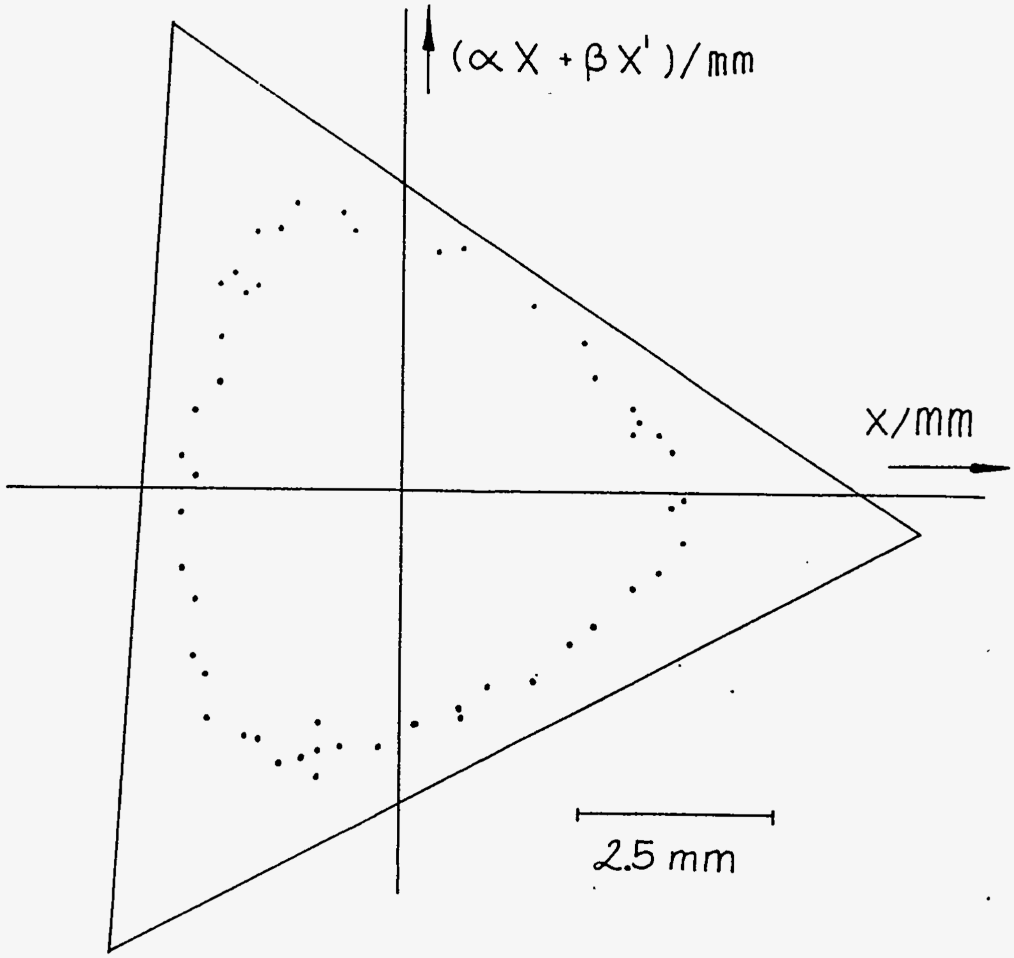

Fig. 3-2. The x, x' plot observed for successive turns in the Tevatron for a tune near a third integer (19.333) with sextupoles powered to drive the third integer resonance. The triangle drawn on the figure is the calculated limit of stability, the separatrix.

In anticipation of the Conceptual Design Report in April 1986, an effort has been initiated to create a detailed "realistic" lattice design that takes into account all known accelerator physics and systems requirements up to date. This effort was begun with a workshop at the CDG on May 29-June 4.

It is necessary to explore the various possible options for the SSC with proper priorities. These include clustered interaction region designs, pp option, polarized beams, ep option, fixed targets, unbunched beams, etc. Extensive studies were made at the 1984 Snowmass meeting* on these options.

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*Proceedings of the 1984 DPF Summer Study on the Design and Utilization of the SSC (Division of Particles and Fields of the American Physical Society, 1985), Snowmass, Colorado.

At the CDG, in parallel with the realistic lattice effort, a study was started to evaluate the implications of clustered interaction regions for the SSC. This study group has held two meetings in April and June (see Appendix A). The plan is to make an explicit recommendation in September for inclusion in realistic lattice design considerations.

3.2 Plans for FY 1986 and beyond

After the selection of the basic magnet design, the most immediate goal of accelerator physics studies is support of the effort on the Conceptual Design Report scheduled for April 1986. To help the conceptual design, a first step is to establish an initial list of parameters during October 1985. Such lists were given in the RDS. The list for the chosen type of magnet will benefit from the studies briefly described in Section 3.1. Such a list will also help the accelerator systems and the conventional facilities designs.

One of the more important elements of the parameter list is the lattice design. As mentioned in Section II.2, an effort has already been started to create a realistic lattice for each of the possible magnet types which takes into account detailed accelerator physics and systems considerations. It is expected that a realistic lattice design will be available at the time of the initial parameter list.

The study of the various options for the SSC needs to proceed in a timely fashion. The option of clustered interaction regions has been started at the CDG since it has potentially the most extensive impact on the overall conceptual design. The study group will make its first recommendation to the CDG at about the time of the magnet selection. The realistic lattice to be presented in October will take into consideration both the magnet selection and the recommendation from the clustered IR study group.

Once the initial lattice and the initial parameter list are established, the accelerator physics studies will proceed in several directions: further aperture evaluation, collective effects, lattice design, options studies, beam-beam effects, operation and systems issues, and boosters and linac issues (see master plan). The results of these studies will be communicated to the other studies in parallel and when applicable will appear as changes in the parameter list. The parameter list acts as a brief summary of the current conceptual design. An interim review of the parameters will be held approximately in January 1986. As time proceeds, the lists will firm up.

Shortly before the Conceptual Design in April 1986, the various accelerator physics studies being carried out will be described in technical reports. The studies to be included are listed below in some detail:

Aperture Evaluation

- networks, data-base maintenance
- field-quality studies (tolerances, trade-off between multipoles, correction of multipoles)
- test lattices
- analytical techniques for aperture evaluation (conventional perturbation theory, Lie algebraic techniques, nonlinear Hamiltonian dynamics)
- program developments, both analytical and tracking programs (Lie algebra codes, kick codes)
- tracking studies (linear aperture, dynamic aperture)
- dedicated processors when applicable

Collective Effects

- impedance calculations (analytical and numerical calculations, 2- and 3-D programs)
- impedance budget (bellows, pick-up electrodes, 4.5K copper resistive wall, rf cavities, kickers, beam separators)
- instability threshold and growth rates (analytical calculations, numerical simulations, needed energy aperture, multi-bunch instabilities, mode coupling, feedback requirements, choice of synchrotron tune)
- intrabeam scattering, Touschek effects (needed energy spread, rf requirements)

Lattice Design

- interaction-region optics (quadrupole arrangements, IR hall requirements, free space for detectors)
- cell optics (cell length optimization, phase advance per cell)
- utility sections (rf, injection, abort and beam scraping sections)
- sextupole schemes (number of families, chromatic aberrations)

Parameters and Options

- parameter optimization (overview, scaling laws)
- options (clustered IR, $\bar{p}$-p, polarized beams, ep, fixed target, alternative acceleration schemes, unbunched beams, terrain following)

Beam-beam Effects

- beam-beam limit (head-on tune shift, resonance widths)
- crossing-angle and long-range effects (bunch spacing, orbit and tune-shift effects, synchrobetatron resonances, coherent beam-beam effects, Pacman effect)
- tracking simulations (crossing angle, simulations with and without lattice errors, coherent and incoherent effects)

Operation and Systems Issues

- operation requirements (linear aperture, first turn, abort trigger, detailed acceleration procedure, bring beams in/out of collisions, computer simulations)
- rf specifications (injection chain, rf noise, transient beam loading, impedance)
- systems elements (realistic lattice, spool-piece definition, orbit-correction scheme, feedback systems, impedance budget, magnet specifications)
- tolerance specifications (magnet alignment, magnet strength errors, multipole tolerance, power-supply ripple, survey errors, beam-position-monitor errors, ground motion, numerical simulation of error effects)
- magnet shuffling

Boosters and Linac

- lattice designs
- collective effects (instabilities in the boosters, space-charge effects, beam break up in linac, gun design)
- emittance budget

After the Conceptual Design Report, it is important to continue the accelerator physics studies along the same lines described above. For example, as the site selection is made, the studies will take into consideration the site-specific issues such as terrain following. As the detector needs are specified, the interaction region optics will be modified. In addition, detailed parameter optimization will continue to require studies to be made on the various accelerator physics issues such as the lattice and the beam-beam and collective effects.

Assuming the availability of adequate resources, the above mentioned studies will be carried out in depth after the 1986 Conceptual Design, leading to a Final Conceptual Design in April 1987.

CHAPTER 4. ACCELERATOR SYSTEMS

4.1 Issues at time of RDS

The Reference Designs Study was primarily concerned with getting a cost estimate for sample SSC designs and determining if there were any indications of significant difficulties in design, construction, or operation. The result of the study was that the SSC is feasible with present day technology, but that there are a number of engineering questions that should be answered in order to design and develop cost-effective, reliable, and high-performance collider rings. The most important issues that affect the Accelerator Systems Division (ASD) of the CDG are listed below:

1. **Magnet Selection.**

Because of the success of the Tevatron, there is no longer any doubt that magnets of sufficient quality and performance can be produced in quantity. The issues that remain are:

(a) The choice of a magnet type that will result in a cost-effective, reliable, and high-performance multi-TeV collider, without excessive R&D.

(b) The effects of a particular magnet type on the designs of the accelerator systems.

2. Systems Tests.

Whatever the magnet type, it will be important to test the prototypes and the production magnets as systems in order to detect design flaws and to determine that the magnet system is able to be integrated into all the other systems that make up the SSC. Tests of strings of magnets are also an important tool in the development of the various accelerator systems. A systems test program must effectively address:

(a) The development of a cost-optimized, but conservative and reliable, magnet system design.

(b) The utilization of string tests as an effective test and development tool for the whole accelerator system.

3. Cryogenics.

The cryogenic systems that were sketched out for the RDS assumed that the magnet cryostats would have a static heat load to 4.5K that was at least a factor of five smaller than the Tevatron. In addition, there were three distinct cryogenic system designs presented in the RDS, none of them optimized.

The major issues of a cryogenics R&D program are:

(a) The development of a cryostat for SSC magnets with sufficiently low heat loads.

(b) The optimization of the cryogenic systems and refrigerators, based on commercially available components.

(c) The feasibility of operating the magnet system at temperatures lower than 4.5K to obtain higher field (and therefore higher energy or the same energy with a smaller ring).

4. Vacuum.

Good beam lifetime requires ultra-high vacuum. The SSC's energy is sufficiently high that the protons emit a considerable amount of synchrotron radiation, one result of which will be to desorb gas from the beam-tube walls. Because there are very little data on photon-induced desorption from cryogenic surfaces, it is necessary to mount a R&D effort to obtain the required information on the expected gas density from synchrotron radiation.

5. Beam Losses.

Its very high luminosity makes beam loss a particular problem for the SSC. With clustered interaction regions, there is a potential exacerbation of the problem because of the creation of a beam halo by small angle elastic scatterings. Beam loss concentrated in one area can cause quenches that would be disruptive to the research program and to the cryogenic and magnet systems. The R&D effort on beam losses must investigate:

(a) The effects of beam loss from one interaction region to another for various arrangements of the lattice and interaction regions.

(b) The optimum design and location for beam scrapers.

(c) The radiation intensity and spectrum in the tunnel, and the resulting effect on electronics and materials used in the magnets.

(d) An effective design of the injection and beam-abort systems to minimize beam loss.

6. Reliability.

The great size and large number of components of the SSC, together with the need for operational availability, make it imperative that all the systems work reliably. The Tevatron provides a model from which a reliability data base can be established and extrapolations made to the SSC. The R&D program should address:

(a) The interpretation of the existing data on accelerator reliability regarding the SSC's construction, commissioning, and operation.

(b) The potential for increased operational availability by improved design, development, and testing, and at what capital and operating cost.

7. Cost Estimates.

The cost estimates of the RDS can be improved and extended in a number of ways. In particular, the estimates of the systems costs were carefully done only for one of the designs, and were based on general rules, not on quotations from vendors. Cost issues needing early R&D are:

(a) Costs of the accelerator systems that are specific to each of the possible magnet types, preferably based on vendor quotations.

(b) Reliable scaling rules to understand the sensitivity of the machine designs to possible changes.

4.2. FY 1985 Activities Bearing on Magnet Type Selection

The tasks assigned to the ASD for the magnet type selection are listed in Table 4-1. They concern the reports of two task forces that were formed to study the effects of the different magnet types on commissioning and operations

Table 4-1. ASD Tasks for Magnet Type Selection.

	Title	Date Due
1.	The Report of the Task Force on Commissioning and Operations of the SSC	June 1985
2.	The Report of the Task Force on Power Supplies and Quench Protection	June 1985
3.	A Preliminary Report on the Photodesorption Experiment for cryogenic beam tubes	August 1985
4.	Analyses of the costs of the systems and installation for the various magnet types	August 1985

of the SSC, and on the design of the power supply and quench protection systems. In addition, there are two other aspects of the early R&D that will influence the magnet type selection: (i) the results of the photodesorption experiment, and (ii) some new cost estimates. These are listed in the table above, and are discussed in more detail later in this chapter.

A Task Force on Commissioning and Operations was formed in January, 1985 to study the commissioning and operating characteristics of collider rings constructed from the various magnet designs (see Appendix A for membership, schedule, etc.). A Preliminary Report of the Task Force on Commissioning and Operations was submitted to the SSC Director on May 20, 1985. The final report is due on July 1. The preliminary conclusions of the Task Force are:

- Machines with reasonable operational characteristics can be built with any of the magnet types now under development.
- There are real differences among the magnet types that result in variances in operational behavior, flexibility, and operating costs.
- One-in-one magnet types are preferred over two-in-one types for their greater flexibility, ease of operation and commissioning, and a number of design details of the complete machine. These factors are considered more important than having fewer cryostats, the major advantage of two-in-one types
- Over/under magnet configurations are preferred to side-by-side configurations, when considering one-in-one types, because of better use of tunnel space and easier installation and replacement. There are also more options for configuring the injection and abort functions for either two-in-one or one-in-one magnet types.
- There is no obvious choice to be made at this time between low-field and high-field magnet types. From the designs presently available, it appears that the low-field design results in a machine that is 5% to 10% more costly to operate than a ring made out of high-field magnets. However, there are other issues, such as synchrotron radiation and collective effects, which may be more important than the operating cost, and have yet to be completely evaluated.

During the studies conducted for magnet type selection, it became obvious that the CDG would need detailed information about the power supply requirements and the quench behavior of the different magnet types. A Workshop on Power Supplies and Quench Protection was held at the CDG on April 1-5, 1985 (see Appendix A for membership, etc.) and at the end of that workshop a report was submitted containing the results of the preliminary studies and an outline of the needed continuing work. A final report is due by July 1, 1985. The issues that were studied are:

- The behavior of the multiple power supplies of the superferric design, particularly taking into account the strongly coupled coil configuration.
- The capability of attaining the required power supply regulation. It appears that a regulation of $\Delta I/I \simeq 10^{-5}$ will be necessary to maintain the tune within an acceptable range.
- An investigation of the expected transmission-line behavior of the power supply and magnet system.
- Agreement about the input parameters that should be used for the quench-propagation calculations.
- A study of questions of passive quench protection, such as the maximum permissible magnet length, the required sensitivity of detection schemes, and the quench-propagation velocities.
- The pressure rise in cryostats during a quench, especially in the high-field magnets.

4.3. Cryogenics.

Since the RDS, a considerable amount of work has been done to answer the questions about the cryogenic system. Work on the cryostat has taken place at FNAL, including the testing of model cryostats. Design of the refrigerator cycle has been done at BNL and at Cryogenic Consultants, Inc. (CCI). The work on cryostats is described in detail in Section 5.4.

Figure 4-1 shows the relative heat leak of the FNAL model cryostat as a function of pressure in the insulating vacuum. It doubles at 5×10^{-3} Torr, a very high pressure, indicating that the thermal multilayer insulating blankets are very effective. The equivalent for the Tevatron is about 2×10^{-5} Torr to double the heat leak.

The total heat-leak measurements are shown in Table 4-2. The 80K and 10K results look very good compared to calculation. The 4.5K result is not as good, being high by a factor of two. However, it is known from other tests that the heat intercepts on the support columns are not at the expected 10K, even though the shield is at 10K, and this accounts for most of the extra heat load.

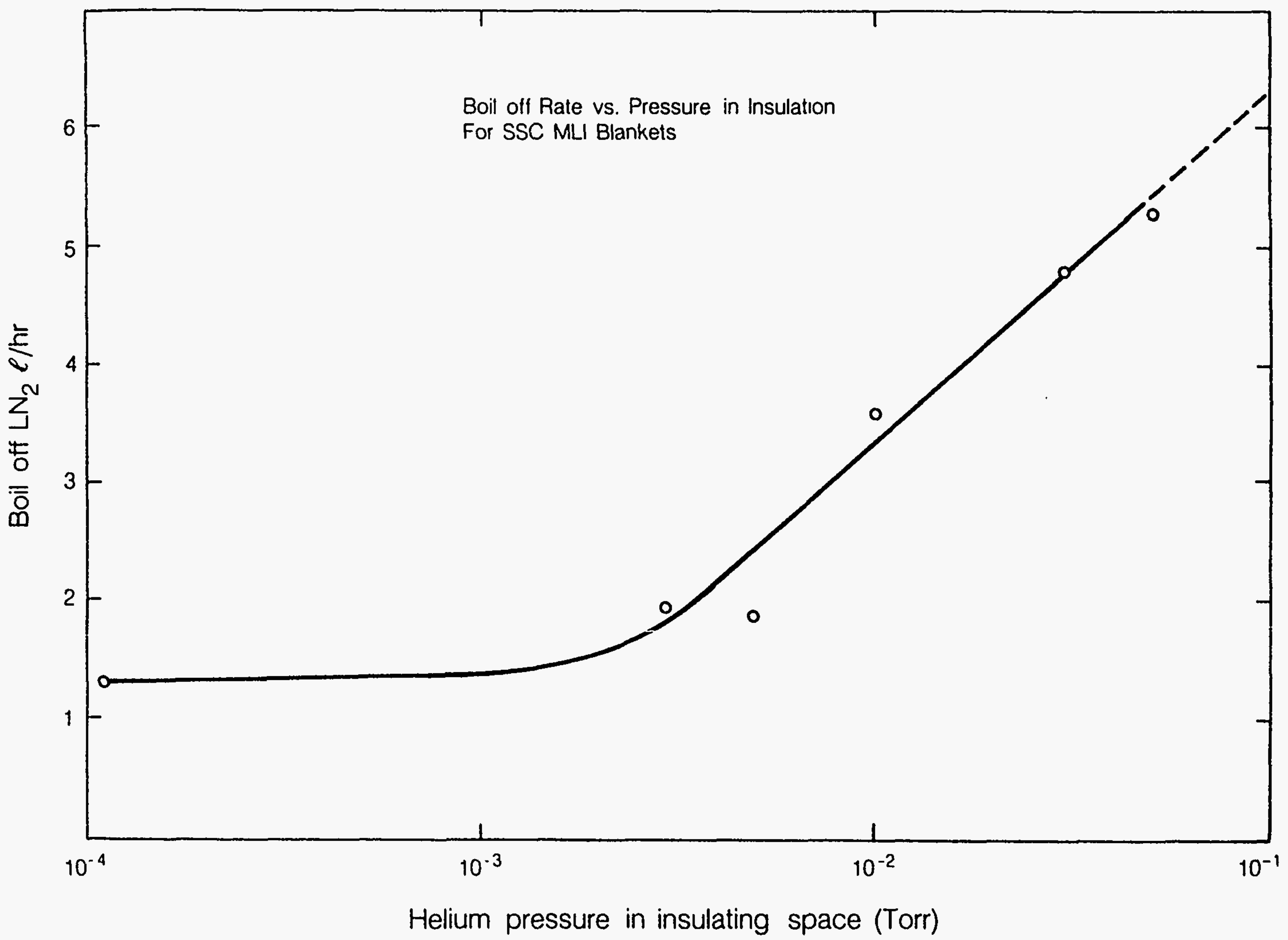

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Fig. 4-1. Liquid nitrogen boil-off rate vs. pressure in insulation region of the Heat Leak Model Cryostat.

Table 4-2. Preliminary Results on Heat Leaks (in watts) from 12 m Thermal-Effects Model Cryostat.

Temperature	Calculated or Auxiliary Prediction		Measured Value	Measurement Method
80K	End vessels (measured)	22.0		Boil off
	Thermal radiation (calculated)	8.3		
	Support conduction (calculated)	21.2		
		51.5W	55.5W	
10K	Thermal radiation (calculated)	0.74		temperature rise of gas stream
	Support conduction (calculated)	1.54		
		2.28W	2.28W	
4.5K	End vessels (measured)	0.450		Boil off
	Thermal radiation (calculated)	0.002		rate of rise of temperature of cold mass
	Support conduction (calculated)	0.125		
		0.577W	1.060W	

A group involving people from FNAL, BNL, LBL, and General Dynamics has been formed to start the design of a type D cryostat. A preliminary design of the cryostat for cost estimating is done, and a design criteria document is in its fourth revision. The design criteria are used as a guide for the final cryostat design work.

Work on modeling the efficiency of the cycle used in the refrigerator system is underway at BNL and CCI. All the designs now use essentially the same system, with pressurized single-phase liquid in the coil region, returning cold gas or single-phase liquid to the refrigerator. The use of two phase return fluid is no longer present in any of the designs.

There are differences in the designs that reflect the opportunities presented by the different magnet types. The one-in-one types, for example, use the fact that there are two separate cryostats to supply the shield cooling in one cryostat and return it through the other cryostat shield. This allows the refrigerator to supply the shield flow at a higher temperature than 4.5K, without needing a separate pipe, resulting in a much higher Carnot efficiency, and therefore less operating cost. The similarity of the designs allows work to proceed to the next level of design, so that the cost estimates can be made more exact without waiting for the magnet type selection.

The development of Design D has made it necessary to understand how to remove the heat generated in the coils by the synchrotron radiation. There must be large flow paths in the cold iron for cooling the mass. This robs flow from near the coils during operation. Studies show, however, that the conduction across the steel is sufficient to keep the temperature of the coils within 0.1K of the fluid, without using complicated flow paths.

4.4. Photodesorption Experiment

In addition to the added heat load, the synchrotron radiation photons desorb gas molecules that are on the walls of the beam tube, thus increasing the gas density in the beam pipe. Previous studies showed that there were essentially no data on photon-induced gas desorption from cryogenic surfaces. New experiments were therefore necessary. A Photodesorption Task Force was set up in August 1984 and recommended a series of experiments at the vacuum ultraviolet ring of the National Synchrotron Light Source at BNL (See Appendix A for membership etc., of Task Force).

It is known from electron storage rings that the pressure rise in the presence of synchrotron radiation can be very large. The problem is solved in electron rings by designing distributed pumping into the beam tube, which removes the gas as it evolves from the wall. Eventually, the strip on the beam tube that is hit by most of the synchrotron power becomes depleted of gas, and the pressure decreases to tolerable levels. The cryogenic beam tube of the SSC is different in a number of important ways: The yield of molecules per photon, is not known. The desorbed molecules merely move to some other place on the tube, where they remain, due to the high sticking probability of the cold tube walls. They are then available to be desorbed by photons reflected with high probability from the walls. There might be desorption processes that are active at cryogenic temperatures that are absent or insignificant at room temperature.

The first results of the experiment are from an aluminum beam tube room temperature. There is more experience with aluminum beam tubes than with any other material, permitting a check on the technique and the calibrations. The experiment on the cryogenic stainless steel beam tube will start in June, 1985, and some preliminary results should be available by the end of July, 1985. The experiment will continue in order to refine the data and to test different materials, and, if necessary, different beam-tube designs.

The most important experiment is to expose the wall of the beam tube to the synchrotron light and measure the total and partial pressures as a function of exposure. This is done to measure the rate at which the clean-up occurs, in order to compare it with other experiments. A total exposure of about 6000 mA-h of circulating beam in the light source has been taken. Preliminary results from an eight-hour exposure totaling about 1000 mA-h are shown in Fig. 4.2. The graph shows the circulating beam current in the light source as a function of clock time, the total pressure normalized to the circulating beam current, and the hydrogen partial pressure normalized to the circulating current. The most puzzling result is the sudden change in the nature of the clean-up of the total pressure during each run, except for the first run, which appears as expected. Detailed interpretation must await the calibration runs. Note that the hydrogen partial pressure, which is largely determined by the beam, does not show the rising effect in any of the runs. The results agree qualitatively with the data taken at DCI, and are also in rough quantitative agreement.

The remaining program of experiments with the warm tube consists of taking beam on the room temperature aluminum tube at 10 mr average angle until the clean-up rate decreases to the point that it is no longer worth the time, exposing the other side (the "fresh side") and observing the clean-up rate,

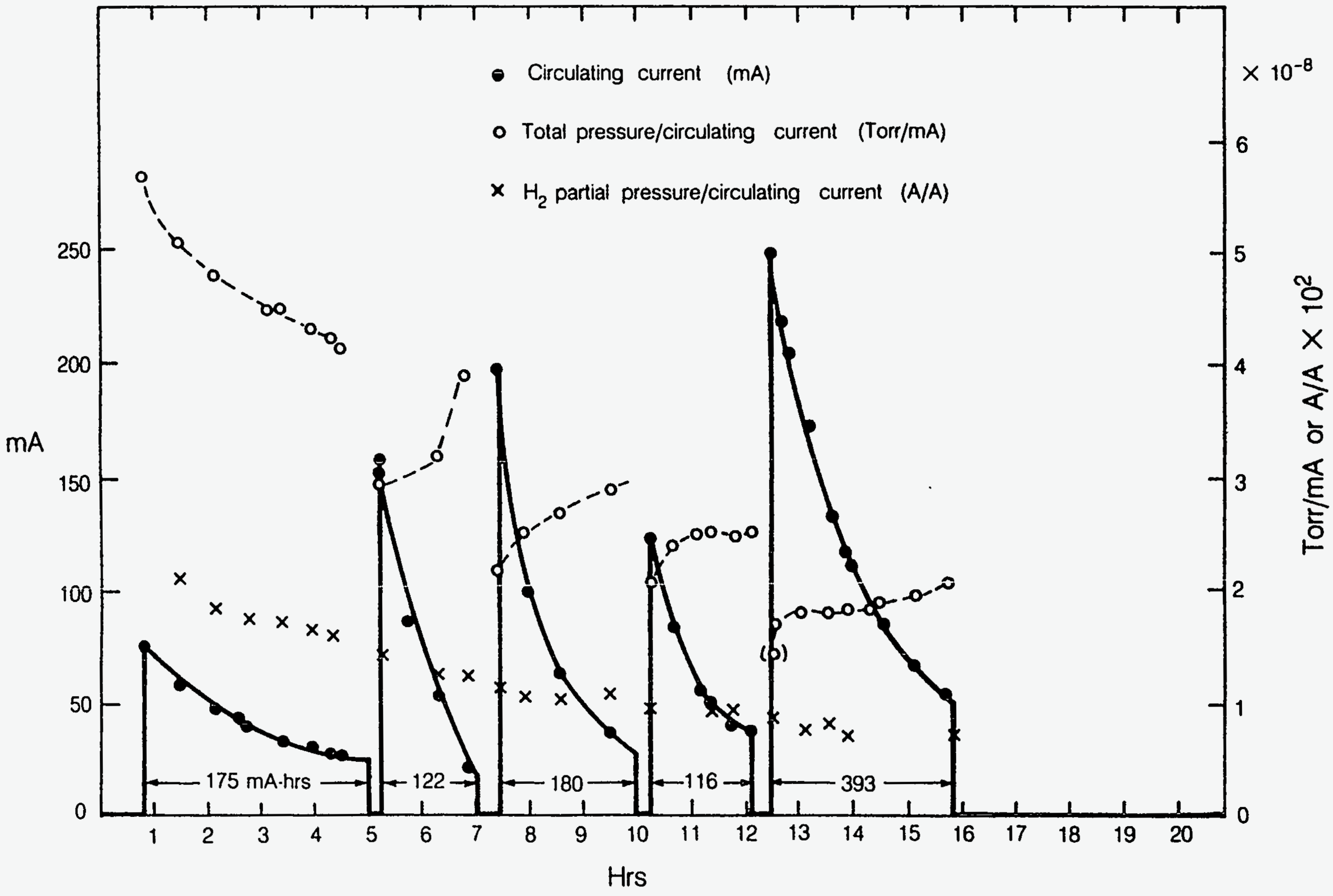

Fig. 4-2. Circulating electron beam current (lefthand scale), total pressure/beam current (righthand scale), and hydrogen partial pressure/beam current (righthand scale) vs. time in hours for synchrotron light incident at 10 mrad on a room-temperature aluminum beam tube.

taking some data at shallower angles of incidence, collimating the beam in the vertical to study the energy dependence of the desorption rate, and backfilling with boil-off liquid nitrogen, pumping down, and seeing if the clean-up rate using beam is faster than the first time. This program should be completed by mid-June, at which point the cold-beam-tube experiment can be installed.

4.5. Beam Losses, Reliability, Cost Estimates

(a) Beam losses.

Progress has been made on calculations of the beam loss, particularly the muon flux present in one interaction region from the collisions at a neighboring interaction point. The sources of muons that are considered are direct muon production, which cannot be reduced by absorptive shielding, meson decay from directly produced mesons and from mesons made in showers, and Bethe-Heitler processes. Figure 4-3 shows the muon flux as a function of the perpendicular distance from the projected direction of the outgoing beam from the neighboring interaction region. Three curves representing different distances between interaction regions of a clustered design are shown. It appears that there will be no difficulty in inserting sufficient bend between interaction regions to reduce the muon flux in the neighboring regions to much less than the cosmic ray flux.

About 30 mb of the total cross section is elastic or quasi-elastic, and most of these particles will stay within the machine acceptance for many turns before they hit the beam-tube wall. The most likely place to hit is in the quadrupoles that make up the low-beta insertions, causing a shower of particles in the close-by detector. The best way to get rid of such particles is to scrape them off somewhere else in the machine, with well-placed collimators. This is one of the inputs to the recently started design of "real lattices."

Calculations have been started at FNAL to understand the cryogenic load due to the inelastic collisions at the interaction regions. This load is significant, since each interaction region generates 1.5 kW at peak luminosity, and a large fraction of this power ends up in the cryogenic system.

Measurements have been made at the Tevatron of the amount of ionizing radiation present in the tunnel during acceleration and storage. It appears that most of this is due to local beam gas scattering, and can be used to estimate the radiation in the SSC tunnel. This radiation is important because

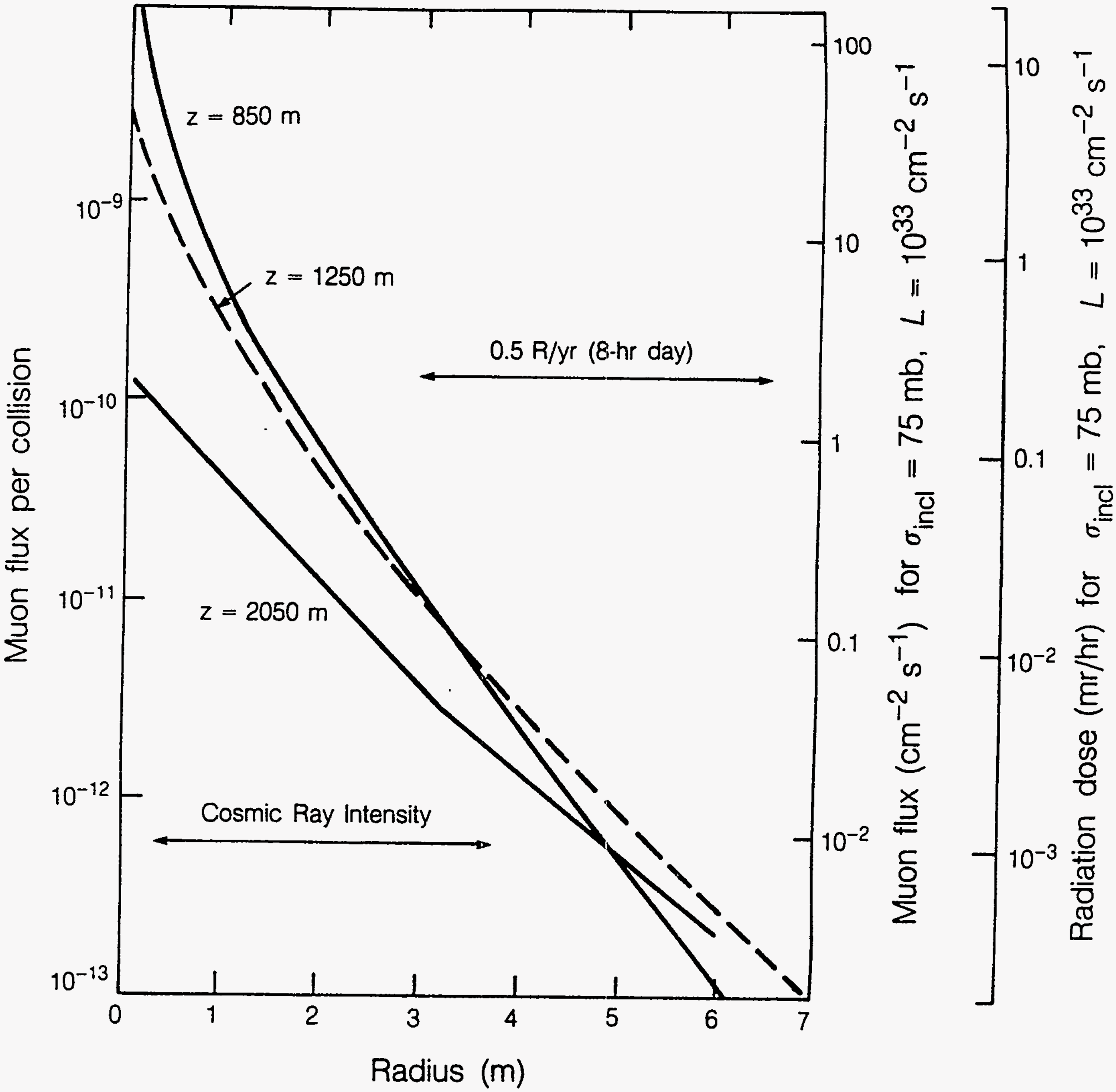

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Fig. 4-3. Muon flux for three different distances (z) between interaction regions, as a function of radial (perpendicular) distance from the axis of the muon distribution. A hadron absorbing well 80 m from the interaction point is assumed.

it affects the choices of materials used in the magnets and the lifetime of electronics in the tunnel. The preliminary results indicate that the radiation will be a significant effect; further measurements and detailed calculations are planned.

(b) Reliability.

A number of organizations, including NASA, Bell Labs, and others have techniques to perform analytical reliability studies. The issue has been discussed with people from Bell Labs, and it appears that they are willing to let the CDG use their software for this analysis. The difficult part of the work is the piece-by-piece engineering analysis of the systems and the construction of failure modes and effects models. Once such models are devised, the sensitivity of the overall system to component failure can be studied, even if the detailed component design work has not been completed. In this way, the engineering effort can be focused effectively and a plan developed for quality assurance during the construction phase of the SSC.

(c) Cost Estimates.

The cost estimates of the accelerator systems presented in the RDS are being updated to reflect new knowledge of the various designs and new design options. In the RDS, only the 6.5T design had a cost estimate for the accelerator systems. That cost estimate is being extended to include all of the magnet types now being considered. A more careful cost estimate of the testing and installation of the various magnet types is being done, and will be completed before the magnet style choice is made.

Scaling rules for cost estimates can be very useful if they are restricted to interpolations or narrow extrapolations. One of the particularly interesting scaling rules concerns the trade-off between various methods of changing the dynamic aperture of the machine. The dynamic aperture can be increased by increasing the physical coil diameter, which decreases the effects of coil errors, or by increasing the strength of the focusing by making the cell length shorter.

Figure 4-4 shows lines of constant cost per meter of effective bend for the sum of the magnet systems, correction systems and the tunnel, as a function of coil diameter and half-cell length for cosine-theta magnets (RDS type A). For a given operating magnetic field, the cost per meter of effective bend is related by a constant to the total cost. As the half-cell

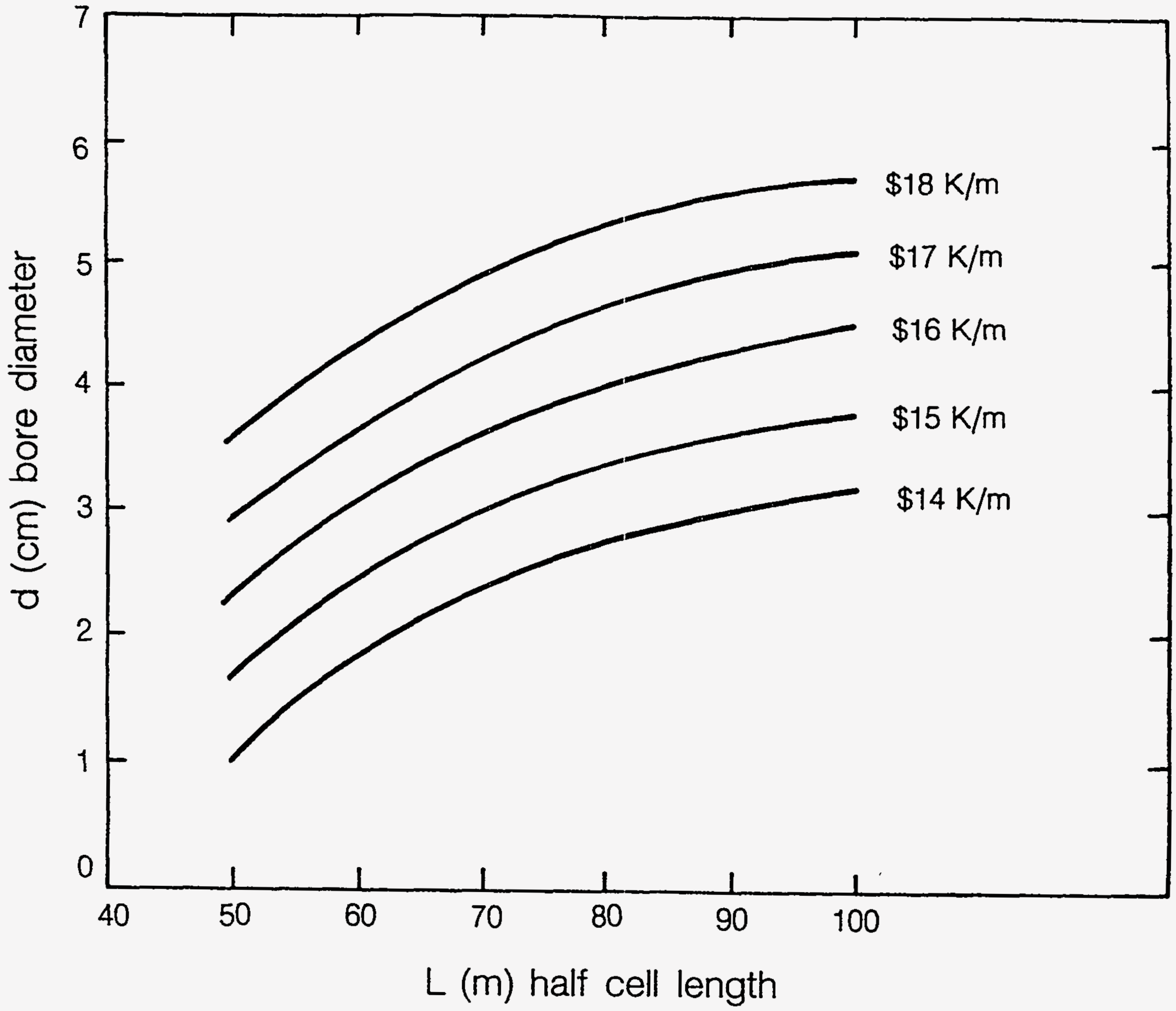

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Fig 4-4. Lines of constant cost/meter of effective bend. The quad strength is scaled as $1/\sqrt{L}$ (cost based on Ref. Design A).

gets shorter, the cost goes up because there are more quadrupoles and correction packages, and fewer bend magnets per unit length. As the coil diameter increases, the cost also increases, since at constant field the amount of superconductor increases. Whether it is better to opt for one method or the other depends on how the dynamic aperture scales with the two variables. Preliminary results indicate that for cells between 65 m and 110 m, and coils of 4 cm and 5 cm, the cost increase is not significant. For cells below 65 m, it appears that larger coils will be a cheaper option than shorter cells. This sort of scaling rule is being developed for each of the magnet designs, and the sensitivity of the rules to fluctuations in component costs is being analyzed.

4.6 Plans for the Future

(a) Systems Tests.

One of the major tasks of the ASD is to plan and manage the the magnet systems tests as described in SSC-SR-1001. As originally conceived, this would consist of two major tests, the so-called long string test, intended primarily for systems development, and a short string test, intended as a life test of the magnet system itself. The original plan has been modified since the report was submitted, adding a system test of a half-cell as early as possible. The plan is to produce one half-cell of full-length prototype magnets to be available for assembly into a string in early FY 1987. This test (Half-Cell Test) will allow early assessment of systems behavior on magnets, as well as provide a vehicle for instrumentation and cryogenic system development. The System Test Site Task Force concluded that the tests could be conducted either at FNAL or BNL.

For subsequent tests, the Half-Cell Test could be extended to become the final configuration of the Systems Development Facility, about one per cent of the SSC main ring. The Accelerated Life Test, which is basically a life test of one or two half-cells, requires a large amount of refrigeration. The decision on where to site that test will be made largely on the basis of refrigeration availability.

The Half-Cell Test effort should begin in January 1986 in order to have the facility ready for first operation at the start of FY 1987. A half-cell is expected to be available at that time, with additional prototype production during FY 1987. The System Development Facility can begin to come into being in mid-FY 1987, as the Half-Cell Test is completed. The Accelerated Life Test will be started when magnets of the final design, or close to it, are available, likely in late FY 1987.

The Systems Development Facility is expected to continue as an important test bed for engineering development and design of technical components well into the construction phase (FY 1988+), since it will be the only available complex approximating the SSC until the operation of the first sector of the main ring, scheduled for July 1990.

Another important date that impacts the Phase I R&D schedule is the projected start of operation of the first prototype refrigerator in the latter half of FY 1988.

(b) Planned Organization of The Accelerator Systems Division.

The ASD will be organized into four groups. The groups and the tasks for which they are responsible are shown in Table 4.3. Each group will have a leader who is in long term residence at the CDG. During the early part of the R&D effort, most of the work will be done at the national laboratories, and by industrial organizations. As Phase I progresses, the CDG manpower will increase.

Table 4-3. Accelerator Systems Groups.

Headquarters	Mechanical	Electrical	Beams
Safety	(Magnets)	Main power supplies	Injection
Reliability	Cryogenic systems	Quench protection	Abort
Quality assurance	Vacuum systems	Correction elements	Beam loss
Desorption experiment	Installation	Control systems	Interaction regions
Systems tests	(Conventional mech.)	(Conventional electrical)	External beams
			RF systems
			Beam instruments
			Operations

(c) Objectives for ASD Groups for Phase I.

The main tasks of the Headquarters Group will be to ensure a coherent set of systems designs, to design the subsystems specifically assigned to Headquarters, and to act as editor for the ASD part of written reports. Another important responsibility of the Headquarters group is to manage the photodesorption experiment and the systems tests.

The major tasks of the Mechanical Group are to design and cost the cryogenic and vacuum systems, to determine the installation method, cost, and schedule, to determine parameters that affect the conventional construction, and to ensure that the magnet design effort results in devices that meet proper standards, and fit in with the overall accelerator design. Specification of mechanical-system interfaces will be important. In addition, because the refrigerators are expected to be the most expensive single part of the accelerator systems, and because the lead time for design and construction of refrigerators is so long, it has been decided to test the first prototype refrigerator as soon after the start of construction as feasible, about nine months after Notice To Proceed. This implies that an active design, purchase, and installation-planning effort will have to be started early in Phase I.

The most important jobs for the Electrical Group are the design and cost estimates of the main power supplies and quench detection and protection of the magnets, and the same for the correction magnets. The power-supply and quench-protection designs have a considerable impact on the magnet design and development, and therefore must be vigorously pursued early in Phase I. The systems will be tested and perfected during the string tests.

A preliminary design must be done for the control systems, and estimates and specifications made for overall power needs, which are used as input to the design of the conventional construction. Despite the argument for delay in order to take advantage of the latest developments in a rapidly changing technology, the early target date for the first sector test gives rise to an equally early target date for a fully designed control system. This implies that design and prototyping, and software analysis and simulation must start fairly early in Phase I. Establishment of electrical-system interface specification will be an important objective.

The primary objective of the Beams Group in the early part of Phase I is to analyze and design the injection and beam abort systems and their integration into the whole system. This will involve a considerable amount of modeling of beam loss phenomena, particularly as they affect the operation of superconducting magnets and experimental equipment. Beam loss will also affect the tunnel design because of radiation safety requirements.

Another important early task is the development of realistic interaction regions of different types, efficiently designed for the many different experiments at the SSC. The detailed design of magnets for injection, abort, and interaction regions can probably be postponed, except for some devices that push the state of the science. Those particular devices should be designed and prototyped early, since their existence may make significant cost savings possible.

CHAPTER 5. SUPERCONDUCTING MAGNETS AND CRYOSTATS

5.1 Introduction

Our understanding of superconducting accelerator magnets has matured in the last few years; the Tevatron is operating, and HERA is under construction in Europe. Many model magnets have operated successfully and superconducting materials are much better understood. To produce a minimum cost SSC, the magnet-bore diameter must be reduced to the limits allowed by beam dynamics and long magnets must be built using mass-production techniques. It is thus essential to conduct a vigorous R&D program at an early stage. The central feature of this effort is the testing of model magnets of advanced design. This section describes the work currently being done at BNL, FNAL, LBL, TAC, and several industrial facilities. It is divided into high-field and low-field activities.

5.2 High-Field Magnets

The present high-field magnet development has been intensively pursued at LBL, BNL, and FNAL. At the beginning of FY 1984, FNAL began development of a 5 cm bore, 5T, "no iron" magnet based on NbTi cable similar to the Tevatron cable, with each of the two rings housed in separate cryostats. BNL was developing a 3.2 cm bore, ~7T magnet based on niobium tin with two coils clamped in the same cold-iron yoke to economize on iron and the number of cryostats (the 2-in-1 configuration that had been proposed for CBA). LBL was developing a 4 cm bore, 6.5T, NbTi design based on cold iron, also in a 2-in-1 configuration. In addition, BNL and LBL began a collaboration in which BNL would construct 4.5 m models of the 4 cm NbTi design, as well as the 3.2 cm Nb_3Sn design. Because of development difficulties with Nb_3Sn, the 4 cm NbTi design soon became the principal BNL/LBL focus. Collars were added for clamping the coil to simplify development and to provide a well-proven structural support. In early FY 1985, after studying cryogenic systems for cold-iron magnets, it was determined that cool-down times would be reasonable, and the 6-6.5T, cold-iron design became the main focus of FNAL as well as BNL and LBL. The three laboratories defined the 4 cm bore, 6-6.5T, NbTi, collared, cold-iron magnet as design D and began a unified development program with major responsibilities as defined in Section 2.2. Details of the development program and significant accomplishments are discussed in the following pages.

Model Magnet Construction. For any high-current-density accelerator-magnet design, building and testing models is essential to verify acceptable performance and to evaluate design details. It is especially important to verify electrical and mechanical stability (i.e., "training" behavior) and reproducibility of field quality. During the past nine months, much effort has been devoted to the design and construction of accurate tooling, the development of reliable high-performance conductors, and the evaluation of cost reduction methods. Operation of models at predicted field levels has already been demonstrated. It is planned to test six 4 cm bore, 4.5 m models in the next three months, and about twenty 1 m models of various designs. This will provide a firm data base for proceeding to design and construct prototype magnets in FY 1986.

The model magnet program can be summarized as follows:

BNL

3.2 cm, 2-in-1 Model. Testing to date has been of 3.2 cm bore, NbTi models using a CBA/Tevatron type of cable, clamped in a 2-in-1 cold-iron yoke. These models are 4.5 m long (CBA tooling and testing facilities existed for this length) and have the enlarged "dog-bone" ends designed for pre-reacted Nb_3Sn. Figure 5-1 shows a magnet during construction.

Although a larger bore diameter and a different cable design have now been proposed for the SSC, the models were completed and tested with excellent results. Four 2-in-1 magnets (eight single-hole equivalents) were built. Their performance is summarized in the training curves shown in Fig. 5-2. The lack of significant training is evident; the magnets achieve a central field exceeding that predicted. The fourth magnet used improved high-homogeneity superconductor and achieved a significantly higher field. The predicted magnetic features of the 2-in-1 design were verified.

4.0 cm Design D. The major BNL activity has been manufacturing tooling and parts for 4.0 cm design D models using the wide LBL cable, stainless steel collars fastened with keys, and a single iron yoke. Coils for six magnets have been wound and cured and the collaring process has begun. The first model was tested in June and performed remarkably well. Five more to follow in the next three months. These magnets will have full-length sextupole correction coils wound with a single layer of 0.023 cm diameter superconducting wire and attached to the o.d. of the bore tube.

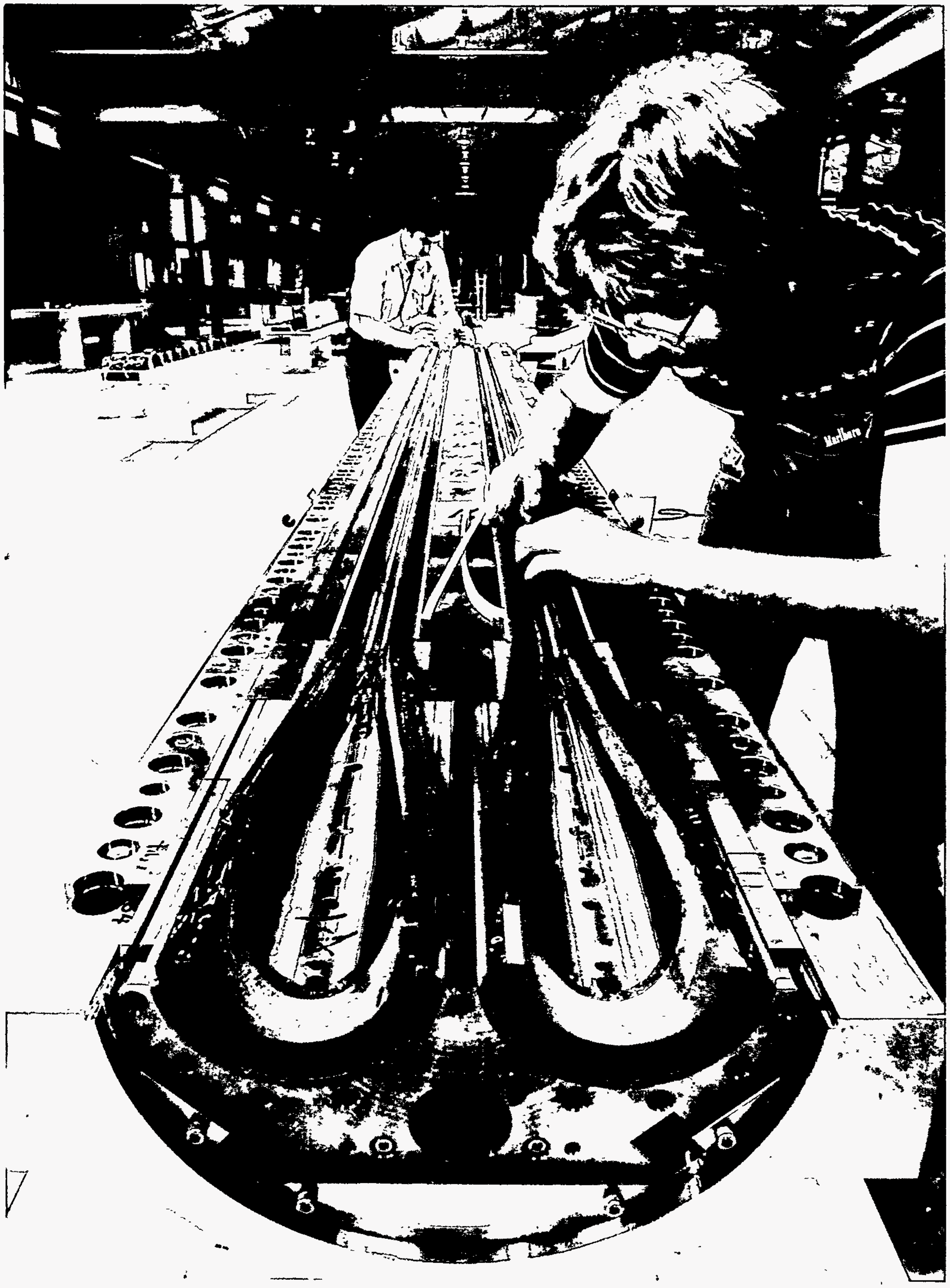

Fig. 5-1. Lower half of two-in-one high field magnet during assembly.

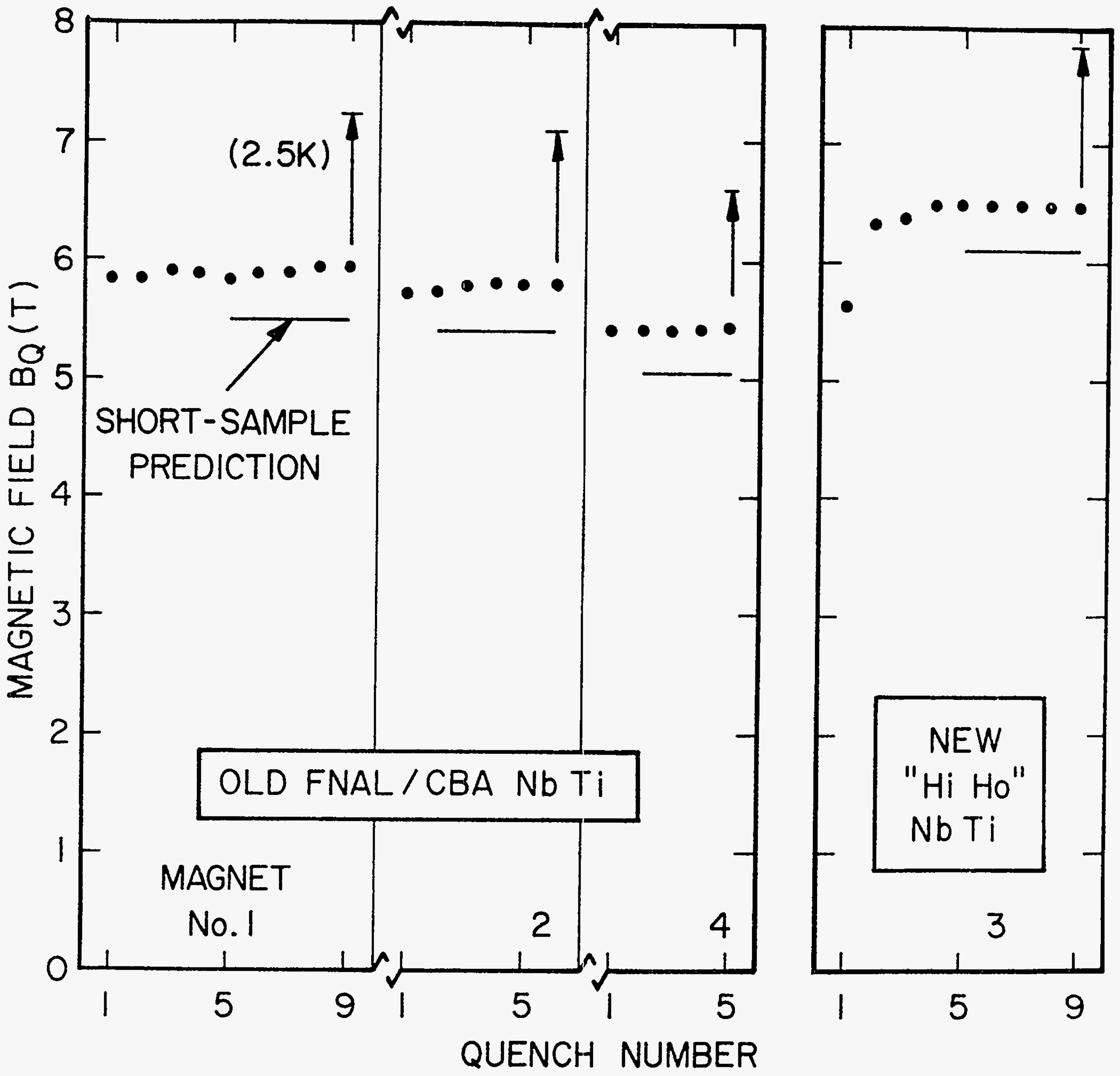

Fig. 5-2. Magnetic field at quench (4.5K) for four 2-in-1, 4.5 m BNL "A" high-field dipole magnet models with 3.2 cm aperture.

LBL

Seven 4 cm models were built, the last five with keystoned cable. Of these five, two had a design A configuration and were clamped directly in cold iron; both reached 6.5T central field. The last three have a design D configuration and are discussed in more detail below. Training curves are shown in Fig. 5-3 for these models; training is minimal. All models had a central field exceeding 6T; the latest model reached 6.5T. They exhibited the expected 2T field increase (to 8T) when operated at 1.8K.

Figure 5-4 shows the coil ends of these models; the slight bulge is to permit easy winding of the wide cable on a 4 cm bore, to decrease the maximum field at the conductor, and to minimize field distortion at the coil ends. Wire-wound correction windings were tested in the models and demonstrated that the sextupole distortion caused by the large filaments (~20μm) can be cancelled as predicted, either by energizing the correction coil from a controlled power supply (the method currently proposed for the SSC) or by simply shorting the coil leads and depending on the induced current automatically to cancel the distortion (a promising method requiring further R&D to prove it practical).

Figure 5-5 shows strain gauges that are used to monitor cable stress during collaring, cool down, and operation.

FNAL

One-meter models have been made at FNAL of a variety of designs. Because of the extensive experience with Tevatron magnets, the first series of thirteen models used 3-inch bore diameter and Tevatron cable and were made to explore the effect of variations in construction details. These included variations in copper-to-superconductor ratio, helium ventilation channels, collar stiffness, and filament size.

Meanwhile, tooling was fabricated for 5 cm models of the design B "iron-free" magnet that required a new cable and collar design. In an effort to reduce the cost, an epoxy-free ("dry wound") fabrication method was developed wherein the coils are wound and collared in a single step. A collapsible mandrel is used to facilitate winding and collaring. Figure 5-6 shows collars being assembled on one of these models. Six models have been wound and cryogenic testing began in June.

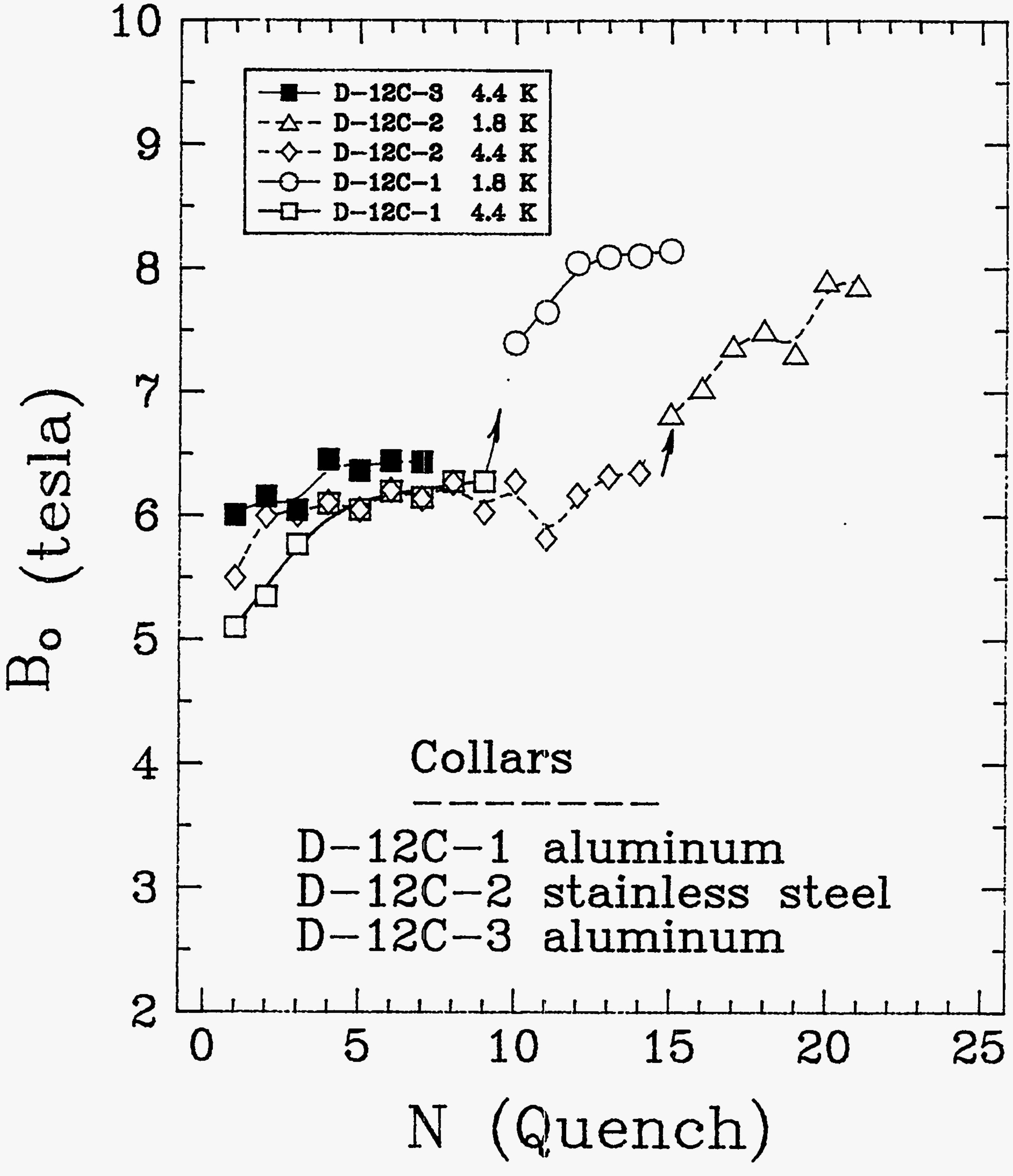

Fig. 5-3. Training for LBL 1 m dipole models, 4.0 cm bore diameter.

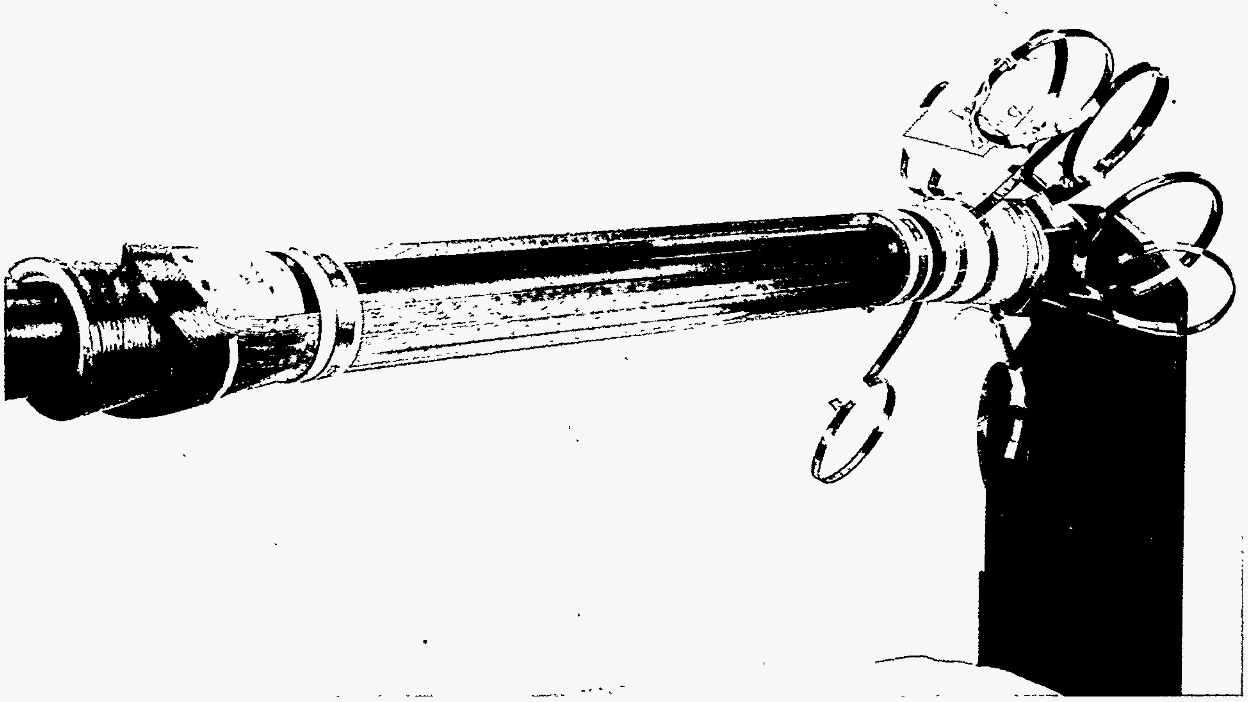

Fig. 5-4. Flared coil-end design for high-field magnets.

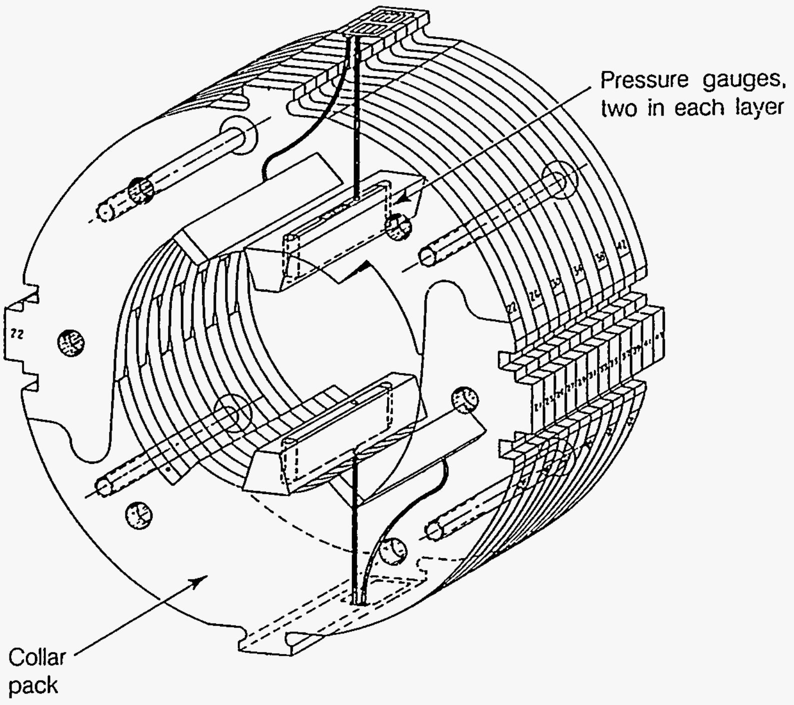

Fig. 5-5. Illustration showing pressure gauges insulated in collars to measure winding pressure during assembly and operation of 4 cm LBL models.

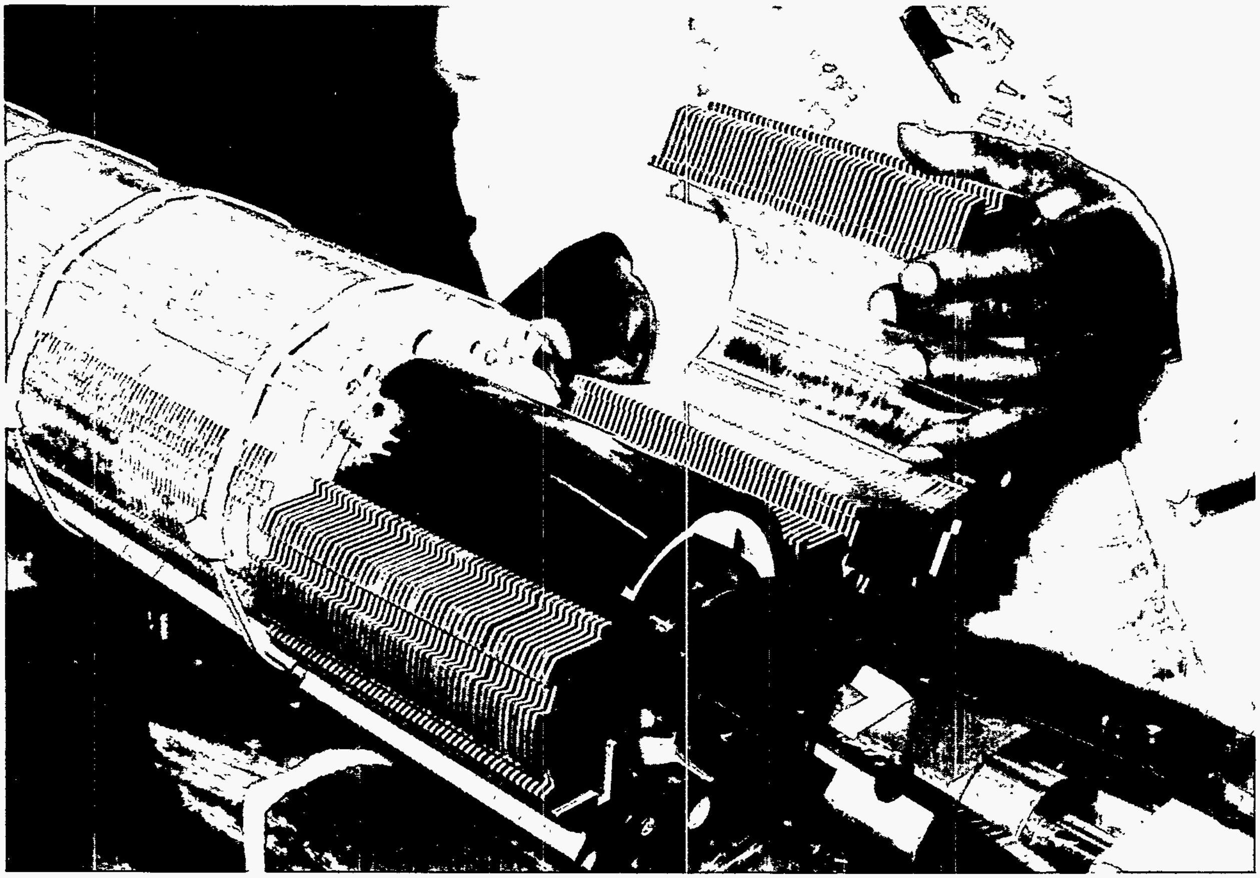

Fig. 5-6. Aluminum collars being applied to a one-meter, high-field, dry-wound (epoxy free) coil assembly.

As a backup construction technique, and for direct comparison of the two approaches, several models are being made using the well-proven Doubler insulation with B-stage epoxy and Fiberglas tape. Tooling has been made to build design D 4 cm bore models using the "dry wound" technique and fabrication will begin in June. It is anticipated that by October, 1985, ten 5 cm design B magnets (5 "dry" and 5 with B-stage epoxy) and five 4 cm design D magnets will be built.

Auxiliary R&D Programs. Several essential developments are being done in support of the magnet program and are summarized below:

Distributed Correction Coils

As an alternative to fine-filament superconductors, we are developing a conventional corrector driven by a separate power supply. Although initial models have wire-wound coils, a mass-production technique to produce low cost coils is being developed at BNL in collaboration with industry. Using technology originally developed for the electronics industry, small diameter (0.008 in.) superconducting wire is being accurately attached to a Mylar base to form single-layer coils. The Mylar, with coils attached, is then wrapped around the bore tube. Wire can be laid down at 5m/min, and the coil can be full length (16 m). Several 2 ft-long sample windings have been produced.

Field-Measurement Mole

Significant economies can be realized if magnetic fields can be conveniently and accurately measured in long, small-diameter magnets. Using existing technology for miniaturized motors, gravity sensors, telemetry, etc., a probe with a rotating coil assembly and a diameter of less than one inch is under development at BNL. The first model has been built and a more advanced model is under construction. Initially a tether will pull the probe through the bore tube, but a self-propelled unit is being designed.

5.3 Low-Field Magnets

Development of a 3T dipole magnet has been pursued at the Texas Accelerator Center (TAC), with support from several high-energy physics laboratories and with extensive industry collaboration. Fig. 5-7 shows the present design in the 2-in-1 configuration. It is extremely compact and, because of the low field, requires less superconductor than the high-field design. Because of the large accelerator circumference (165 Km) required at the 3T field level, the program is aimed at developing very long magnets to minimize the number of units requiring in-tunnel connections. It is hoped that 115 m-long units can be fabricated consisting of three 35 m dipoles, a 4.7 m quadrupole, and with correction coils, cryogenic equipment, and expansion joints contained in the remaining 5.3 m.

Since TAC started work about one year ago (March 1984), considerable effort has been devoted to assembling shop facilities, cryogenic facilities, magnet instrumentation, and a staff. The main effort at TAC has been to complete the dipole design and to fabricate models.

To maintain field uniformity up to 3T, the coil is divided into two circuits that are driven by separate, coordinated power supplies, and a one turn correction winding, driven by a third power supply. Fig. 5-8 shows the magnitude of current in the three windings as central field varies; the relative currents must be closely controlled to maintain field uniformity over the entire field range. TAC has assembled three 1 m single-channel magnets, one 1 m 2-channel magnet, and one 7 m 2-channel magnet. Two 1-channel models are shown in Fig. 5-9. An end of the 7 m model with the two elliptical bore tubes protruding is shown in Fig. 5-10. In addition, General Dynamics-Convair Division, has assembled a 1 m 1-channel magnet and has contracted to assemble three 28 m models at their San Diego facility using parts supplied by TAC, and to ship them to TAC for testing. These models will be complete with cryostats. Tooling is built (see Fig. 5-11); the first magnet is under construction and is expected to be shipped in late September.

Cable for the low-field magnet contains more copper than the high-field cable, to limit the heating rate in the event of a quench. The ratio of copper to superconductor is 4.0, obtained by wrapping 24 0.7 mm-diameter strands around a rectangular copper strip, soldering the strands in place, and rolling to size. The strand was chosen to be idential to the strand used for the design D inner cable, but drawn to 0.1 mm smaller diameter. Thus there is interchangability between conductor procurements. A benefit of the large amount of copper appears to be good electrical stability; the models reach design field with little or no training. Quench propagation velocities are close to predicted values.

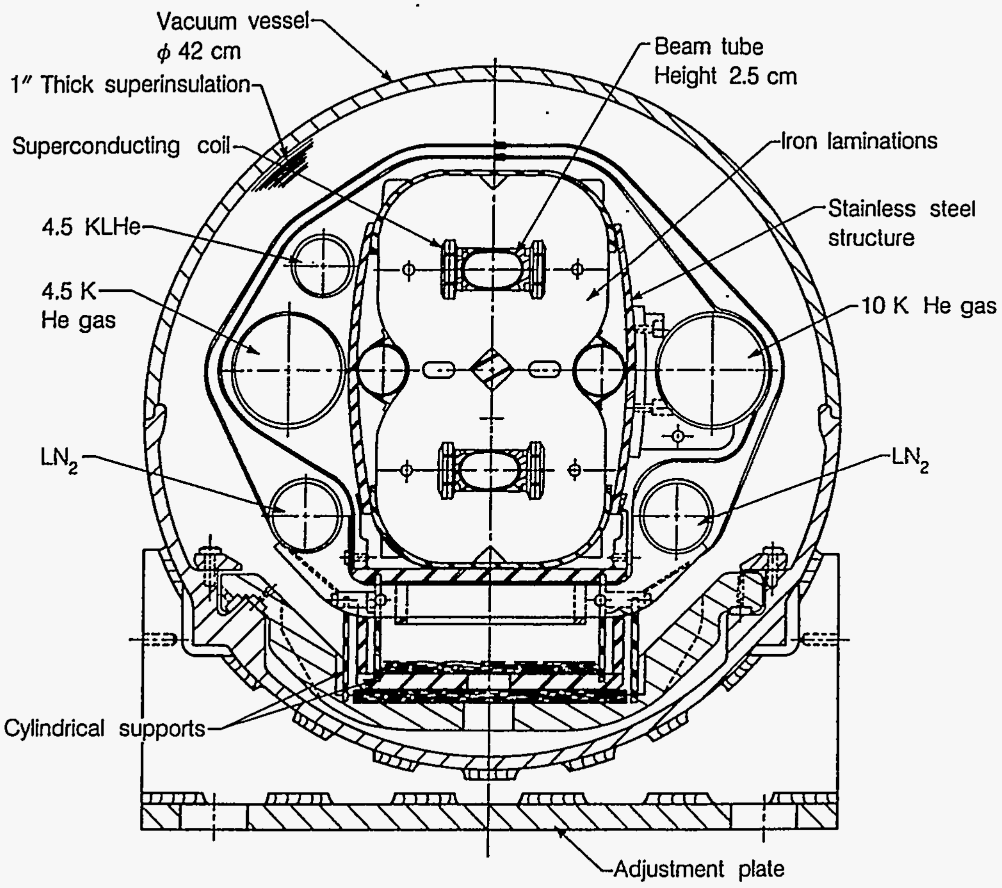

Fig. 5-7. Current version of the 2-in-1, low-field superferric magnet design.

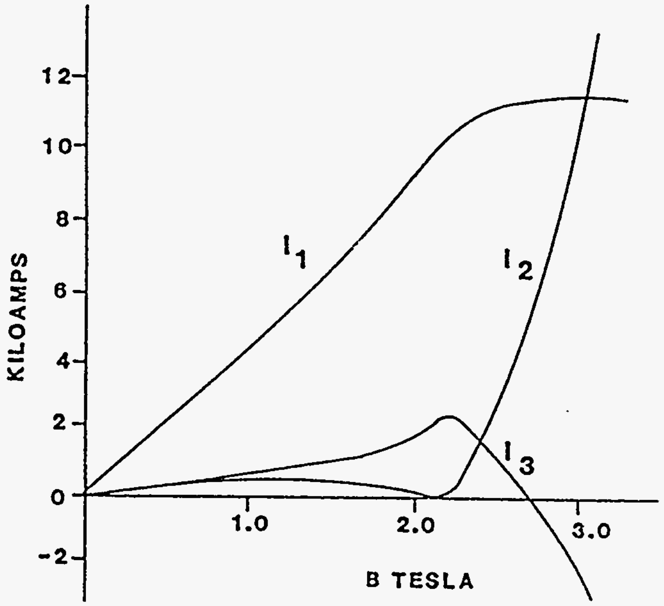

Fig. 5-8. The three independent currents as a function of magnetic field.

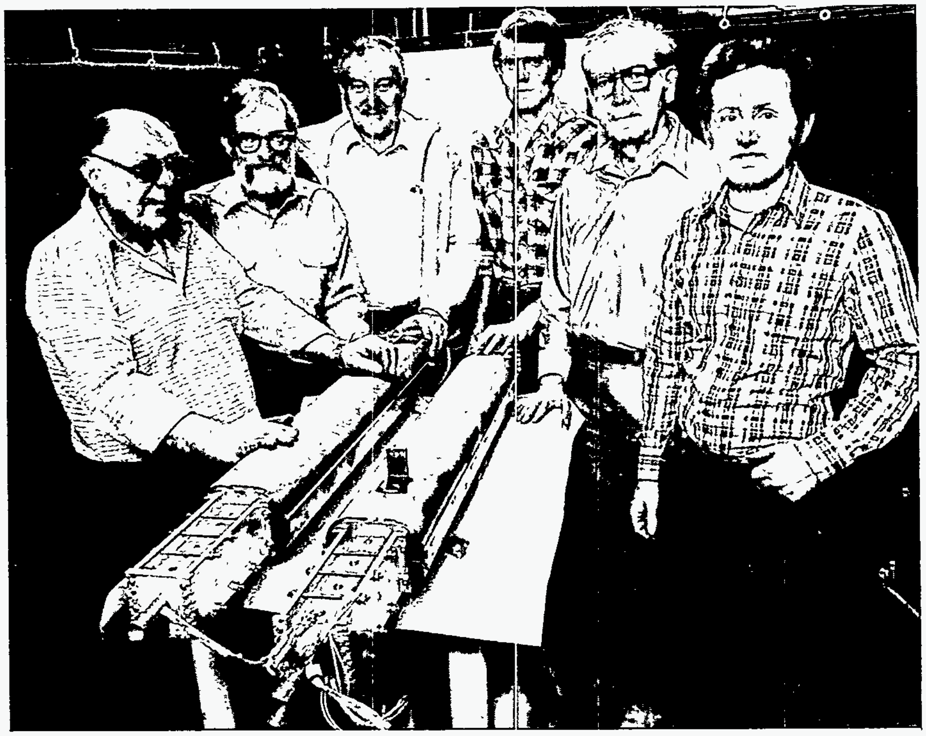

Fig. 5-9. One meter models of low-field superferric magnet.

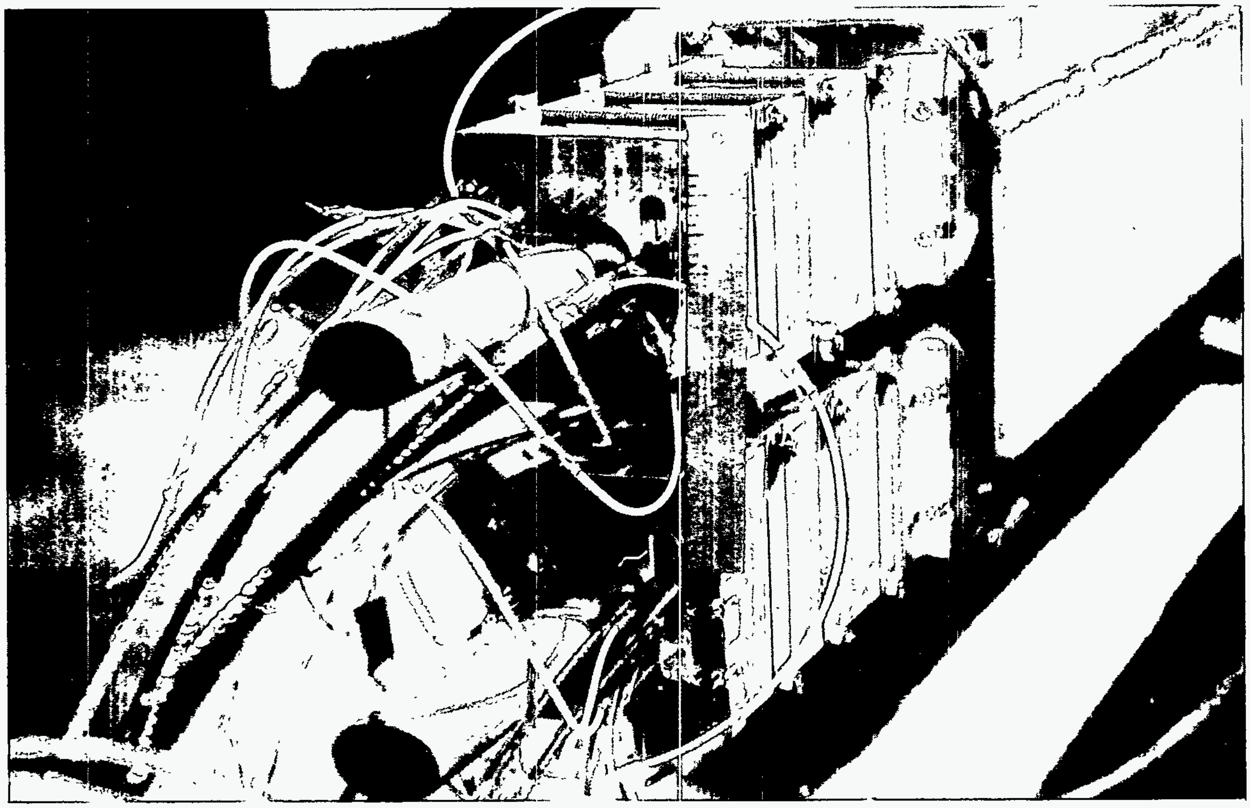

Fig. 5-10. End view of 7 m model of low-field superferric two-in-one magnet.

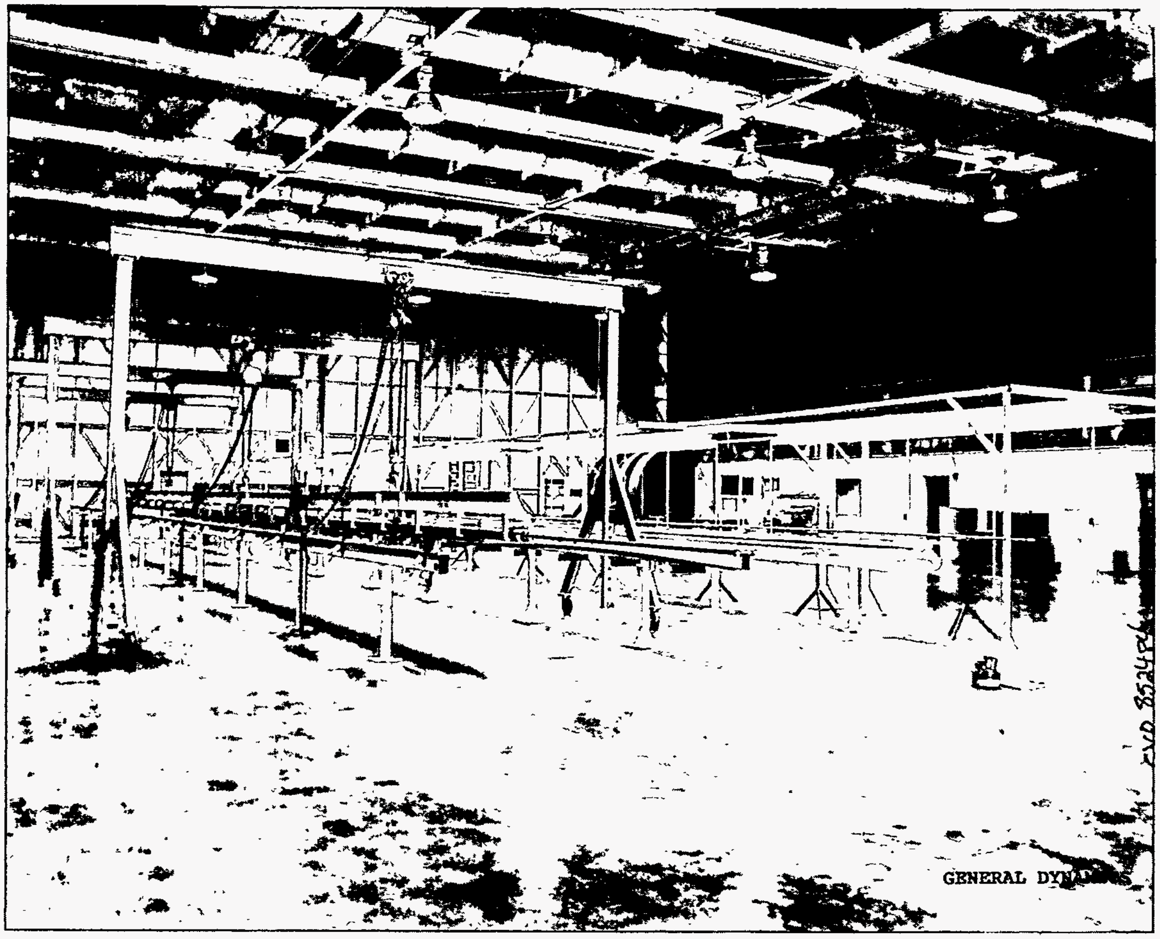

Fig. 5-11. Tooling for production of 28 meter superferric model at General Dynamics.

Considerable effort will be devoted in the next few months to experimental evaluation of magnet field uniformity. Field quality measurements have been encouraging but not yet definitive. Measurement facilities are being improved and several additional models of both 1 m and 7 m length will be built at TAC in the next few months.

5.4 Cryostat Development

Cryostat development work to date has largely been done at FNAL and has been focused on the original iron-free design. However, the techniques developed can be adapted to other magnet types. The following three major projects were done at FNAL.

In the iron-free design B, the field envelops the heat shields and creates forces between the coil assembly and the iron cryostat wall. A 20 ft-long model was constructed to evaluate experimentally the effect of eddy currents on heat shield deformation during quenching and to measure the interaction between coil and cryostat wall. A Tevatron coil was installed. The test sequence evaluated the response of cryostat components to magnet coil quenches at various levels of current. The mechanical and thermal response of the radiation shield was measured; the coil was then deliberately mounted slightly off center and retested, with results that agreed with predictions.

Another model was constructed to evaluate heat leak into a design B cryostat, shown in cross section in Fig. 5-12, with a dummy magnet to simulate the correct size and mass. End terminations, shown schematically in Fig. 5-13, were constructed to permit determination of the very small heat leaks by measuring the boil-off of helium and nitrogen. Figure 5-14 shows this cryostat under construction with the multilayer insulation blanket being applied. The heat leaks to 4.5K, 10K, and 80K temperature components was measured. The results are discussed in Section 4.2.

A small Dewar facility illustrated in Fig. 5-15 was constructed to evaluate a variety of low-heat-leak magnet-support designs and also to provide preliminary data on multilayer insulation schemes (MLI). Measurements on a post type of support in this Dewar were completed. The measurements included heat leak into the intermediate temperature shield operated at temperatures other than 10K, i.e., 20K, 30K and 40K. The results of the measurements agreed well with those predicted. Measurements were also made with the connection to the intermediate temperature shield removed and with the shield operating at 10K, 20K, 30K and 40K. This Dewar is now being converted to evaluate multilayer insulation systems and their application techniques. The initial MLI system to be evaluated is reflective polyester film with a Fiberglas mat spacer. A program is being developed to study the effects of various insulation techniques and suspension systems.

In addition to experimental work, several preliminary design efforts were carried out to evaluate candidates for a type D cryostat, and a Cryostat Task Force was established. This work is still in progress. A design criteria document was developed to guide design efforts on type D cryostats. A rather complete design utilizing tension supports, shown in Fig. 5-16, was made for the purpose of cost analysis. A design based on compression-member supports was done by General Dynamics-Convair, under contract to LBL, and creep-testing

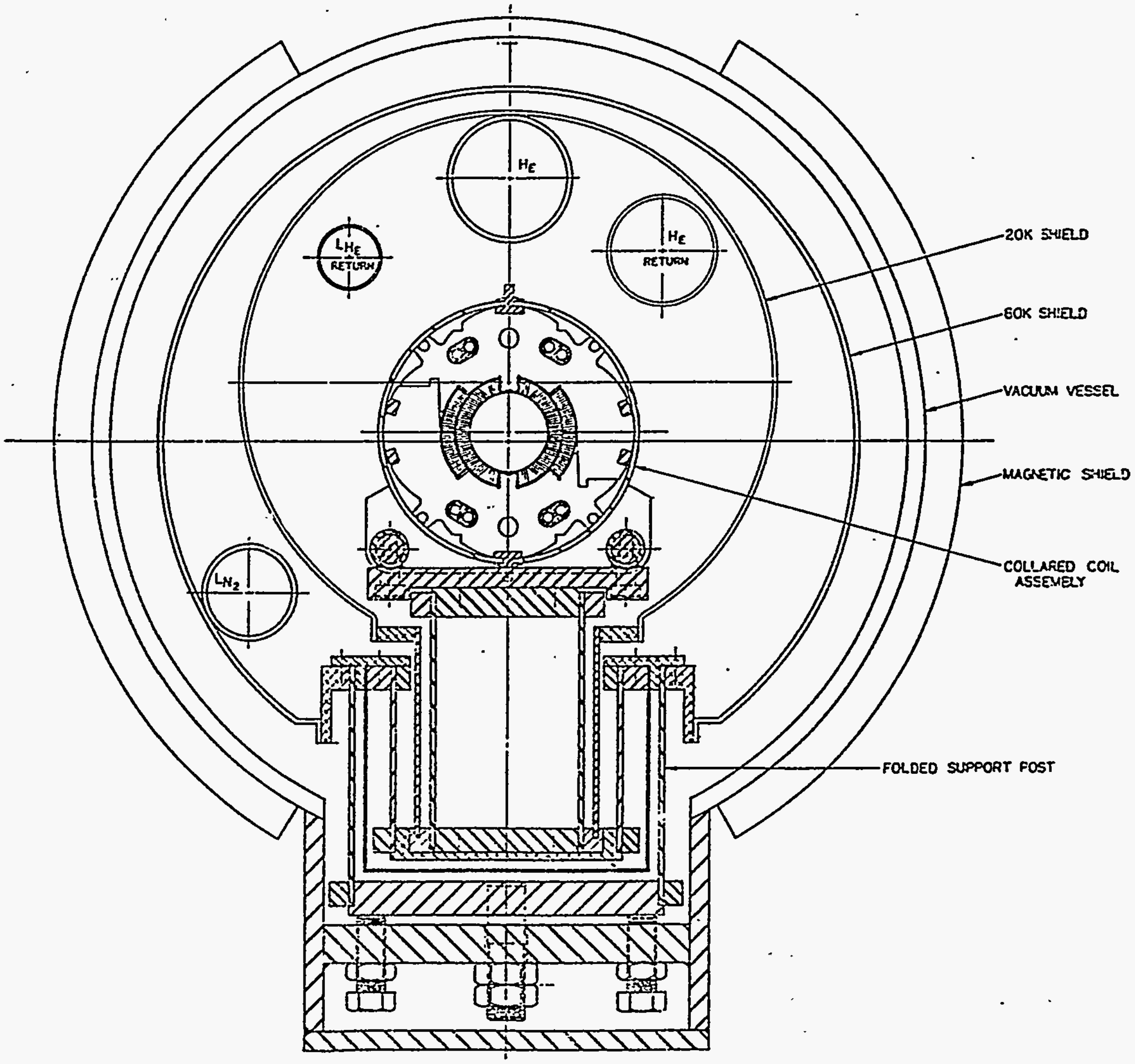

Fig. 5-12. Modified Design B magnet assembly with folded post arrangement.

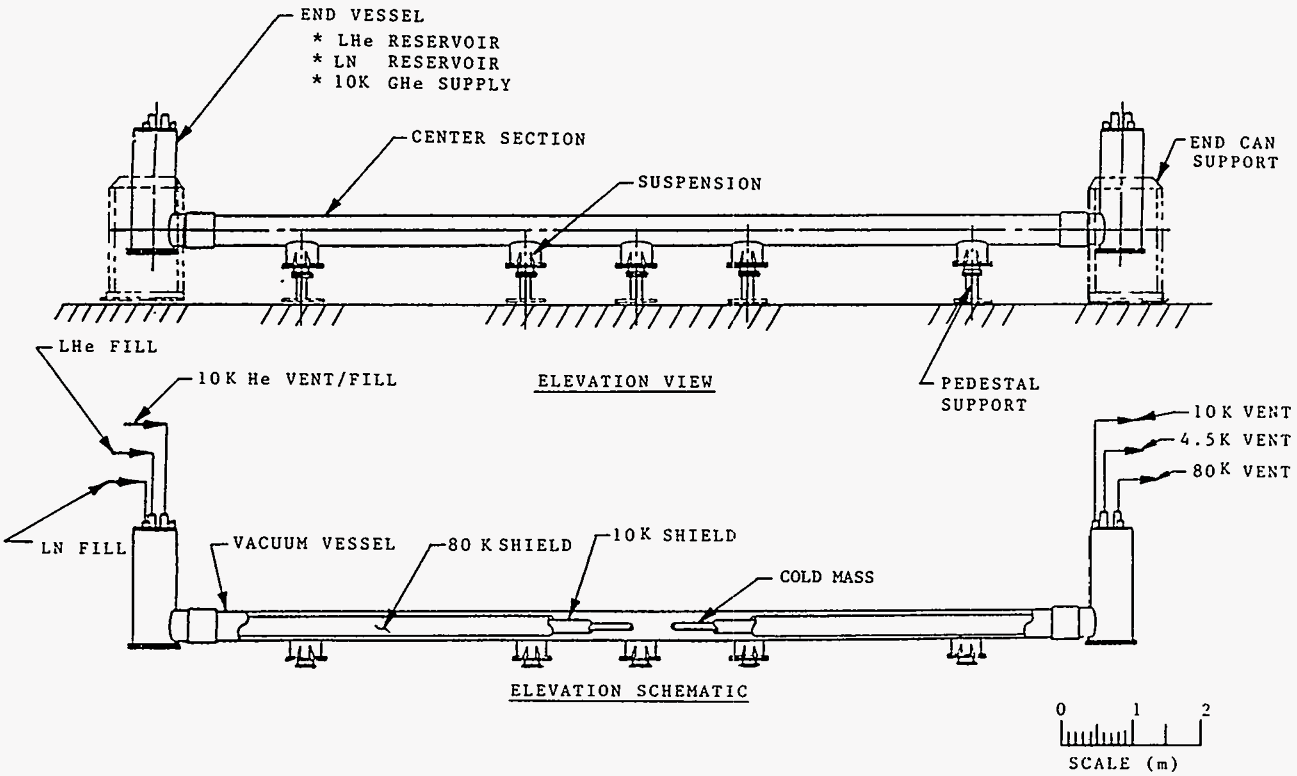

Fig. 5-13. 12 m Heat Leak Measurement Model

Fig. 5-14. Final installation of the multilayer insulation blankets on the Magnetic Effects Model.

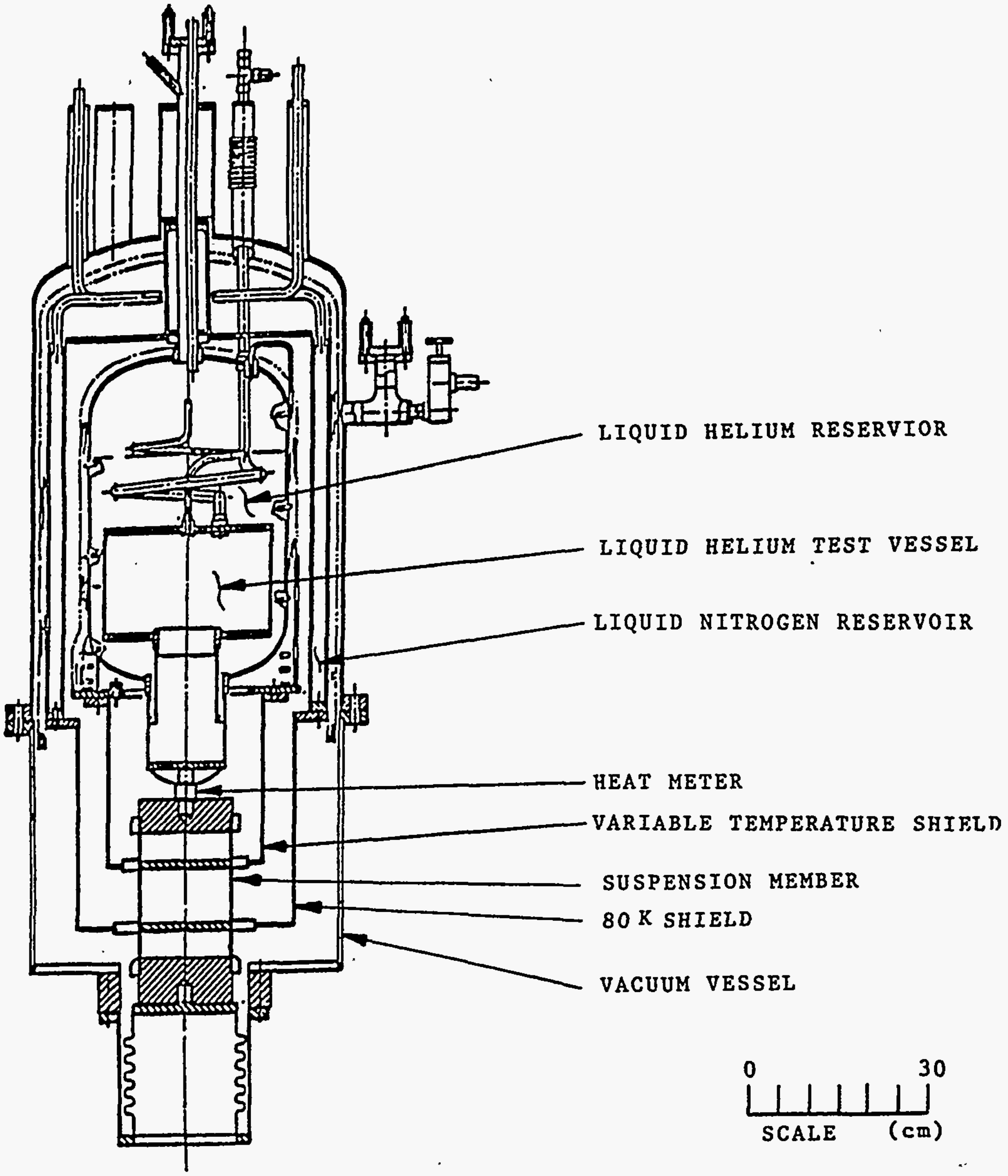

Fig. 5-15. Suspension Heat Leak Measurement Dewar

of a model compressive strut was initiated by LBL at the NBS-Boulder laboratories. An adaption of the HERA cryostat design was proposed by BNL. During June and July, a design will be selected for further evaluation and for use with the long (12-16 m) magnet models planned for FY 1986.

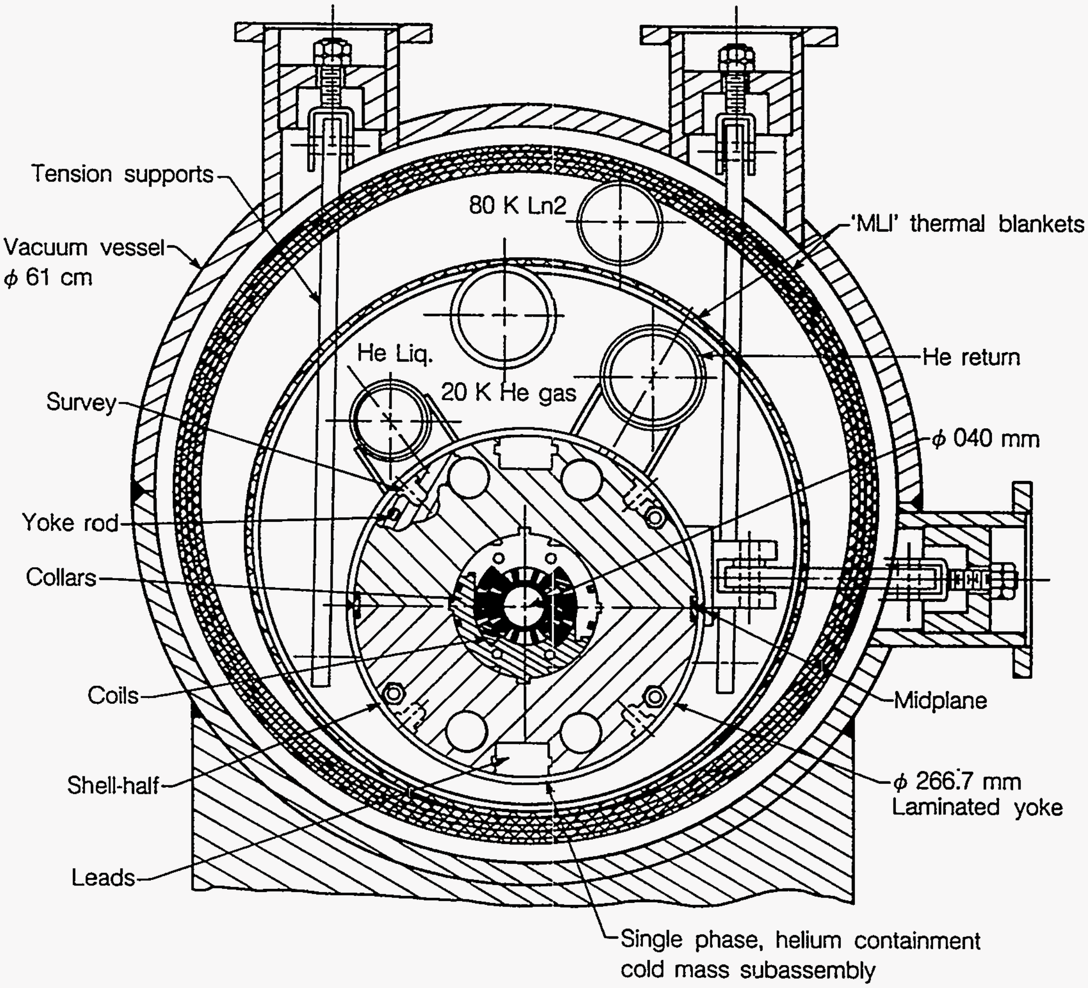

Fig. 5-16. The current concept of the FNAL cryostat for the type D SSC magnet.

5.5 Superconductor R&D

(a) Increased current density.

Early in 1984, for the RDS, we assumed that a significant improvement might be made in the current-carrying capacity of NbTi superconductors compared to the commercial material available at that time. This assumption was based on the discovery by Larbalestier at the University of Wisconsin that commercial material was inhomogeneous on a microscopic scale (± 5% in atomic fraction of Nb or Ti over 50-100 µm distance). Since a uniform concentration of precipitates, caused by heat treatment and wire drawing, is assumed to be responsible for high current density, it was hoped that, with more homogeneous NbTi, higher performance might be achieved. Some evidence from small laboratory-size lots (reported in 1982 by the Baoji group in China) had indicated that high-performance conductors might be possible.

A collaborative experiment aimed at testing Larbalestier's ideas was begun in August 1983. A special lot of high-homogeneity alloy was purchased by LBL from Teledyne Wah Chang Albany (TWCA) and provided to Intermagnetics General Corporation (IGC) for processing in an experimental 10-in billet. After extrusion, the material was divided into two lots, one for processing by IGC, using their standard commercial process, and the other to be held until Larbalestier could complete a J_c-optimization study and suggest an alternative treatment. Conventional processing techniques produced an improved J_c (about 2300 A/mm^2 compared with about 2000 A/mm^2 for the best Tevatron/CBA material). This result was verified on two additional billets procured by LBL. The remainder of the experimental billet, processed with a new heat-treatment schedule, resulted in significantly improved J_c values (from 2365 A/mm^2 to 2645A/mm^2 for the 0.025 in. diameter strand). Based on these results, LBL ordered two additional billets and FNAL ordered five billets. This material was delivered in January, 1985. The J_c values in all cases exceeded our specification values of 2400 A/mm^2.

The final order for material for design D dipoles was placed by LBL in November 1985 after the competitive bidding was won by IGC. IGC delivered 820 pounds of inner-layer strand and 830 pounds of outer-layer strand in April, 1985. The J_c (5T, 4.2K) values are 2509 A/mm^2 for the inner and 2719

A/mm^2 for outer-layer material. Outer-layer material, properly processed with the new heat treatment (3 periods of 40 h each at 375°C), has a significantly higher J_c than inner-layer material. The FNAL material is equivalent to the superior outer-layer material. A possible explanation of this behavior is that the additional cold working of the outer-layer material after extrusion is beneficial in improving the J_c. If true, this result suggests that it may be possible to get somewhat higher J_c values in the fine-filament conductors that also contain more cold working.

Another favorable result from these procurements has been much longer piece lengths (less breakage during drawing) compared with the Tevatron/CBA experience, which greatly facilitates cabling and also simplifies testing and quality control.

There now exists a substantial data base from these production-size billets (15 billets for a total weight of approximately 5000 lbs, including the FNAL billets), and several conclusions can be drawn:

(i) The interim SSC specification value for J_c (5T) of 2400 A/mm^2 can be met in industrial-scale production;

(ii) The specification of high-homogeneity NbTi appears to reduce the spread in J_c values (although a more stringent test of this hypothesis will come when more than one manufacturer is in production);

(iii) The use of high-homogeneity NbTi has resulted in extremely long piece lengths.

Improved heat-treatment schedules are still being investigated. There are indications that further improvements in J_c of production material (perhaps to 3000 A/mm^2) might be possible. For design D, a 12.5% increase of J_c (5T, 4.2K), from 2400 A/mm^2 to 2700 A/mm^2 would result in an 8% savings in total cable cost (about $25 M). Alternatively, if the magnet is operated at 4.2% higher field with the same cable, the accelerator size could be reduced (implying a cost reduction of about $40M). Cost savings proportional to the reduced amount of superconductor used will accrue to the low-field design, too.

(b) Fine Filament Superconductor.

The SSC magnets must have a very uniform field over a range from 5-10% of full to full field. Eddy currents that do not decay are induced in superconducting filaments when the field is changed. These persistent currents cause a distortion in the field that, for a given conductor, is roughly proportional to filament size. For example, Fig. 5-17 shows the expected distortion in a 4 cm type D model with various filament sizes. Measurements

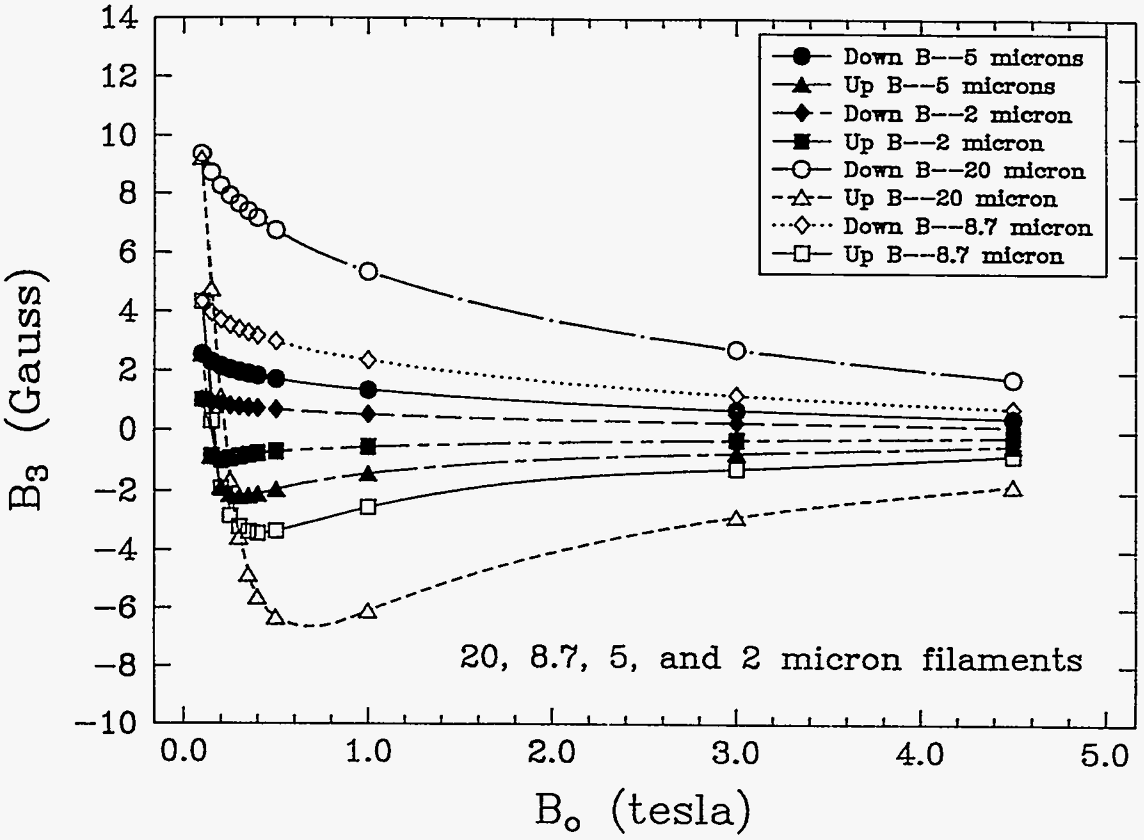

Fig. 5-17. Examples of prediction of sextupole component of field distortion caused by induced persistent currents, for 2, 5, 8.7, and 20 μm diameter filaments.

agree with these predictions. (The effect is much smaller in the 3T, type C configuration) This distortion can be corrected by a small correction coil wound on the o.d. of the bore tube. However, if filaments of 2-3 μm can be used, this correction coil is not needed. Therefore, vigorous efforts are being devoted to the development of fine-filament NbTi. The technical and economic problems of very fine filaments can be summarized as follows:

Conventional production of NbTi superconductor consists of a hot extrusion (500-600°C) of NbTi rods in a copper matrix. During this extrusion and the prior heating of the billet, a layer of titanium-copper intermetallic compound, 1-2 μm thick, can form around the filaments. This brittle intermetallic layer does not co-reduce and thus can become equal to the filament diameter at final wire size. This results in extensive filament breakage and sometimes strand breakage. The problem can be eliminated by enclosing the NbTi rods at extrusion size in a barrier material, such as Nb, which prevents the formation of the intermetallic titanium-copper. The barrier need only be 0.1 to 0.2 mm thick, and will be reduced to an insignificant fraction of the filament cross section at final filament size.

Another problem can arise from the introduction of foreign particles during the billet preparation. Any "dirt" consisting of micron-size particles or any inclusions of this size in the NbTi rods or the copper components can result in filament breakage at the final wire size. This type of problem is insidious, since processing may proceed successfully until the final wire size is approached. Also, the size of inclusion that is tolerable depends upon the desired filament size, e.g., a one-micron-diameter inclusion is acceptable for a 20 micron filament, but not for a 2 micron filament. This problem can be eliminated by careful selection of raw materials and by clean-room practice in billet assembly.

When a large number of rods are stacked in a billet, as is necessary to achieve fine filaments, voids may be present that can lead to non-uniform reduction during extrusion and drawing. This can lead to filament breakage and reduced performance. The problem can be eliminated by compacting the billet before extrusion.

When these potential problems are eliminated by proper processing and quality control, there is no metallurgical reason why a J_c of greater than 2400 A/mm^2 cannot be achieved in filaments less than 2.0 μm in diameter. In fact, the increased total reduction in area of the NbTi filaments may mean that it is possible to introduce more heat treatment cold work cycles and hence raise the value of J_c further.

When these potential problems and the proposed solutions were discussed with the superconducting material manufacturers, several manufacturers responded with proposals to investigate the production of high J_c, fine-filament NbTi using several different methods, and contracts were placed in October 1984 to deliver material for determination of J_c and construction of model magnets, and for an economic analysis of the fabrication method. The feasibility of utilizing hydrostatic extrusion to produce fine-filament

NbTi is also being explored. Figure 5-18 shows some very encouraging preliminary data from several samples.

To have filaments as small as 2μm in practical strand sizes, the finished strand must have as many as 50,000 filaments. This requires some form of rebundling during wire manufacture or during cabling (cable of cables). A preliminary estimate of the costs for fine-filament NbTi produced by these alternative methods has been made. A rough estimate of the costs of fine-filament NbTi indicate a 15 to 30% premium compared with the costs of conventional 20 μm filament material. More accurate cost information will be obtained at the end of the R&D work (September 1985).

(c) Cable Development.

Cable made from round strands and flattened to approximately 90% compaction is used for nearly all accelerator magnets because it is easy to wind, can be made in a large variety of shapes and sizes, and can have low eddy-current losses when the field changes. The SSC presents more stringent cable requirements than the Fermilab Doubler because of field-uniformity requirements and the need to use a different cable in the inner and outer layers of the winding in order to minimize the cost of superconductor.

The techniques and specifications for manufacturing the type D cable for the SSC models were developed at the LBL cable facility (shown in Fig. 5-19) and utilized by New England Electric Wire Company (NEEW) to produce cable for the type D models. 20,000 feet of cable for type D magnets have been produced, about half at NEEW and half at LBL for type D model construction at BNL, FNAL, and LBL.

Improvements have included a new mandrel design to reduce friction and "crossovers," more accurate tension control, and a new Turkshead roller system to maintain accurate cable thickness. In addition, specifications for cable dimensions, and strand pitch, and twist, etc., were developed at the laboratory facility. Continuing work is directed at closer control of cable dimensions, improvement of winding ease, and minimizing superconductor damage caused by wire deformation.

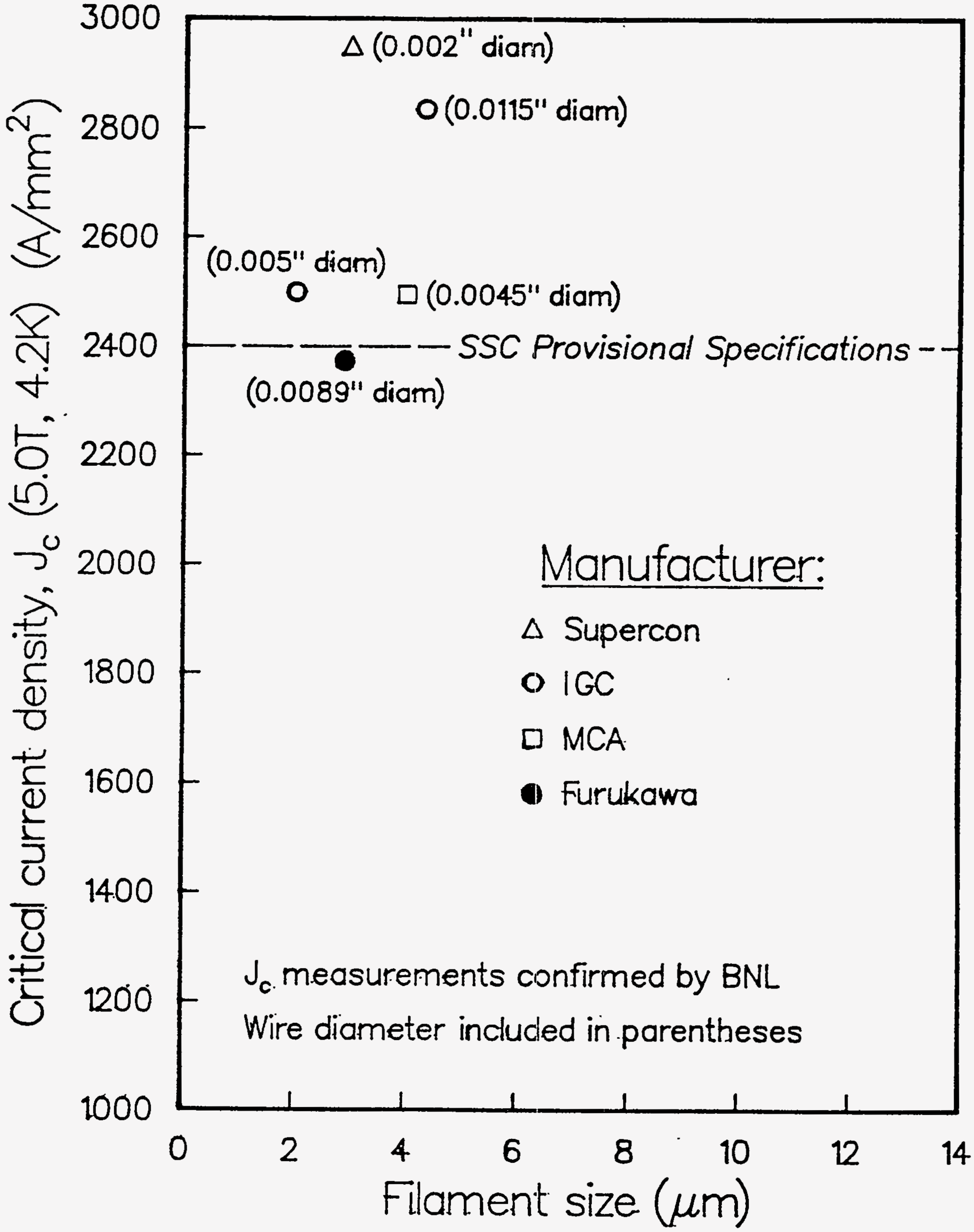

Fig. 5-18. Recent fine-filament NbTi results on maximum J_c at 5T, 4.2K.

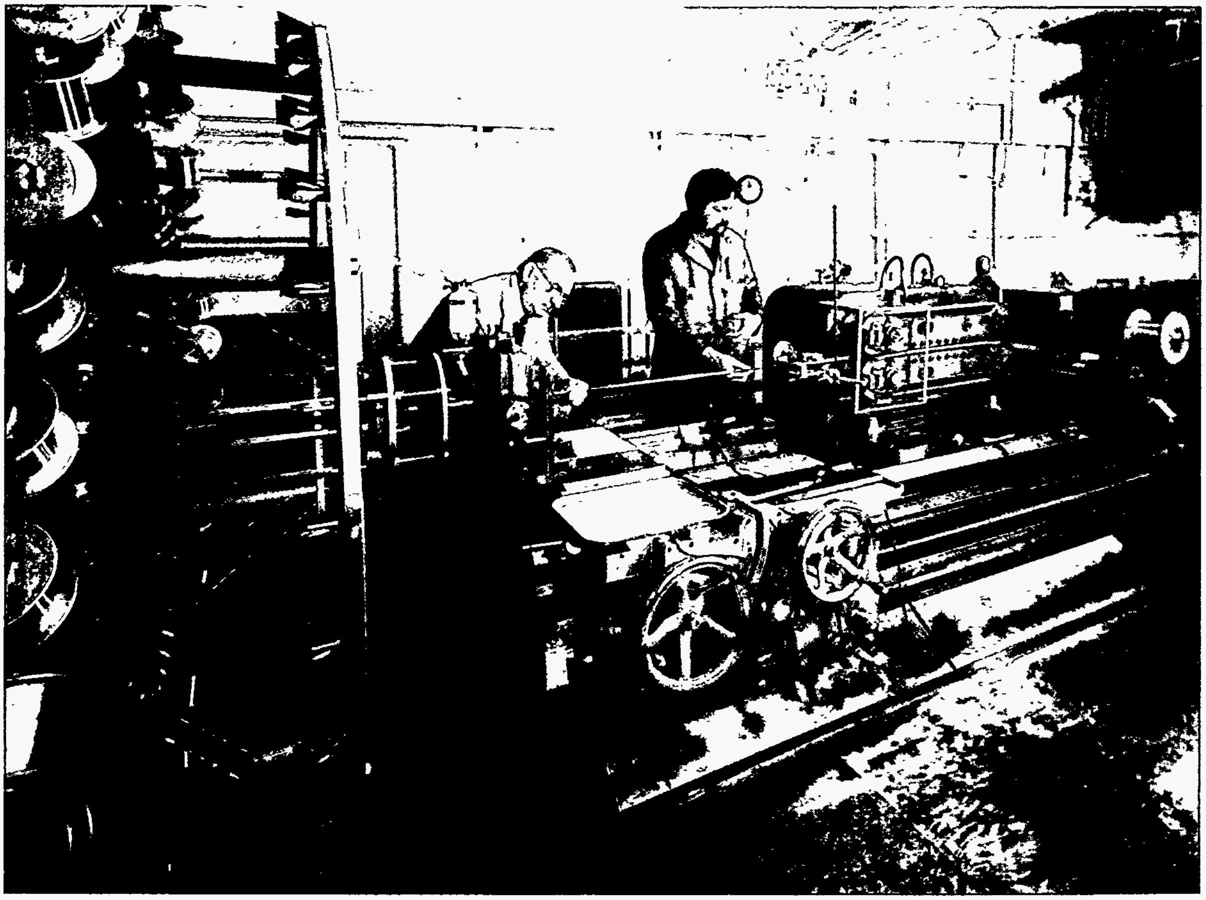

Fig. 5-19. LBL cabling machine, planetary drive for strand spools at left, mandrel and Turkshead, center, caterpillar tensioning device, right.

5.6 Plans

During the current, pre-selection stage of magnet modeling, laboratory-style tooling for each of the basic magnet types has been assembled and used. Given the rates at which models of the various types have been produced in FY 1985, it is reasonable to expect that a half cell equivalent length of full length dipoles can be produced and individually tested in FY 1986, even with the expected design changes that will be made by the CDG after basic type selection. Manpower and shop resources now engaged in parallel magnet developments of the various basic types will be freed to enhance dipole production or to begin work on quadrupole and/or spool model development. Each of the laboratories now participating in magnet R&D will be invited to take up one or more of these areas. As shown in Fig. 9-3, p. 113, ten quad models and four R&D spools represent a reasonable expectation based on historical performance records for these items at FNAL and BNL, where specialty quadrupoles have been rapidly produced for various purposes in the past several years. Achievement of technical performance verification for the selected magnet type appears a practical goal for FY 1986.

Looking forward, however, it is clear that a beginning in 1986 of significant industrial involvement in magnet prototyping and redesign for efficient production would be highly desirable. This early industrial participation would have several advantages: It would draw in industrial experience for the benefit of the first prototypes; it would lead to firmer cost estimates for magnet production; and it would start the process of discovering those firms truly competent to participate in the SSC. Further, if several parallel contracts could be let, a well-defined vehicle for U.S. and foreign industrial participation in the SSC would be created. In the schedule for FY 1987 and FY 1988 of Fig. 9-3 it has been anticipated that industry will be prepared, through FY 1986 activities, to begin actual prototype production in FY 1987 that will contribute to those magnets included in the FY 1987 magnet-system tests.

Based on the anticipated modeling and design program for FY 1986, the quadrupoles needed for the Systems Development Facility can be produced in FY 1987, as well as the spool pieces needed to complete the cells and couple them to the refrigeration system.

A number of high-gradient quadrupoles are needed to produce the tight focus at the high-luminosity interaction regions. With the improved superconductor now available it may well be possible to construct quadrupoles which exceed the performance anticipated in the RDS. If so, this increased gradient may be parlayed into improved performance in terms of event duty factor or cost savings through lowered beam intensity. Thus the program planned for FY 1987 includes significant R&D development of these important components.

CHAPTER 6. INJECTOR

6.1 Plans for FY 1986 and Beyond

An important effort will begin in FY 1986 on development of an optimum injection system for the SSC collider ring. The desired parameters of the injected beam will be established in concert with the determination of the collider ring lattice and magnet characteristics. The injection system is currently visualized as a sequence of three accelerators: a 1-Gev linac, a rapid-cycling low-energy booster synchrotron (70 GeV) with conventional magnets, and a high-energy booster with superconducting magnets and an energy of 1 TeV. Further studies will determine the optimum energy and beam characteristics of each injector accelerator system. Work will begin on the overall lattice system for both booster accelerators and the required magnet parameters. In particular, for the high-energy booster a program will be inaugurated to provide prototype models of the superconducting magnet designs.

While the parameters of the injected beam will be matched to the requirements of the main storage ring, it is important that the overall injection system of cascaded accelerators be designed for maximum reliability in operations. This will require careful consideration of the design and component specifications for the many subsystems of each of the injector accelerators.

Other considerations for the injector complex will include an examination of the the use of the proton beam from the high-energy booster as a source of test particles for detector development and calibration. Since the collider will require its beams for only an hour a day or so, the injector could be used for test purposes, provided an economical mode of operation is found.

CHAPTER 7. DETECTORS

7.1 Introduction to the problem

There is strong agreement in the U.S. high-energy physics community that the SSC detectors will present formidable technological challenges. It is also clear that detector requirements will have an impact on the actual accelerator design and the conventional construction in the interaction regions. Some of these questions have been addressed in a preliminary way in the DPF-sponsored Summer Study at Snowmass in 1984. That study reinforced the general feeling that the detector R&D should not be postponed for very long if efficient SSC detectors are to be available at the time of the SSC turn-on.

As a historical guideline for the SSC detector time scale, one could consider the LEP example. The formal approval for four 4π detectors was given by the Director in the summer of 1982, some six and a half years before the actual scheduled turn-on of the LEP itself. The initial collaborations for these proposals actually started about two years earlier. This may be an extreme example. Both the UA1 and UA2 detectors were conceived, designed, and built on a time scale about a factor of two shorter than the LEP detectors. However, because of some rather difficult technical challenges that will confront the SSC detectors, one could argue that their optimum time schedule should be closer to that used for the LEP detectors.

There are also administrative questions connected with the problem of SSC detector R&D. Major efforts need to be mounted in some areas of detector R&D in order that the outstanding problems be solved. These efforts will require substantial resources in terms of money, manpower, and test-beam time. Some coordination of these efforts thus appears warranted to assure that the use of these resources is optimized. Opinions have been expressed that the detector R&D effort needs to go beyond the traditional university group participation and CDG might have to play a significant role in this area.

To explore these technical and administrative questions, a Detector R&D Task Force has been appointed by the CDG under the chairmanship of Professor M. Gilchriese of Cornell University. The details of the charge, composition, and meetings of this Task Force are listed in Appendix A. The preliminary report of this Task Force was prepared and presented to HEPAP at its May 24 working group meeting at SLAC. The description of the required SSC detector program is largely based on this report.

The specific technical challenges that will be faced by the detectors at the SSC are attributable to the anticipated high luminosity, high energy, and large scale of the detectors and to severe physics-motivated requirements. These problems, and thus the required R&D, can be broken down into several different areas, i.e., tracking devices, calorimetry, electronics, data acquisition, triggering, computing, muon detection, particle identification, and large superconducting magnets. All of those, except the last two, are discussed in the Task Force preliminary report.

Several specific areas requiring generic (i.e., independent of specific detector design) R&D have been identified. Understanding potential radiation damage to the tracking devices, local electronics and calorimetric material, and finding ways to prevent or cure it are crucial to high luminosity operation. The implementation of triggering to achieve 10^8 to 1 reduction in data rate is another important problem. Data-acquisition techniques and the best way to implement large-scale computing requirements need serious study. Because the events are expected to be complex and frequently overlapping in time, detailed Monte Carlo studies need to be made to understand pattern-recognition problems, required parameters of tracking devices, and potential faking of rare events. The high energy of the SSC imposes serious problems connected with muon tracking, questions of how deep calorimeters need to be, and stringent requirements on tracking devices if momenta are to be measured via sagitta determination.

The above is by no means an exclusive list. It exemplifies some of the problems that require investigation and indicates the need for an early start on detector R&D problems.

7.2 Time Scale and Required Resources

It is proposed that well-organized, focussed workshops or study groups could be productive almost immediately. The goal of this phase would be to achieve a better understanding of the problems and to make recommendations for specific work. A reasonable time scale to achieve some conclusions would be the 1986 Snowmass Summer Study. For these workshops to be productive, significant participation by experts in the area of study is necessary. Since these experts might have to come from abroad or from industry, they may require travel support. Most of these problems will need extensive additional

Monte Carlo work to aid in designing the prototypes and understanding experimental results.

The results of these workshops and study groups would lead to specific hardware and software R&D that should commence at the beginning of FY 1987. The generic detector R&D probably should not be extended much longer than 1-2 years. After that it would be appropriate to focus on more specific problems and subsequently begin overall detector design. The time scale for large detector construction for the SSC is estimated to be 7±2 years, the error being at least partially due to potential uncertainties in the funding profile.

A crude and preliminary cost estimate for the generic detector R&D in FY 1987 and beyond is given in Table 7.1 In addition, an estimate of about $250K/year in travel funds was deemed necessary starting in FY 1986 to support the required travel budget for invited workshop participants.

These cost estimates do not allow for any test-beam support or additional test-beam construction. The availability of test-beams is rapidly becoming a crucial worldwide problem even without the SSC requirements. It appears that additional test beams will have to be built at Fermilab to accommodate the future requirements. This will have fiscal implications for capital equipment funds, beam-maintenance personnel, and possibly additional running time. Later on, high-energy test beams will be needed both from the SSC injector and perhaps from the SSC itself.

7.3 Organization and Plans

The Detector R&D Task Force has recommended that the CDG play a significant role in organizing and managing the detector R&D effort. Some of the arguments behind this recommendation are continuity of effort (particularly for workshop activities), ability to influence the budget, need for a full-time advocate for detector R&D and for a source of information about detector R&D needs. In discharging their detector R&D responsibilities the CDG would be advised by a Detector R&D Advisory Committee that would most naturally be an evolution of the Task Force.

The Detector R&D Task Force is at present being reconstituted to include broader participation from the high-energy physics community in this country as well as several foreign members. The foreign members will bring to the Task Force the know-how about the detector R&D in their respective regions and

Table 7-1

Preliminary Cost Estimate for Generic Detector R&D Starting in FY 1987*

	K$/year
Radiation damage to wire chambers	250
Radiation damage to silicon microstrips	100
Custom IC design capability	500
Fast response calorimetry	200
Radiation damage to sampling media	100
Extension of calorimeter prototype tests to high λ, E	500
New sampling media for calorimeters BaF_2, silicon, warm liquids, glass	500
Scintillating glass fiber development	250
Semiconductor device/detector R&D	450
Muon ID tests at high energy	200
Better hadron shower codes	50
Vectorization of some codes	50
Incremental support for multiprocessor projects - offline and triggering - test beds for SSC	1000
Networking - worldwide: must be improved for SSC	~350
	$4500 K/yr

*All of these activities are generic and need to be pursued for any future collider detectors, be they at an SSC or any other facility addressing the TeV physics domain. It is assumed that this work will be carried out under the rubric of advanced technology R&D, and thus no specific SSC budget line for detectors seems appropriate at this time.

also stimulate joint international R&D efforts in the future. The Task Force, at least at the beginning, is expected to a major role in initiating and organizing various workshops and study groups.

If the CDG is to discharge its coordinating role in the detector R&D, it will need to hire additional personnel. Three FTE's will be necessary to coordinate the program described in Sect. 7.1 and Table 7-1. The two major goals for the detector program during the coming year would be preparing the relevant part of the Conceptual Design Report, due in the spring of 1986, and organizing the detector program for Snowmass '86. The final Conceptual Design Report would require additional input regarding how detector needs influence the machine and the interaction regions. The Snowmass '86 study should summarize the results of all the workshops and study groups up to that time and outline specific hardware and software R&D to be pursued in the following years.

CHAPTER 8. CONVENTIONAL SYSTEMS

8.1 Accomplishments Since RDS

Following the publication of the RDS in May 1984, an effort was initiated with Parsons, Brinckerhoff personnel to consider the tasks to be addressed prior to the start of construction. This helped to define significant Phase I activities in the areas of SSC conventional facilities. The results of this effort were incorporated in the draft program plan, prepared in late June 1984.

Following the 1984 Snowmass Summer Study, preparatory work was undertaken at Fermilab, studying historical material concerning the site-selection process followed in choosing the Illinois site in 1966. This study covered an examination of the technical information about the design of the "200 BeV" machine, including the criteria that were recommended to the Atomic Energy Commission (AEC). As a by-product, it was possible to reconstruct the essential elements of the selection process, including the steps that involved the National Academy of Sciences and the AEC.

The next step was to prepare a plan and tentative schedule for the work over the next several years associated with the site and conventional facilities activities of the SSC. Elements in the plan covered the following topics:

- A Site Parameters Document
- SSC Conceptual Design
- Generic Environmental and Safety Studies

To accomplish these tasks a plan was prepared with a series of steps to be taken in the months ahead. With respect to the Site Parameters Document, a technical description of the SSC facility was prepared. This built upon the technical and conventional facilities that were described in the RDS.

A major effort involved acquiring professional engineering help for the siting studies, especially in the preparation of the Site Parameters Document, which describes in general terms the planned facility and its requirements. To acquire the needed help, DOE Chicago recommended using a firm already under contract, namely the CER Corp. Discussions were held with R. Ryan of CER, which in turn lead to a subcontract being placed with Parsons Brinckerhoff.

The development of site criteria was initiated after a thorough reading and examination of the work done prior to the founding of NAL, now known as Fermilab. The process that was followed consisted of an extended consideration of the information that would be needed to evaluate a proposed site.

Following discussions within the CDG and with the A/E personnel, the following topics emerged: Setting, Environment, Geology and Tunneling, Community Resources, Utilities, Man-made Disturbances, Climate, and Cost and Schedule.

The criteria, topics were selected with care and arranged according to the priorities suggested by the CDG. Some topics are quantitative, including magnitudes, while others are of a "softer" nature, leading to qualitative statements. A summary of the recommended criteria is shown in Table 8-1.

Longer term plans have been laid for a two-year program of A/E work leading up to the preparation of a Conceptual Design Report. The Chicago Office of the DOE set up an A/E selection process with input from the CDG. An announcement soliciting A/E services appeared in the December 6, 1984, issue of the Commerce Business Daily.

Table 8-1. Summary of Site Criteria Statements.
(As recommended to DOE)

SETTING	space for ring circumference of 60-100 miles looking for a site for a planar machine which is flat (level) or with a tilt < 1° need up to 11,000 acres
ENVIRONMENT	SSC will comply with NEPA need baseline data
GEOLOGY AND TUNNELING	long, uniform material, extensive characterization avoidance of active faults, good soil stability avoid unconsolidated solids with ground water awareness of seismic activity
COMMUNITY	staff needs: housing, education, cultural reasonable commuting times major airport, all-weather roads adequate industrial/construction resources
UTILITIES	up to 2000 gal/min of water up to 250 MW, separate feeds, outages < 2/yr
MAN-MADE DISTURBANCES	excessive noise--avoidance vibration--3 Hz is bad
CLIMATE	desirable average temperature 35° - 80°F desirable average relative humidity 25%-70%
COST AND SCHEDULE	land costs, utility rates what's being offered

The full criteria statements are contained in the Siting Parameters Document (SSC-15). The material in the Document is organized as follows:

I. SSC Project Description
II. Features of the SSC
III. SSC Siting Criteria
IV. Information Needed about Proposed Sites

Starting from a general description of the high-energy facility, the case is made for the criteria, leading up to a list of information that DOE is encouraged to seek from prospective site proposers. The document was submitted to DOE on April 15, and is available upon request.

Meetings were held at Chicago Operations for selecting an A/E firm for the conceptual design of the SSC. Four firms were interviewed: DUSAB (Daniel, Urban, Seelye, and Bechtel); Morrison-Knudsen; Parsons, Brinckerhoff, Quade & Douglas; and RTK (Raymond Kaiser, Tudor, Keller Gannon-Knight). Thorough presentations were made by each firm or joint venture. In preparation for initiating work with the selected firm, an evaluation of the scope of work was done and a description of the tasks and their priorities examined.

In June the DOE selected the RTK firm to carry out the A/E work for the Conceptual Design Report. Work has commenced in collaboration with RTK (based in Oakland, California), focusing initially on tunneling costs.

8.2 Plans

Attention within the Conventional Systems Division of the CDG is being directed to the considerable work that lies ahead. With the assistance of engineering firms, it is intended that the design work done for the RDS be extended and augmented. For the purpose of a proposal, selected design work will be attempted with the attention concentrated upon developing an overall project schedule integrated with the needs of the technical systems. Following that, a master plan will be developed to guide the subsequent work. In this phase there will be an examination of the space and facility requirements of the accelerator and research groups, including university users. The next step will be a conceptual design where attention will be paid to a number of technical problems. The tunnel requirements will be studied in much more detail, including an examination of a number of safety considerations. The integration of technical and conventional systems will be addressed and optimization carried out. Since the site will not have been chosen, generic studies will be undertaken in the area of environmental analysis, site infrastructure, utility systems distribution, etc. As before, attention will be paid to achieving an integrated schedule that will lead to efficient construction in a cost-effective manner. This will be demonstrated by a detailed cost estimate, including the needs for annual funding.

The specific work of the Conventional Systems Division is being organized under the following headings:

- Planning and Coordination
  - Administration
  - Technical Studies
  - Environmental and Safety
- Siting
  - Parameterization
  - Technical aid to DOE if needed
- Conceptual Designs
  - Proposal (Non-site-specific)
  - Master Plan
  - Conceptual Design
  - Pre-Title I
- Preliminary Design
  - Adaption of Conceptual Design
  - Advance Design
  - Mobilization

Plans for further work associated with detailed design, construction, inspection, etc. are being formulated as part of the over-all project plan.

In support of the pending magnet decisions the Conventional Systems Division is exploring the implication of the design and cost differences between colliders built using 6T or 3T magnets. The major impact is with the longer (100 mile) tunnel, required by the weaker magnetic field compared to a 60 mile tunnel needed to enclose 6T magnets. Other items such as service areas, exits, utilities, roads, etc., are different. Increased transit time for personnel at the longer ring leads to an estimate of approximately 10Δ more maintenance/service people needed in that case. Following a decision on the magnet, the site parameters document will be amended to take into account the specific physical implications of the decision.

Clarification of the magnet field and site requirements will make it possible to prepare a conceptual design (non-site-specific) for the SSC. In this phase the ideas and concepts for an SSC will be extended beyond what was accomplished during the RDS. Technical subjects concerning tunnel construction, other underground systems, safety, radiation design, possible test beams, and clustered experimental areas will be examined. Since a specific site will not likely have been chosen by DOE before March 1986, generic studies will be done with respect to environmental considerations.

When a site is selected, physical and geotechnical information will be assembled so that the earlier design work can be adapted to the specific characteristics of the site. This work will result in a final Conceptual Design where design options can be evaluated in order to achieve an optimized configuration. This will lead into a pre-Title I design and report, due in August 1987. The accomplishment of this goal will make possible the advanced design of facilities that will be needed for early occupancy on the site and rapid mobilization when the Notice to Proceed (NTP) is received from the DOE.

Current planning is aimed toward providing early access to one sector (1/12) of the collider ring for the installation of magnets, cryogenic distribution system, and a helium refrigerator within two years after NTP. This would permit the testing of prototype components under realistic conditions. Meanwhile detailed design would proceed in order to have an orderly progress into full-scale construction.

CHAPTER 9. PROJECT PLANNING & MANAGEMENT

9.1 Activities in FY 1985

Initial activities in FY 1985 involved establishing the operations and support structure for the CDG at LBL. This work included the development of administrative procedures, staffing, and coordination with LBL support groups.

Financial tasks have included the development of a chart of accounts for the CDG within the LBL account structure. While the majority of SSC costs are accounted through the LBL system, the CDG operates independently of LBL under DOE/URA contract DE-AC02-76CH03000, Account 3001. Therefore independent financial records are maintained by the CDG. The chart of LBL accounts for the CDG operation are given in Table 9-1.

A system of accounts was set up for each of the laboratory programs. The account structure for the CDG and the Laboratory efforts also reflects the reporting categories for the SSC R&D activities. This system was reviewed in detail by the Fiscal and Management Review Panel (see Appendix A). The accounts were established to reflect the costs for the major areas of research within the SSC program at each laboratory as planned by the CDG-Laboratory Agreements.

Other specific tasks have included formal agreements between the CDG and individual laboratories for work to be performed (see Section 2.2), the SSC Program Plan, the SSC Management Plan, and Field Task Proposal/Agreement. Continuing activities include budget accounting, reporting, cost estimating, and long-term planning for both Phase I and Phase II.

One of the most important tasks in the Project Planning Group is the assembly and coordination of all costs related to the various magnet design styles. During the spring of 1985, a complete review of the magnet system cost estimates for all of the candidate superconducting magnet types being considered for the SSC main ring will be carried out. In addition, cost estimates are being re-examined for other major accelerator systems and for conventional construction areas to provide appropriate cost data for a projected complete SSC facility utilizing each of the candidate magnet styles.

Table 9-1. Chart of LBL Accounts for the CDG.

8390		SSC Central Design Group
		CDG Directorate (subs 1-4)
	01	General
		Program Management (subs 5-21)
	05	Program Planning and Technical Coordination
	20	Administrative Support
		Accelerator R&D (subs 22-59)
	22	General
	25	Theory & Computation
	30	Accelerator Systems
	40	Magnets
	50	Injector
		Conventional Systems (subs 60-69)
	60	Planning & Coordination
	61	Site Criteria
	62	Conceptual Design
	63	Tunnel Concepts
8391		Central Design Group Equipment Purchases
	01	Administration
	05	Program Planning & Coordination
	25	Accelerator R&D
	60	Conventional Systems
		Capital Improvement Project
	80	Improvements, 90, 4th Floor
	81	Conference Room
	82	Ventilation Modifications, 90, 4th Floor

For the overall cost comparisons for the total SSC project, the same major Work Breakdown Structure (WBS) and cost categories described in the RDS are being used:

1.1 Project Management
1.2 Central Laboratory Facilities
1.3 Injector Facilities
1.4 Collider Facilities
1.5 Experimental Facilities
1.6 Systems Engineering and Design
1.7 Contingency.

All current costs are developed in FY 1985 dollars. In cases where the RDS costs have been utilized, they were scaled to allow for a nominal FY 1984-85 escalation rate (5% was used for the estimate comparisons). Where the costs were developed or reviewed explicitly for the current study, actual FY 1985 costs are used directly.

The various magnet system detailed costs are being estimated both by participating laboratory magnet groups and by industrial manufacturing firms; they will be assembled, reviewed, and analyzed by the CDG for uniformity, consistency, and completeness. In addition to the specific magnet style designs, as part of the overall cost development, study, and analysis, certain "variable" issues are being considered separately from the basic magnet styles. The effects of variation in the magnet aperture are considered for high-field cosine-theta magnets and low field superferric magnets, and scaling factors are being developed for certain of the key magnet components. Some analysis will be done to re-examine the overall cost implications of magnet length variations, lattice cell structure, number of lattice quadrupoles, etc.

A Cost-Estimating Task Force has been established to assemble, review, and analyze the total information in a manner which will facilitate comparisons of the various magnet styles.

The detailed cost information for each magnet style is being developed by the laboratory magnet groups. A WBS format has been developed by the CDG to provide data in the same categories for each magnet style to the maximum extent possible. The format is similar to that used for the 1984 estimates in the RDS.

In addition to the laboratory efforts, two industrial firms with experience in the superconducting magnet area, General Dynamics-Convair Division and Westinghouse Electric Corporation, are each providing independent manufacturing plans and cost estimates for two particular magnet styles C and D. These two styles provide examples of both high-field and low-field magnet design. The two contracts started in April, 1985, and are due to be completed by July 1, 1985. Five specific tasks are being studied and developed under these industrial contracts:

1) Develop a comprehensive manufacturing sequence and flow chart depicting all major manufacturing operations from receipt of raw materials and vendor-supplied components through final magnet assembly. Significant inspection and test operations should also be indicated.

2) Prepare a plant layout for most efficient work flow for large quantity production of these magnets. Estimate size and cost of production facilities.
3) Prepare schematic designs for the required tooling for producing these magnets. Estimate tooling production rate and determine tool quantity requirements. Estimate tool design and fabrication costs.
4) Consider and list all in-process and acceptance-test requirements and associated equipment. Estimate test-span times and determine the quantity of test stations required to support the necessary production rate. Estimate the test equipment and operation costs.
5) Prepare a detailed cost estimate for the magnets. This should be supported by vendor quotations for as many of the raw materials and subassembly components as practicable. Internal estimates should be generated to supplement the vendor quotations as necessary.

There are five magnet style categories considered in the cost studies that are described below:

Type A is a high-field (6T) superconducting magnet utilizing a two-layer, collared cosine-theta coil (stainless steel collars), cold iron for the flux return, and arranged with two bores side by side in one single yoke (i.e., 2-1), all contained in a single cryostat. The coil i.d. is 4 cm and the bore tube i.d. is 3.28 cm. The magnet has an effective magnetic length of 16.6 m and an overall length of 17.6 m. For a 20 TeV SSC, 4200 such magnets would be required if the central field is 6T. The Type A design has been developed in collaboration between LBL and BNL.

Type B is a high-field (5T) magnet utilizing a two-layer, collared cosine-theta coil (with aluminum collars) and no cold iron. The outer vacuum vessel is a warm iron shell that provides magnetic shielding; the magnets are all single bores (1-1). The coil i.d. is 5 cm; the overall length is approximately 12 m (magnetic length 11.25 m). Approximately 14880 such magnets are required for 5T operation. Style B was developed by FNAL.

Type C is a low-field (3T) superferric magnet. This magnet has cold iron and is arranged with two magnetically decoupled units to be mounted one above the other in a single cryostat. The iron gap is 2.54 cm high and approximately 3.2 cm wide for the useful aperture. Each bore of the magnet has three separately energized coils used for tuning out unwanted multipoles, and each coil set must follow a prescribed ramping program sequence.

These magnets are fabricated in 35 m elements. Current design has three 35 m elements preassembled in a single cryostat with a quadrupole and correction coils at the laboratory site to form 115 m units. Approximately 1000 each of these long units (or 4000 of the fabricated 35 m units) are required for the SSC. Style C was developed by TAC.

Type C* is a (1-1) version of type C with the same magnetic geometry and parameters, but utilizing two independent magnets in separate cryostats. Hence for C*, 2000 each of the long units (or 8000 fabricated 35 m units) would be required for the SSC. Style C* is also being developed by TAC.

Type D represents a magnetically and cryogenically decoupled (1-1) version of style A. Magnet parameters are similar. Approximately 8400 units at 6T central field operation are required for the SSC. Style D is being developed by a BNL, FNAL, and LBL collaboration.

The Cost Estimating Task Force (CETF) will assemble the above data on dipole magnet costs. The data will be analyzed together with the final magnet report from the Aperture Task Force in order to normalize costs to the prescribed aperture. The CETF final report will also include cost information from the Magnet Systems Group on cryogenic systems, installation, and other accelerator systems. The report will also address cost variations for conventional systems appropriate to each magnet design style.

The final CETF report together with reports from the Accelerator Physics Division regarding magnet field quality, the Low Temperature Operations Task Force, the Operations and Commissioning Task Force, and the Power Supply-Quench Protection Task Force will form the body of information available to the Magnet Selection Advisory Committee.

The magnet selection process described above is a major part of the CDG effort for the last half of FY 1985 and involves nearly all of the CDG Divisions. Other specific R&D efforts are described elsewhere in this report. The total CDG effort for FY 1985 involves Management, Planning, Accelerator Physics, Accelerator Systems, Injection Systems, Superconducting Magnet Program, and Conventional Systems (including A/E contracts). The planned vs. actual costs for the CDG program through April, 1985, are shown in Fig. 2-3, p. 27.

9.2 Schedules

The overall goals and major milestones for the SSC R&D program are summarized in Fig. 2.4, p. 30. In FY 1986 the program will encompass more details of the overall SSC technical systems in a sufficient manner to provide a construction proposal with associated cost information; however, the superconducting magnet program will remain as the major focus of the R&D activities. The most significant milestone for FY 1986 will be the submission of a SSC Non-Site-Specific Conceptual Design Report in April 1986.

In order to make a significant demonstration of major component feasibility together with cost estimate verification, the FY 1987 R&D efforts must increase substantially over those of FY 1985 and FY 1986 (see Table 9-4). The CDG activities will require a significant increase in manpower to plan properly all aspects of the technical systems of the SSC. Approximately one-third of the CDG budget ($5M) will be used for engineering services to provide for pre-Title I Design & Planning for the Site and Conventional Facilities. Detailed planning and coordination of all efforts will be vital to an expeditious and efficient construction start. In the area of SSC technical systems, the magnet program will remain as the largest effort; however, other accelerator systems for the SSC including the injection accelerators will become a more substantial part of the total program.

In general, the CDG, building on the accelerator physics and engineering studies of FY 1984 and FY 1985, will carry out design-optimization studies based on a single magnet style. This program will encompass all accelerator systems including the injection accelerator systems. As specific system-design concepts evolve, studies will be undertaken to understand and optimize the overall operational reliability and performance of the SSC.

The activities of the Accelerator Physics (AP) Division are intimately meshed with all of the accelerator activities. In general an iterative process is involved between theoretical projections and component designs. As seen in Figs. 9-1(a) and 9-1(b) the AP Group will provide initial parameters for major systems in FY 1985 which serve as the design guide. The design R&D may alter or require new calculational evaluations. The Conceptual Design Report of April 1986 will represent a complete SSC design for overall systems. R&D on subsystems and components will continue through FY 1987.

The AP Group activities on lattice design, aperture specifications, and field quality are vital to the magnet-development program. Studies of

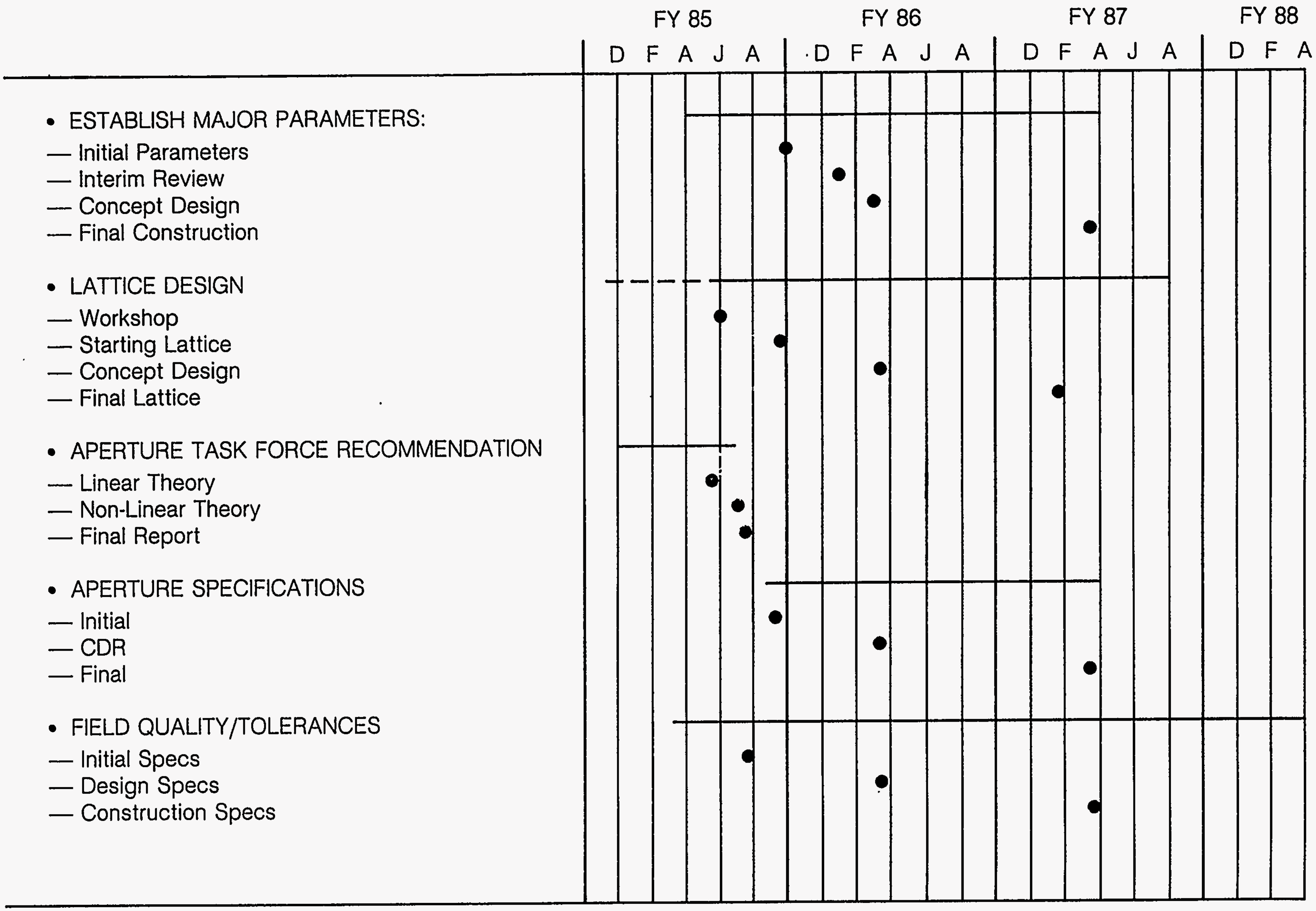

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Fig. 9-1(a). Accelerator Physics activities and goals.

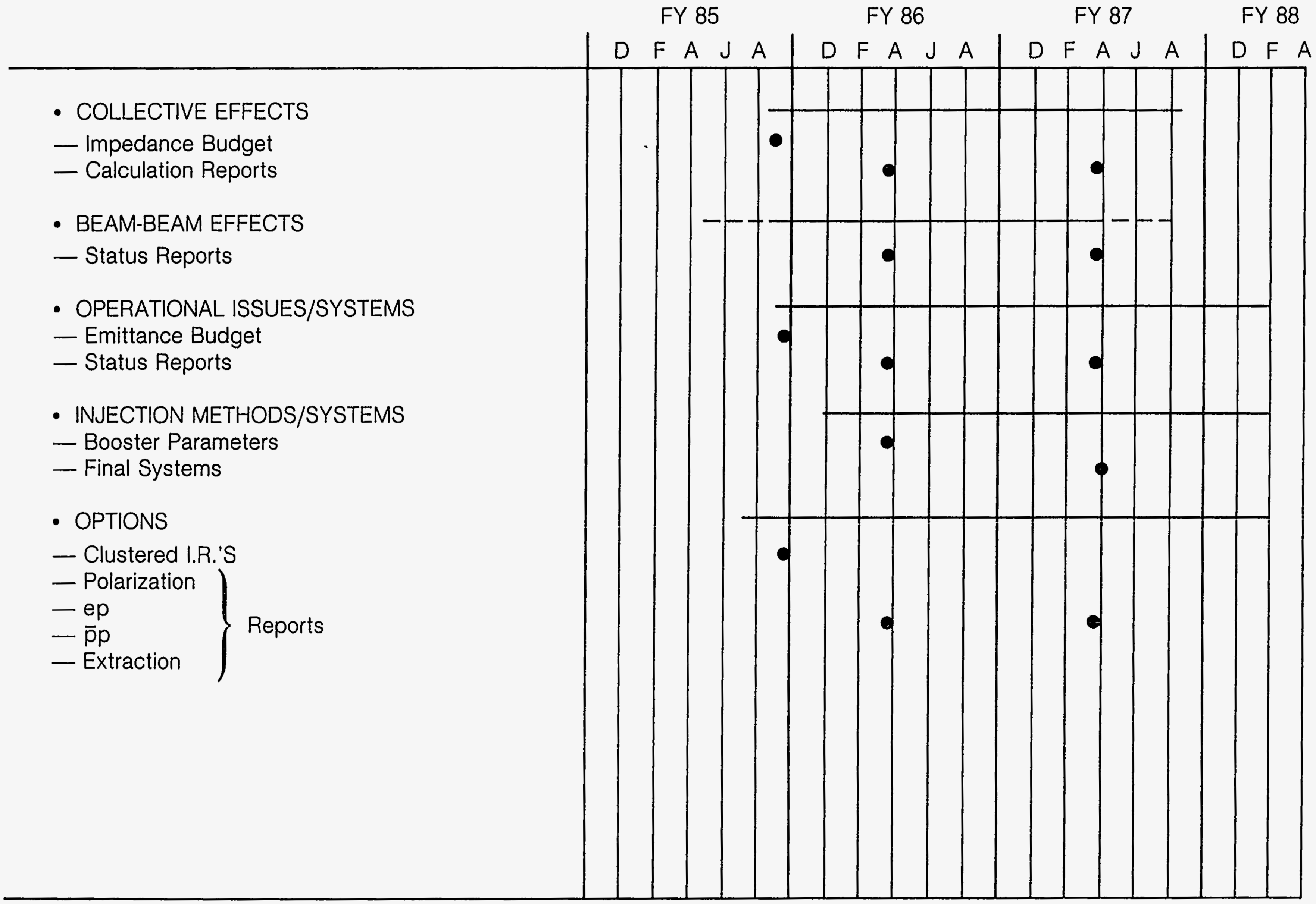

Fig. 9-1(b). Accelerator Physics activities and goals (continued).

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collective and beam-beam effects are important to materials and fabrication techniques and projected operational performance.

Determination of the SSC lattice system and insertion regions together with site-specific data will allow the conceptual designs of the experimental area structures to be further developed. This effort must proceed in concert with plans for experimental detectors. The detector systems will be large and complex and will require significant R&D efforts by high-energy physics research groups.

The Accelerator Systems for the SSC includes all the main storage ring systems and components apart from the superconducting magnets; however, the integration of the magnets into a complete operational system falls in this category. A WBS listing of the major components and subsystems which are included is given in Table 9-2.

Table 9-2

1.3.3 Accelerator Systems

1. (Magnet) Systems Integration
2. Cryogenic Systems
3. Vacuum Systems
4. Power Supplies and Quench Protection
5. Correction Element Power Supplies and Quench Protection
6. RF Acceleration and Feedback
7. Injection System
8. Abort System
9. Beam-Loss Calculations
10. Control Systems
11. Safety and Interlocks
12. Beam Instrumentation
13. Installation
14. Reliability Evaluation and Quality Assurance
15. Operations
16. (Conventional Mechanical Systems)
17. (Conventional Electrical Systems)
18. Insertion Regions
19. Extraction

Planning details for the Accelerator Systems activities are provided in Figs. 9-2(a) and 9-2(b). The magnet systems integration is an important part of this program. While the prototype magnets will be individually tested as they are made, assessment of their behavior as part of a complete system is crucial in evaluating their effectiveness and reliability for the SSC. The first test of a set of magnets (Half-Cell Test) is projected for FY 1987. Overall systems tests for engineering design and reliability studies will continue into FY 1988 and beyond.

Cryogenics, vacuum, and power-supply systems are closely tied to the magnet design and represent significant efforts for FY 1986 and FY 1987. The other systems noted in Figs. 9-2(a,b) will be examined in sufficient detail for the Conceptual Design Report. Fabrication of prototype units and testing are indicated in the schedule.

With regard to the Magnets, an extensive examination of a range of basic dipole magnet types is currently being carried out, with a selection to be made in the last quarter of FY 1985. Building on the extensive preselection design work under way, the final prototype design will be completed in early FY 1986, and prototype fabrication will begin at a modest, budget-limited rate. Efforts will be focused on optimizing this design with regard to costs and performance. The program will also include engineering studies of quadrupoles and other special units such as correction-element spools, injection-system magnets, and insertion-region magnet elements.

Most important will be continuation of the development, in collaboration with U.S. industry, to improve the current-carrying capacity and other characteristics of commercially available superconducting material. Prior to the beginning of the recent improvement program, wire containing filaments capable of transporting 1800 A/mm^2 was commercially available. The Reference Design Study assumed in its cost estimates that an improvement to 2400 A/mm^2 could be effected by R&D prior to SSC construction. This goal has already been exceeded, and even higher values may be available for the SSC during the coming year.

In FY 1987, after individual tests of the first group of prototype dipoles for field quality and performance and installation and operation of the Half-Cell Test, it is planned that approximately 40 additional dipole units be

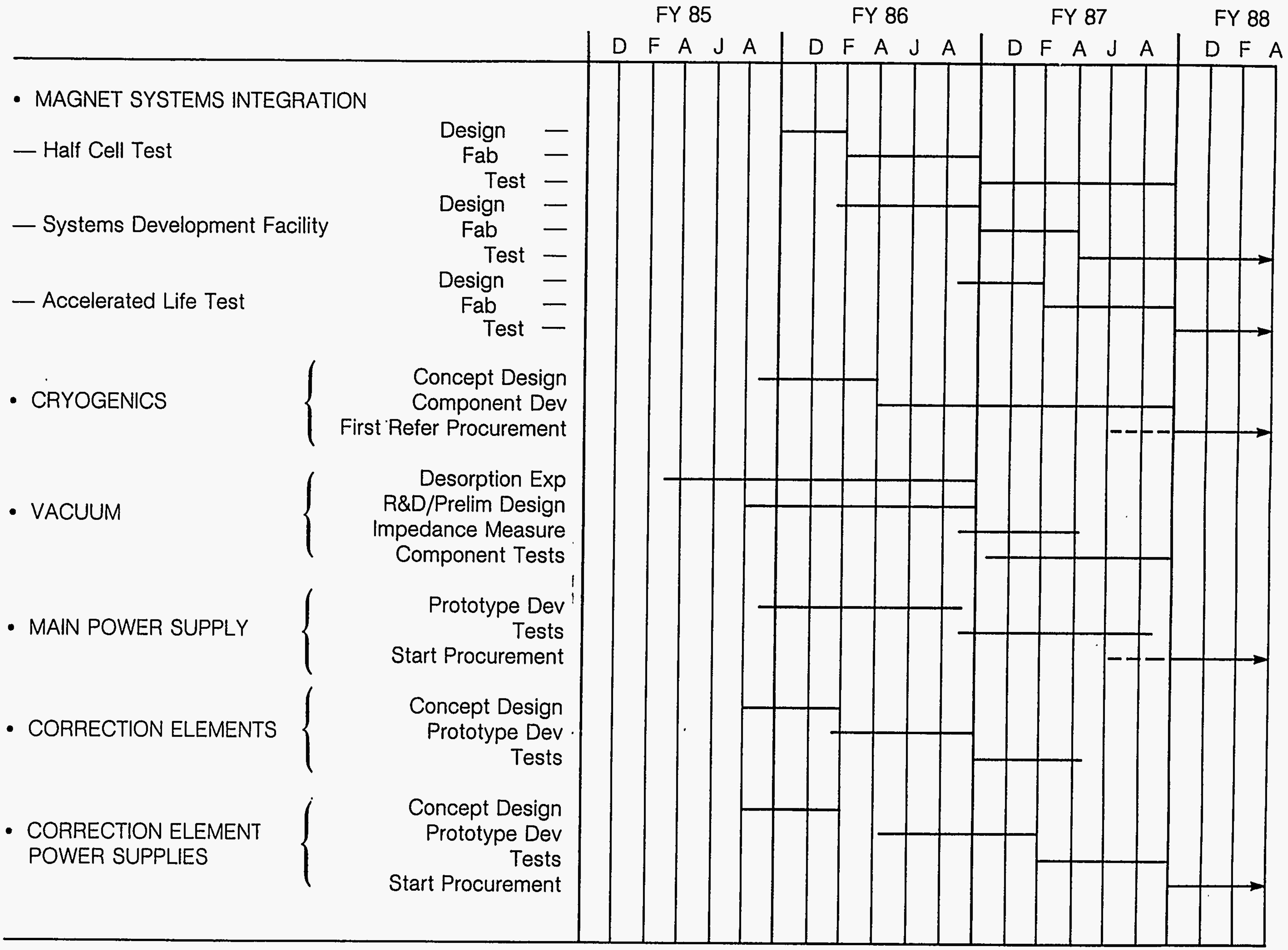

Fig. 9-2(a). Accelerator Systems program.

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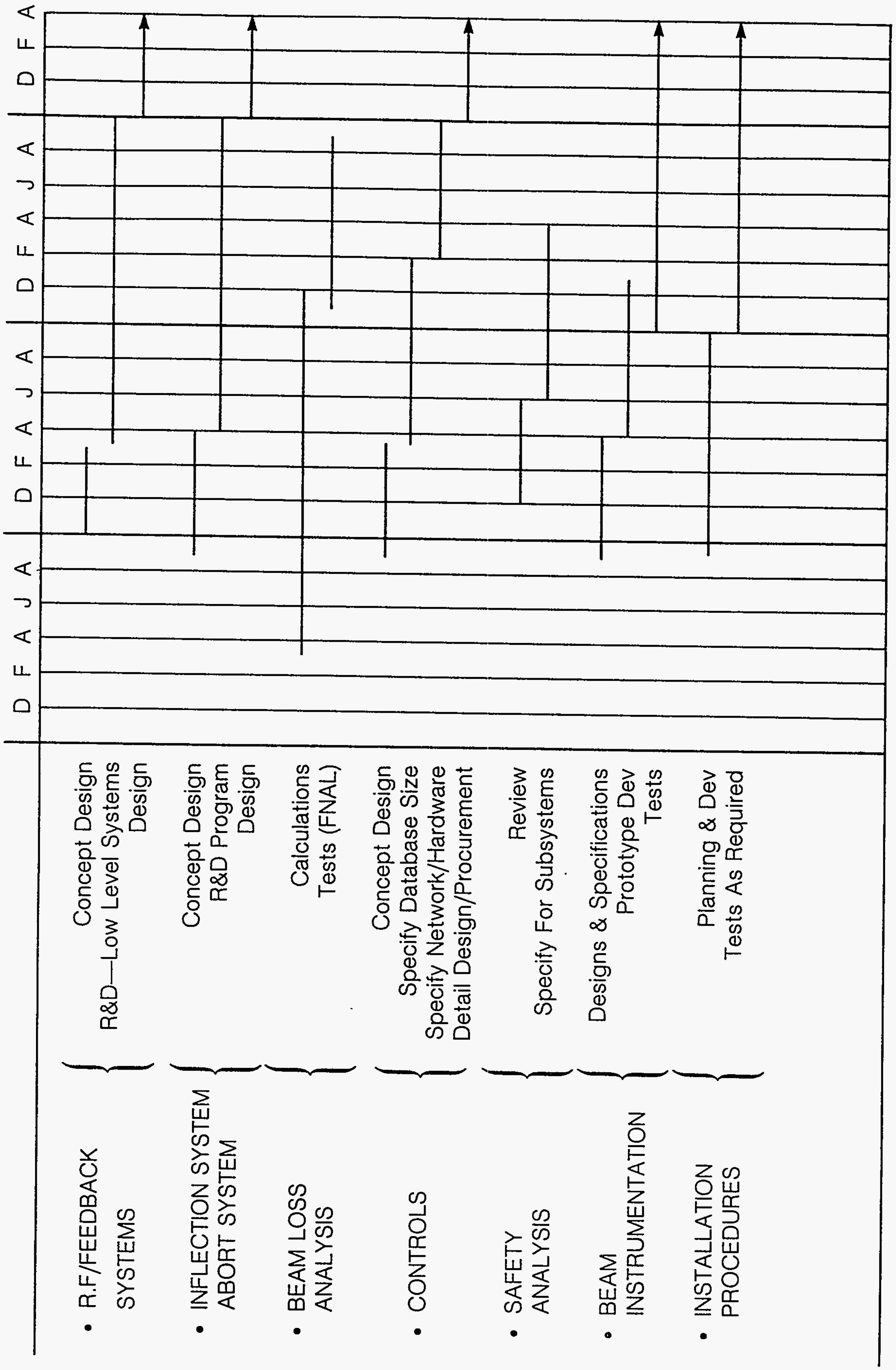

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Fig. 9-2(b). Accelerator Systems program (continued).

produced. These magnets will be utilized and tested in a Systems Development Facility at one of the DOE laboratory sites. The purpose of this facility is to generate and answer questions that arise concerning the engineering design of components other than magnets, while studying the operation of large numbers of magnets as a coherent system.

In addition to the Systems Development Facility, there will be an installation to conduct Accelerated Life Tests on a half or full cell of magnets close to the final design. The resulting information will be used to further develop and verify designs in the following systems:

- Magnet Systems
- Magnet Cryogenics
- Power Supplies
- Quench Detection and Protection
- Controls
- Vacuum
- Correction Coils
- Safety

The schedule for fabrication of R&D models and preproduction prototype units of dipoles, quadrupoles, and other main ring elements is provided in Fig. 9-3 and Table 9-3. This program is geared to provide a 35-cell test (~1/12 ring) of the main ring in the third year of construction.

Table 9-3
S.C. Magnet Program -- Magnet Production Plan
During Construction of the SSC

	FISCAL YEAR					
	88	89	90	91	92	93
Number of Cells Produced	5	30	85	150	150	

The development of an optimum Injector system will begin in FY 1986. The desired parameters of the injected beam will have been established in concert with the determination of the storage ring lattice magnet characteristics. The injection system is currently visualized as a sequence of three accelerators, a 1-GeV linac, low-energy booster synchrotron (approximately 70 GeV), and a high-energy booster with energy in the 1-TeV range. Studies will determine the optimum energy and beam characteristics of each of these injector accelerator systems. Work will begin on the overall lattice system for both booster accelerators and the required magnet parameters. In particular for the high-energy booster, a program will be initiated to provide prototype models of the superconducting magnet designs. While the parameters of the injected beam will be matched to the requirements of the main storage ring, it is important that the overall injection system of cascaded accelerators be designed for maximum reliability in operations. This will require careful consideration of the design and component specifications for the man subsystems for each of the injector accelerators

Figure 9-4 shows the general plan for the injectors. An optimized overall design will be provided for the Conceptual Design Report. Details of the systems will be developed in late FY 1986 and FY 1987. The development of high priority components will commence in FY 1987.

For the Conventional Systems, a cost estimate based on a "median" site was featured in the RDS. For FY 1986 an important supplement to that will be the development of cost ranges to be expected for potential real site variations. In addition, the non-site-specific features of the conventional systems will need to be developed further to optimize their adaption to scientific need. Further studies of utilities distribution and organization of other site services and arrangements will also be needed to assure cost effectiveness of the conceptual design.

Selection of a favorable site for the SSC will be crucial for maximizing its cost effectiveness. Accordingly, it will be important to study extensively the potential impact of the SSC on its environment and the implications of various types of environment for SSC costs. It is expected that this process will continue throughout the period prior to site selection.

As seen from Fig. 2-4, p. 30, the site selection is projected as a major milestone in the first quarter of FY 1987. The achievement of this milestone would give access to the site-specific information that is required to provide the conceptual design. For example, the final site geology and topography would allow a determination of tunneling techniques to be used. Power and cooling-water systems could be more accurately specified and preparation made for initial site services. A master plan for the layout of the central

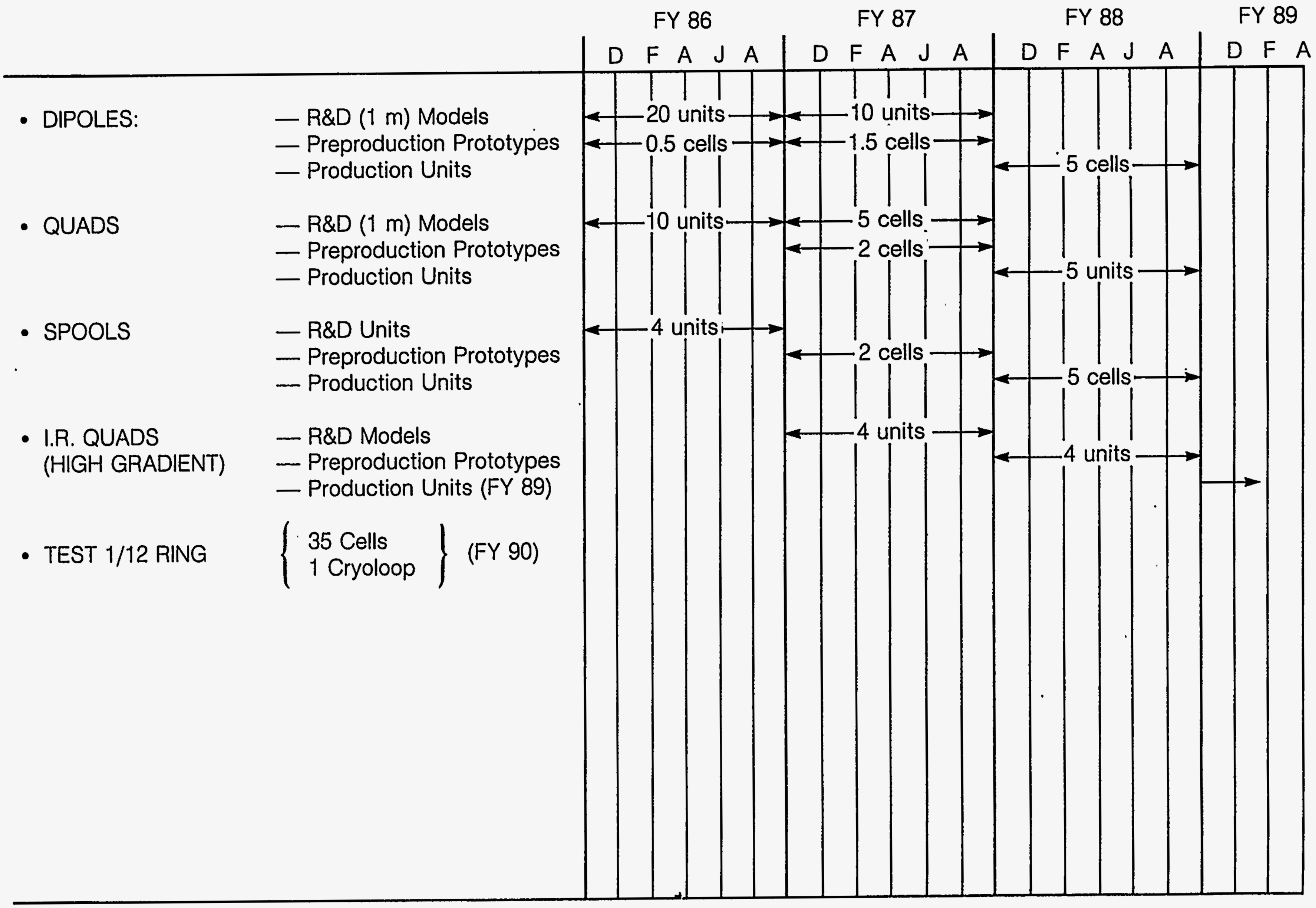

Fig. 9-3. Superconducting magnet fabrication plan.

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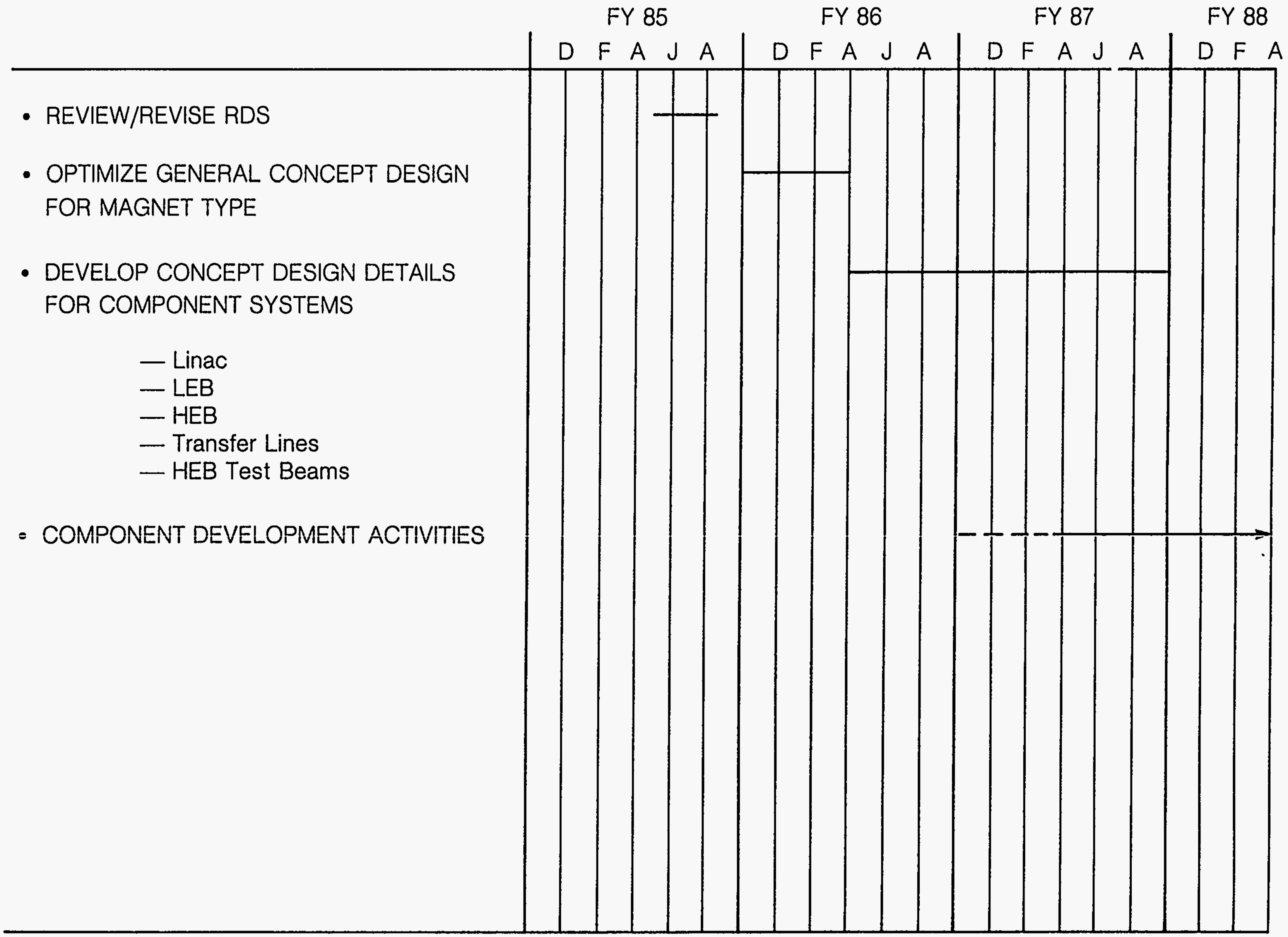


Fig. 9-4. Injection system plan.

XBL 857-9867

office, research offices, laboratories, assembly building, and warehouse facilities could then be extended together with appropriate structures for housing refrigerator systems, rf systems, power systems, and various support facilities. Roads and transportation systems will be of significant importance to both the construction and operation of a ring on the size scale of the SSC. The determination of construction methods and an optimized construction schedule will be vital part of the conventional facility effort in FY 1987. The overall plan of activities is indicated in Figs. 9-5(a) and 9-5(b).

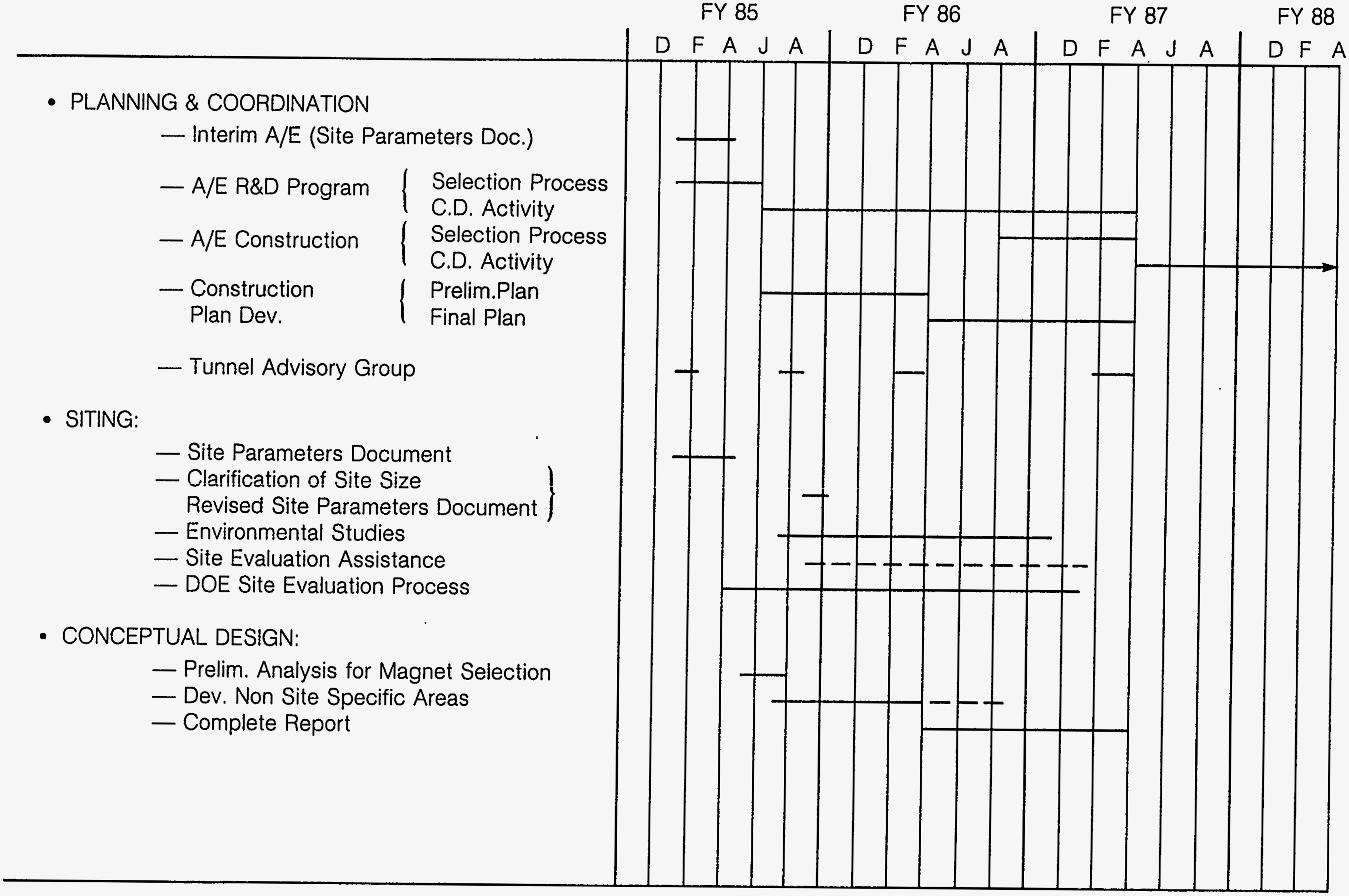
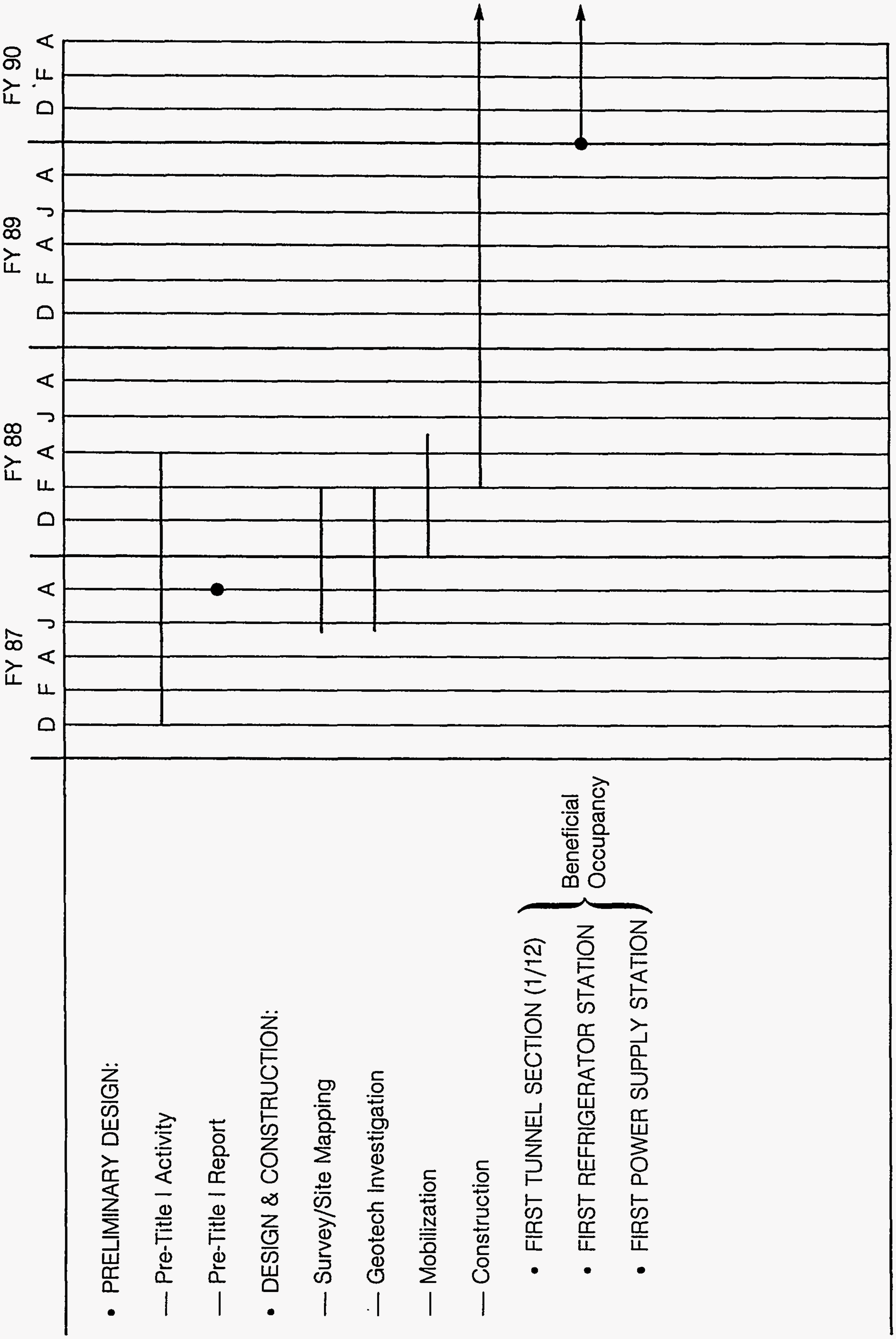


Fig. 9-5(a). Conventional Systems program.

XBL 857-9868



XBL 857-9869

Fig. 9-5(b). Conventional Systems program (continued).

9.3 Budgets

The R&D program plan through FY 1988 is shown in Table 9-4. The CDG costs are distributed according to the current budget and reporting categories.

For FY 1985 the CDG budget is projected at $5.3M. The monthly and cumulative expenditures through April 1985 have been given in Fig. 2-3, p. 27. Table 9-4 shows that $0.83M of A/E contract services is included within the $1.1M indicated for conventional systems. The SSC program at the laboratories and TAC (projected at $14.7M for FY 1985) is given according to the current budget and reporting categories in Table 9-5.

The current plan for FY 1986 is shown in column 2 of Table 9-4. In this plan the total budgets remain the same as in FY 1985. Within this total the CDG budget will increase by $3.8M. $1.2M of this increase is for Conventional System engineering studies. The remainder of the increase, $2.6M, is required for staff to produce the non-site-specific Conceptual Design Report and for the associated R&D program in all of the areas described in the report. The components of the work carried out at the Magnet R&D Centers in the current FY 1986 plan are still dominant, but are reduced by comparison with FY 1985 as more of the technical work shifts to the Design Center. The decrease in the magnet program is partly apparent and partly reflects the narrowing of magnet work to focus on a single basic magnet type. The apparent decrease stems from the shift of some magnet design work to the Design Center and to the creation of a new budget category of String Test as shown in Table 9-4.

As anticipated in Section 5.6, a revised request for the FY 1986 magnet program is shown in Table 9-6. This revised plan reflects the need for initiation of strong industrial participation and our preparedness to do so in early 1986 after selection of a basic magnet type. In addition, the revised request includes tooling to be used for modeling of focusing magnets and spool pieces (containing the cryogenic apparatus and dipole, quadrupole, and higher multipole correction packages).

These requested additional resources will significantly enhance the demonstration of technical viability of the magnet system and bolster efforts to reduce the cost of that system through application of industrial manufacturing expertise.

The FY 1987 budget plan is provided in column 3 of Table 9-4. A total of $55M is requested for the SSC program in that year. Increases over FY 1986

Table 9-4. SSC R&D PROGRAM PLAN (M$).[a]

CDG	FY85	FY86	FY87	FY88
Adm/Plan/Support	2.1	2.65	4.0	2.0
Accelerator Physics	1.0	1.4	2.0	2.0
Conventional Systems	1.1	2.5	7.0	--
Purchased Engineering Serv.	(.83)	(2.0)	(5.0)	--
Injector	0.1	0.5	1.0	5.0
Magnets	0.5	1.1	1.3	4.0
Accelerator Systems	0.5	1.0	1.7	5.0
CDG Subtotal	5.3	9.1	17.0	18.0
LAB				
Accelerator Systems	0.7	1.9	10.3	15.0
String Test	--	1.5	2.5	7.0
Magnet Program	14.0	7.5	25.2	13.0
Lab Subtotal	14.7	10.9	38.0	35.0
SSC Total Operating	20.0	20.0[b]	55.0	53.0
SSC Equipment	0.5	0.5	5.0	10.0
LAB RELATED PROGRAMS				
Supercon Dev.	1.71	1.7	2.0	
Cryo-Systems Dev.	1.66	1.66	2.0	
Accelerator Physics	1.63	1.63	2.0	
Lab Related Subtotal	5.0	5.0	6.0	6.0
EFFECTIVE TOTAL PROGRAM[c]	25.5	25.5	66.0	69.0

---

[a] Assuming construction start FY 1988

[b] Revised request FY 1986 - $27.0M

[c] SSC Operating + SSC Equipment + Lab Related Subtotal

Table 9.5. FY 1985 Budget Plan for Magnet R&D Centers.

Monthly Reporting Categories	BNL	FNAL	LBL	TAC	
General	800	340	115	825	
Magnet Models	2200	3225	395	2810	
Analysis	--	-	125	130	
Inst. & Measmt.	--	--	155	--	
Tooling	800	--	--	630	SSC ($14.675M) Program
Mag. Measure Devel.	400	--	--	--	
P.S./Q.P.	280	--	--	--	
Cryotesting	500	--	--	--	
Facility Devel.	--	340	--	605	
	4980	3905	790	5000	
S.C. Dev.	900	400	410	--	
Cryo Dev.	770	890	--	--	
	1670	1290	410	--	Lab Related ($5M) Programs
Accel. Physics	--	830	800	--	

Table 9-6. Revised Request. FY 1986 SSC Magnet Program Plan.[a]

	M$
Gen/Adm/Support	1.0
Tooling	2.0
20 Dipole Models (1 M)	1.5
5 Dipole Prototypes	2.0
Operations/Testing	1.5
10 Quadrupole Models	1.0
4 Spool Models	0.5
Industrial Participation (5 magnet models including tooling by industry)	5.0
Total	14.5[b]

[a] Plan supports production of one half cell of magnets.

[b] Present Budget Plan indicates $7.5M. (See Table 9-4)

are requested in all areas of the CDG program, both for engineering studies of Conventional Systems and further R&D in technical systems. A three-fold increase is required of the SSC laboratory programs to accomplish all of the tasks under Accelerator Systems (as indicated in Section II-3 above) and to strengthen the superconducting magnet program. A breakdown for the requested magnet program is provided in Table 9-7. This plan, in particular for main ring dipoles, is essential in providing a significant number of magnets for systems testing and in validating cost estimates, thereby laying the groundwork for a timely construction start. At this level of support the magnet production plan outlined in Table 9-3, p. 111, will be feasible.

Table 9-7. FY 1987 SSC Magnet Program Plan.[a]

	M$
Gen/Adm/Support	2.0
Tooling	2.5
10 Dipole Models (1 M)	0.8
20 Preproduction Prototype Dipoles	6.0 (Labs)
20 Preproduction Prototype Dipoles	6.0 (Industry)
Operations and Testing	4.0
5 Quadrupole Models	0.5
8 Quadrupole Prototypes	1.6
Spool Pieces (8 units)	0.8
4 High Gradient I.R. Quadrupole Models	1.0
Total	25.2[a]

---

[a] Does not include magnet models for the booster accelerators.

Table 9-8. FY 1988 SSC Magnet R&D Program[a] Plan.

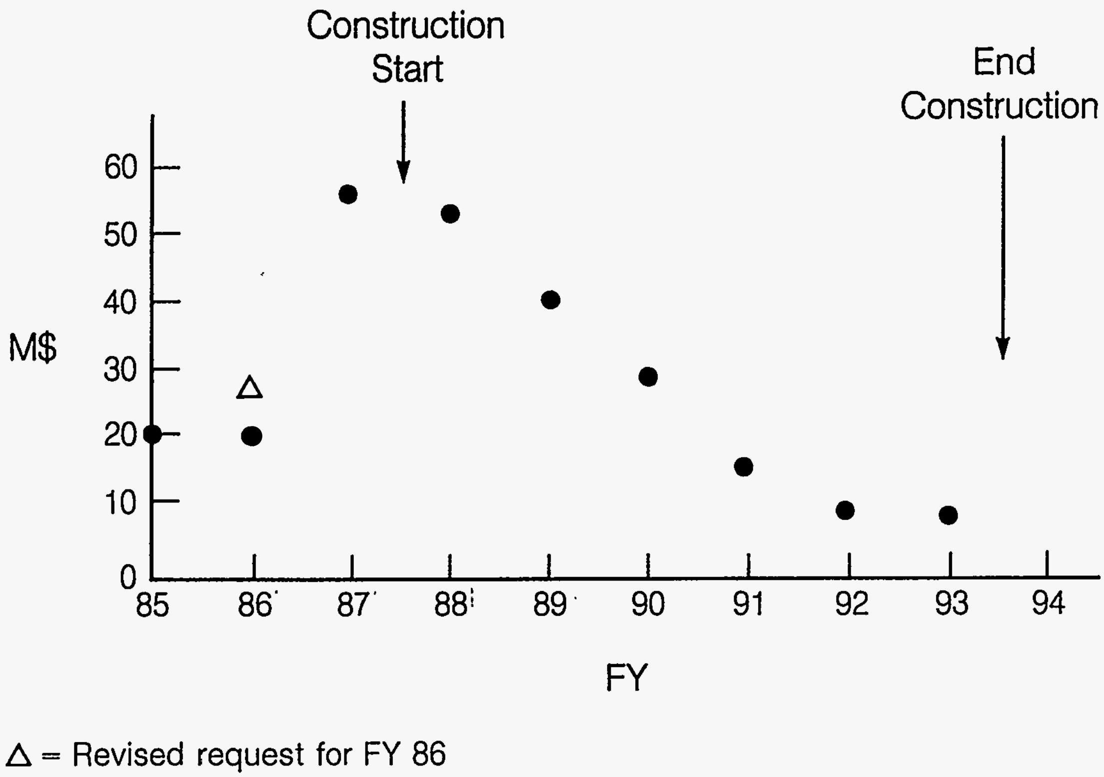
	M$	
Gen/Adm/Support	2.0	
Tooling	2.0	
4 Dipole Models (1 M)	0.3	
6 Preproduction Prototype Dipoles	2.0	Labs and/or Industry
6 Preproduction Prototype Dipoles	2.0	
Operations and Testing	3.0	
5 Quadrupole Models	0.5	
5 Quadrupole Prototypes	0.5	
Spool Pieces (2 units)	0.2	
2 High Gradient I.R. Quadrupole Models	0.5	
Injection System Models & Prototypes (HEB, LEB, Transfer Lines, Kickers)	4.0	
Total	17.0	

---

[a] Total CDG and Lab efforts

The FY 1988 R&D program assumes a construction start in 1988. Accordingly, as shown in column 4 of Table 9-4, a decrease in R&D Administration and Support is projected, as well as a decrease in the Superconducting Magnet R&D effort. Expanded development efforts are required for the many components of the accelerator systems area and the injector. Continued operation of the Systems Development Facility and operation of the Accelerated Life Tests will be a significant part of the FY 1988 R&D program. Table 9-8 shows the projected elements of the FY 1988 magnet R&D program. A phase-out of the prototype development of main ring dipoles is indicated together with a significant increase in models and prototypes for the various standard accelerator systems needed for the facility.

The total SSC Accelerator R&D program related to construction is plotted in Fig. 9-6 with projections to the end of the construction period.



XBL 857-9859

Fig. 9-6. SSC <u>R&D Program</u> Projection.

9.4 Manpower

Table 9-9 projects the scientific manpower levels for the SSC Research and Development program through FY 1993. Tables 9-10 and 9-11 provide a further breakdown by institution and task of the manpower numbers within the CDG and at the laboratories through FY 1988. The distinction between CDG and existing laboratories is extended through FY 1988. Although this is projected into the first year of construction only, it is anticipated that the existing laboratories will be strongly involved beyond FY 1988 while the SSC organization is being built up at the chosen construction site. However, the nature of the involvement will depend on many factors which cannot be fully evaluated at this time. Thus only an overall R&D projection is provided beyond FY 1988.

The manpower required for construction has been estimated with the following assumptions:

1. All technical EDI will be accomplished by the SSC Laboratory staff.
2. Fabrication of most technical components will be accomplished by industry.
3. Conventional facility EDIA and construction would be accomplished by industry.
4. Final assembly, installation, and testing of all technical components will be accomplished by the SSC staff.
5. Overall construction would be accomplished in six years.

Table 9-9 shows significant manpower increases in FY 1987. While some of the needed individuals may be recruited from outside the U.S. high energy physics community, the majority can be obtained from within. This is made possible by the shift from construction to operation by the two major U.S. facilities now nearing completion.

An analysis of the Administration and Support category leads to the projected need for a staff of 363 people (average) over the six year construction period. Similar breakdowns have been used for the categories of EDI and Assembly and Testing.

The overall results for each category are shown in the Fig. 9-7,8,9.

Table 9-12 summarizes the average manpower in each category over its period of operation within the six-year construction time. In line with the assumptions, the manpower was estimated according to the following categories: Administration and Support (AS), Engineering, Design and Inspection (EDI), and Assembly and Installation (AI). The categories of EDI and AI were analyzed for the major technical systems as follows: injection systems, collider ring magnets and cryogenics, and other systems, (rf, power supplies, controls, beam dump, etc.)

Table 9-9. Overall SSC R&D Program Manpower Projections.

(Man Years)

	FY 85	86	87	88	89	90	91	92	93
CDG	25	43	80	120	230	160	70	50	50
Laboratories	96	72[a]	220	190					
Total	121	115	300	310	230	160	70	50	50

---

[a] 96 in Revised Request

Table 9-10. R&D Program Manpower Projections by Institution.

(Man Years)

	85	86	87	88	89	90	91	92	93
A. SSC Program									
CDG	25	43	80	120					
BNL	40								
FNAL	25								
LBL	6								
TAC	25								
Lab Total	96	72[a]	220	190					
SSC Total	121	115	300	310	230	160	70	50	50
B. Related Laboratory Programs									
BNL	12								
FNAL	20								
LBL	8								
Lab Total	40	40	40	40					
Total Manpower	161	144	340	350					

---

[a] Lab Total = 96 based on Revised Request for FY 1986

Table 9-11. SSC R&D Program Manpower Projections by Task for Central Design Group.
(Man Years)

	FY85	FY86	FY87	FY88
Management	4.5	6	9	5
Project Plan	4.0	5	8	4
Accelerator Theory	6.0	9	12	12
Accelerator System	5.0	10	17	44
Injection	1.0	2	5	19
Magnets	1.5	6	8	36
Conventional Facilities	3.0	5	20	0
	25.0	43	80	120

Table 9-12. SSC CONSTRUCTION PROJECT - Estimated Staff Levels.

Category	Average Staff (Heads)	Activity Period (Years)
Administrative Support	360	6
EDI		
Injection Systems	135	4
Magnets/Cryogenics(Main Ring)	237	6
Other Systems (Main Ring)	71	5
Assembly/Installation		
Injection Systems	266	3
Magnets (Main Ring)	768	5
Other Systems	190	4
TOTAL	2,027	
PEAK	2,300	
SIX YEAR AVERAGE	1,650	

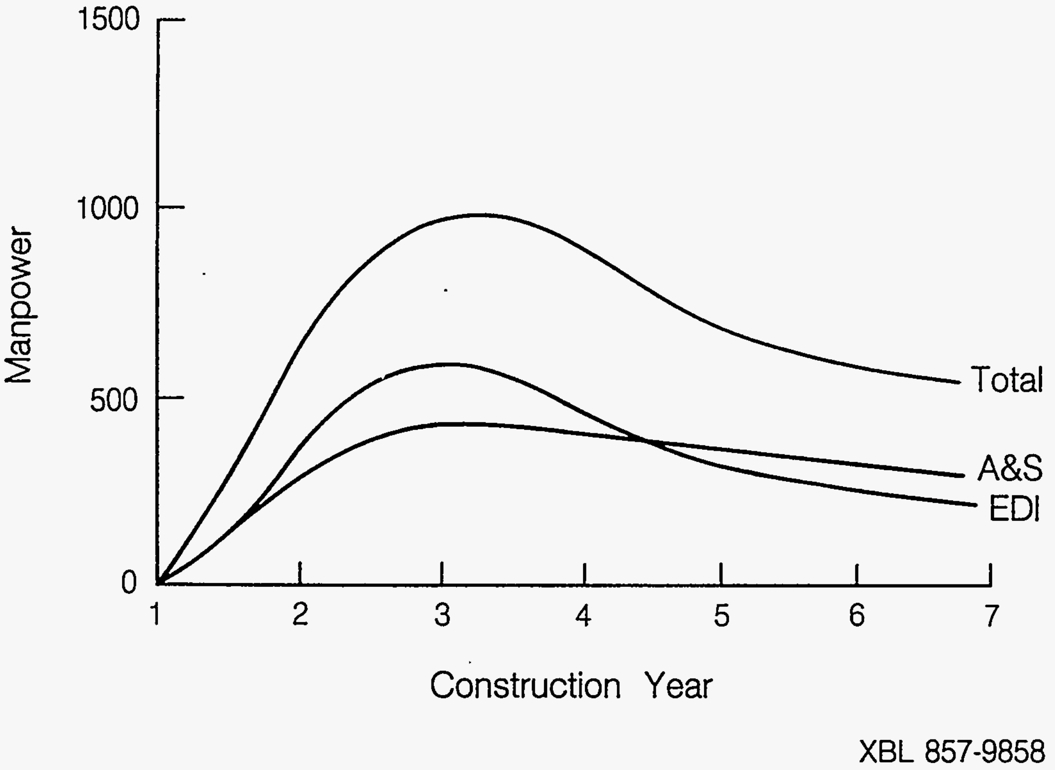


Fig. 9-7 Manpower loading for administration and support and for EDI (total) over the six-year construction period.

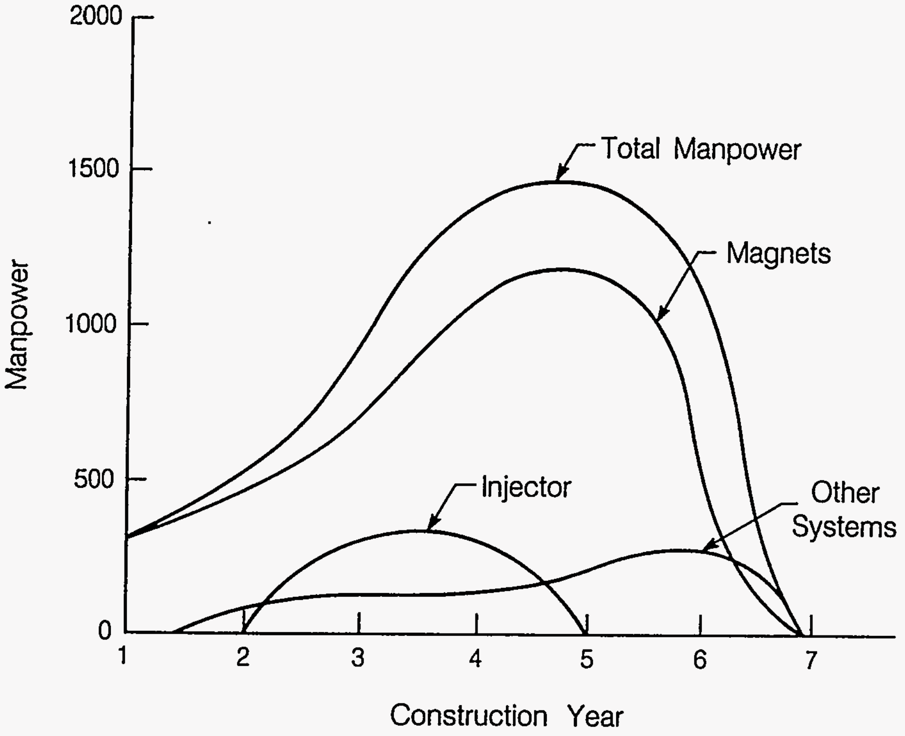
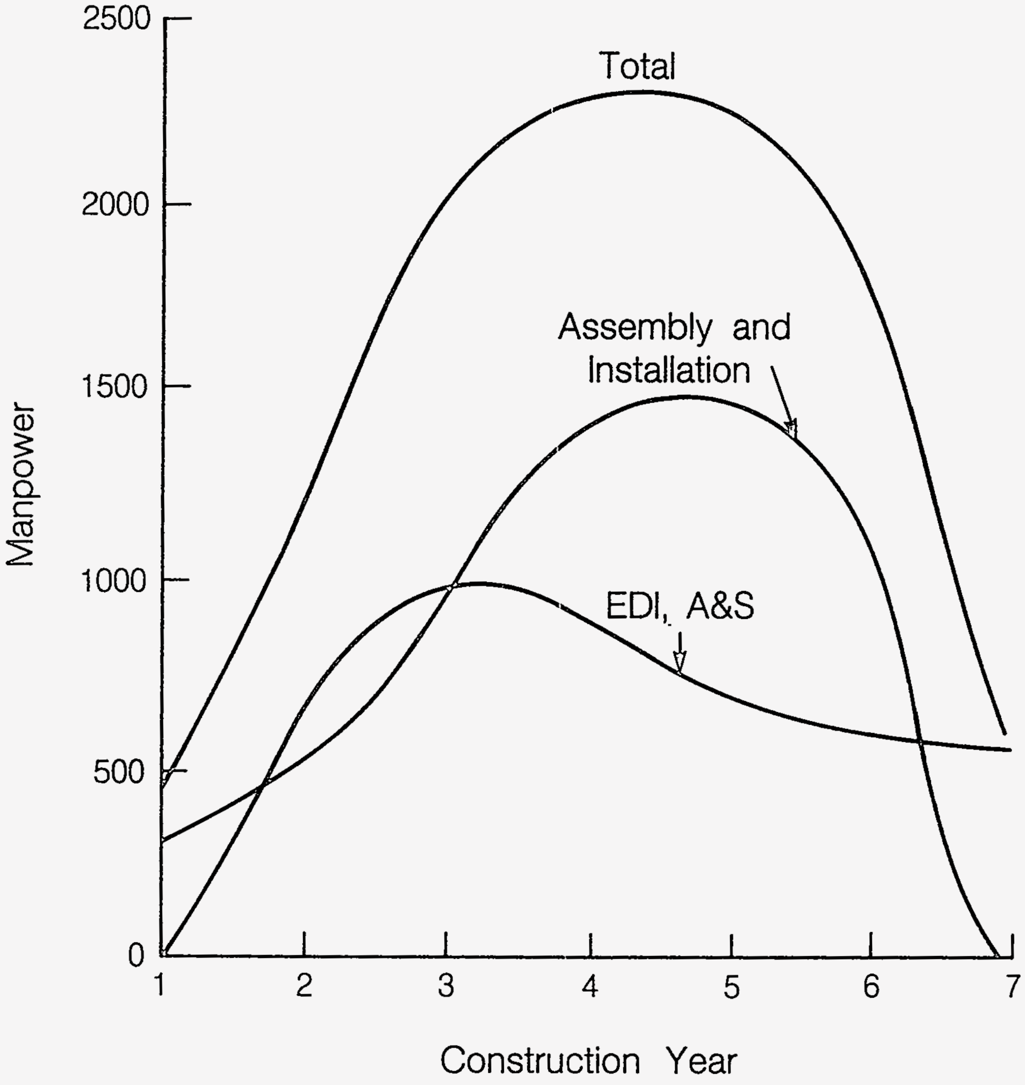


Fig. 9-8. Assembly and installation manpower distribution for magnets, injector, and other systems.



XBL 857-9860

Fig. 9-9. Total Manpower Distribution

APPENDIX A

Task Forces, Panels, Workshops

SSC Interim Report - Appendix A

Workshops, Panels and Task Forces Conducted by SSC/CDG Since 10/1/84:

TITLE PAGE

Accelerator Physics:

Accelerator Systems:

Conventional Systems:

Magnets:

Project Planning and Management:

General CDG Administrative:

Detectors:

Name: Aperture Task Force

Charge:

To evaluate the apertures for the various magnet types suggested for the SSC.

Task Force Sub-groups:

Group A -- Test Lattices (E Courant, Chair)
Group B -- Aperture Criteria (D. Edwards, Chair)
Group C -- Magnet Errors (E. Fisk, Chair)
Group D -- Database, networking (S. Peggs, Chair)
Group E -- Tracking (A. Dragt, Chair)
Group F -- Analytic Methods (C. Leemann, Chair)
Group G -- Experiments (H. Edwards, Chair)

Task Froce Members:

Group coordinators (listed above)
A. Chao
J. Peterson

Name of Initiating Workshop: Aperture Workshop

Workshop Leader: A. Chao

Workshop Date: November 5-9, 1985

Workshop Members: (see attached listing)

Task Force Meetings:

December 3-5, 1984/Group A/BNL/12 participants
December 3-5, 1984/Group C/CDG, Berkeley/9 participants
December 17, 1984/Task Force Meetings/CDG, Berkeley/10 participants
February 7-8, 1985/Group C/CDG, Berkeley/9 participants
February 19, 1985/Task Force Meeting/FNAL/9 participants
March 4-6, 1985/Group E/CDG, Berkeley/14 participants
March 11-12, 1985/Group C/TAC/7 participants
March 14-15, 1985/Group D/CDG, Berkeley/16 participants
April 22-23, 1985/CDG, Berkeley (Review Meeting)/47 participants
April 24, 1985/CDG, Berkeley (Task Force Meeting)/9 participants
May 17-18, 1985/Group D, Linear Aperture/CDG, Berkeley/3 participants
June 6, 1985/Group D, Linear Aperture/FNAL/3 participants
July 1985/Group E/Location undetermined/15 participants (estimated)

Reports Generated by the Task Force:

SSC Aperture Workshop Summary (SSC-2)
Aperture Task Force Report (SSC-3)
Aperture Task Force Report (SSC-11)
Interim Reports (from several groups, some completed, others in progress)
Status Report #2 --August 1985

Appendix 11. SSC Aperture Workshop Participants
November 5-9, 1984

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Name: Impedance Workshops

Leader: J. Bisognano

Workshops:

December 6, 1984/ LBL/7 participants
June 26-27, 1985/CDG Berkeley/tentatively 15 participants

Charge:

To examine the impedance issues relative to the design of the SSC.

Reports Generated:

First report by J. Bisognano appeared as a paper in particle accelerator conference, May 1985, (Vancouver).

Name: Clustered IR Study Group

Leader: A. Chao

Members:

A. Chao
M. Furman
D. Groom
D. Johnson
C. Leemann
P. Limon
D. Neuffer
S. Peggs
L. Schachinger
W. Swanson
R. Talman
T. Toohig

Name of Initiating Workshop (if any): None

Meetings:

April 25, 1985/ CDG, Berkeley
June 6, 1985/CDG, Berkeley

Charge:

To study the option of clustered interaction regions in the SSC and to make a recommendation to the CDG by early September 1985 on the clustered IR issue.

Reports Generated:

Meeting minutes

Name: "Realistic" Lattice Workshop

Leader: A. Garren, SSC/CDG

Dates: May 29-June 4, 1985, CDG/Berkeley

Members:

M. Allen
A. Chao
E. Courant
D. Douglas
A. Garren
S. Heifets
D. Johnson
B. Leemann
C. Leemann
P. Limon
Z. Parsa
S. Peggs
L. Schachinger
K. Steffen
M. Syphers

Charge:

To study the lattice issues taking into account the realistic accelerator physics and systems considerations.

Reports Generated:

Workshop report in preparation.

Name: Task Force on Commissioning and Operation of the SSC

Leader: P. Limon

Members:

W. Fowler
D. Groom
D. Hartill
F.R. Huson
C. Leemann
P. Limon
D. Lowenstein
R. Orr
P. Reardon
P. Wanderer

Name of Initiating Workshop (if any): Commissioning and Operation of SSC

Workshop Leader: P. Limon

Workshop Dates: January 14-18, 1985

Workshop Members: (see attached list)

Task Force Meetings:

February 26-27, 1985/FNAL
March 25-26, 1985/FNAL
April 12-13, 1985/CDG, Berkeley (Final Meeting)

Charge:

This task force was charged with evaluating the commissioning and operating characteristics of rings made with various types of magnets.

Reports Generated:

Interim report of the Workshop on Commissioning & Operations -- Jan. 1985
Final Task Force Report -- July 1985

PARTICIPANTS

Workshop Coordination

Don Groom	University of Utah
Peter Limon	Central Design Group
Karen Larsen	Lawrence Berkeley Laboratory

Cryogenics Group

William Fowler, Coordinator	Fermi National Accelerator Laboratory
Donald Brown	Brookhaven National Laboratory
Claus Rode	Fermi National Accelerator Laboratory
Peter VanderArend	Cryogenics Consultants, Inc.
John Van Sloan	Air Products & Chemicals, Inc.
Richard Wolgast	Lawrence Berkeley Laboratory

Design Group

Christoph Leemann, Coordinator	Lawrence Berkeley Laboratory
Alex Chao	Central Design Group--SSC
Ernest Courant	Brookhaven National Laboratory
Don Edwards	Fermi National Accelerator Laboratory
Eugene Fisk	Fermi National Accelerator Laboratory
Albert Hoffman	Stanford Linear Accelerator Center
Steve Peggs	Central Design Group--SSC
Jack Peterson	Lawrence Berkeley Laboratory

Operations Group

Paul Reardon, Coordinator	Brookhaven National Laboratory
Phil Bryant	CERN
Lyn Evans	CERN
Mike Harrison	Fermi National Accelerator Laboratory
Russ Huson	Texas Accelerator Center
Andrew Hutton	Stanford Linear Accelerator Center
Derek Lowenstein	Brookhaven National Laboratory
Robert Mau	Fermi National Accelerator Laboratory
Rich Orr	Fermi National Accelerator Laboratory
John Poole	CERN
Luc Vos	CERN
Peter Wanderer	Brookhaven National Laboratory

Systems Group

Donald Hartill, Coordinator	Cornell University
Dixon Bogert	Fermi National Accelerator Laboratory
Richard Cassel	Stanford Linear Accelerator Center
Karl Koepke	Fermi National Accelerator Laboratory
Gerry Tool	Fermi National Accelerator Laboratory
Peter Yamin	Department of Energy
John Ziegler	Texas Accelerator Center

Name: Photo Desorption Task Force

Leader: N. Mistry (Cornell)

Members:

N. Mistry
P. Limon
H. Halama
A.G. Mathewson
G. Williams
T.S. Chan
E.L. Garwin
H. Jostlein
S. Krinsky
M. Tigner

Name of Initiating Workshop (if any): Photo Desorption at the SSC

Meetings:

August 28-29, 1984/BNL
April 28-29, 1985/Gaithersburg, MD (with additional attendees)

Charge:

To address the question of the effect of synchrotron radiation on spoiling the vacuum by desorbing the molecules frozen on the inside surface of the vacuum pipe.

Reports Generated:

Note to M. Tigner -- September 5, 1985
Proposal for experiment to NSLS - December 19, 1985 (by H. Jostlein)

Name: Power Supply and Quench Protection Task Force

Leader(s): W. Hassenzahl and D. Hartill

Members: (same as shown below in "Workshop Members")

Name of Initiating Workshop (if any): Power Supply and Quench Protection

Workshop Leader: P. Limon

Workshop Dates: April 1 - 5, 1985

Workshop Members:

G. Cottingham
D. Hartill
W. Hassenzahl
K. Koepke
H. Kraus
G. Lopez
A. Prodell
G. Tool
T. Tamanaka
J. Zeigler

Task Force Meetings: April 1 -5, 1985 / CDG, Berkeley

Charge: To investigate the power supply requirements and quench behavior of different magnet types.

Reports Generated:

Interim Workshop Note to M.Tigner from P. Limon -- April 1985

Name: Task Force on Low Temperature Operation of the SSC

Leader: M. McAshan

Members:

C. Taylor
W. Hassenzahl
S. Caspi
P. Vander Arend
W. Fowler
R. Shutt

Name of Initiating Workshop (if any): None

Meetings:

April 12, 1985/CDG, Berkeley
May 19, 1985/CDG, Berkeley
June 14, 1985/CDG, Berkeley

Charge:

Examine technical feasibility and potential cost advantages of operation at 2K. This examination is to include refrigeration schemes and magnet configurations appropriate to operation at both 6T and 8T -- all at a temperature of 2K.

Reports Generated:

"Report of the Task Force on Low Temperature Operations" slated for completion June 14, 1985.

Name: Site Parameter Document Review Panel

Leader: J. Sanford

Members:

W. Alexander
P. Livdahl
R. Matyas
R. Neal

Meeting Dates:

February 12, 1985
March 27 & 28, 1985

Attendees:

W. Murphy
A. Gursoy
P. Gilbert
W. Alexander
P. Livdahl
T. Toohig
R. Neal
V. More

Charge:

To review the SSC Siting Parameters Document that was being prepared by personnel from CER Corporation and its sub-contractor PBQ&D.

Reports Generated:

Letters to M. Tigner following the meeting on March 28, 1985.

Name: Tunneling Technology Review Panel

Meeting Date: December 9-10, 1984

Leader: R. Matyas

Name of Initiating Workshop (if any): None

Panel Members:

H. Cerruti
E. Cording
D. Hammond (Chair)
J. Hattrup
J. Lilly
J. Monsees
T. O'Rourke
F. Kulhawy (Planner)

Charge:

To review unsolicited proposal from Texas A&M Research Foundation on tunneling technology and to determine its feasibility.

Reports Generated:

Panel Report and Recommendations Received at CDG -- 12/22/84
Report to Director, CDG -- 1/5/85
Summary Report Sent to Wallenmeyer -- 1/5/85

Name: DOE Workshop on Fine Filament NbTi Strand

Leader: R. Scanlan

Members:

E. Fisk
A. Green
D. Larbalestier
R. Lundy
A. MacInturff
R. Remsbottom
R. Rocha
W. Samson
R. Scanlan (Chair)
M. Suenaga
C. Taylor
M. Tigner

Dates:

January 17, 1985
April 17-18, 1985

Charge to the Task Force: (1) To review the status of procurement of conductor and cable for the SSC, (2) to review fine filament R&D and evaluate new proposals and (3) evaluate methods for further increasing current density.

Reports Generated by the Task Force:

"SSC SC Working Group Summary" -- January 17, 1985
Meeting notes -- April 18, 1985

Name: Magnet System Test Site Task Force

Leader: R. Neal

Members:

D. Brown
P. Limon
G. Cottingham
R. Louttit
E. Willen
P. Vander Arend
D. Bogert
R. Orr
C. Rode
A. Tollestrup
G. Tool
W. Hassenzahl
F.R. Huson

Name of Initiating Workshop (if any): None

Panel Meetings:

September 13-14, 1984/SLAC
September 25, 1984/FNAL
September 26-27, 1984/BNL
October 11-12, 1984/Chicago (O'Hare)

Charge: (see attached text)

Reports generated:

Final Report, October 1984 (SSC-SR-1001)

CHARGE TO THE MAGNET SYSTEM TEST SITE TASK FORCE

Introduction

It has been anticipated that thorough testing of the proposed SSC magnet system components in a system setting will be necessary prior to construction of the SSC. In view of the relatively long lead time needed to prepare for and carry out the test, it seems appropriate to examine the question of where to carry out the test. There seems to be wide agreement that the test site can be independent of magnet style and of place of magnet manufacture. There also seems to be wide agreement that, by virtue of existing facilities and experience, BNL and FNAL are the two best candidate sites. Consequently it seems appropriate to restrict our considerations to those possibilities at this time.

In determining the most advantageous venue for the test, both cost effectiveness and availability of the needed facilities and manpower are primary factors. In assessing what facilities are needed, it is necessary to have a clear concept of the scope of the system(s) to be tested, of the types and numbers of tests to be carried out and of the likely length of time for which this initial system test facility must be available.

Report

Wanted is a report with a critical evaluation of the two potential sites with regard to availability of the needed facilities and manpower on the needed time scale and an estimate of the cost to designated SSC R/D funds of preparing each of the sites for the tests and for operating the facilities during the test period. It seems reasonable to assume that the cost of installing the magnets and other components to be tested will be relatively site independent and consequently need not be considered in the report unless this hypothesis is believed by the Task Force to be incorrect. In writing your report you should assume that adequate magnets and other components will be available early in CY 1987 and that all initial major design validation tests need to be completed in CY 1987.

This report, dealing with the technical aspects of the SSC Magnet Systems test, will be used as a major part of the input in deciding the most appropriate venue and management for these Magnet System Tests.

The Task Force Report should contain 6 major items:

1. A description of a suggested Test System(s) for each of the three magnet styles of the RDS. For example, in the case of design A it might be 5 lattice cells together with all cryogenic distribution, power supply, control and monitor equipment needed for accelerator operation or alternatively it might be two cryogenically independent groups of X cells for simultaneous testing of different features, etc., etc.

2. A description of a suggested test regimen(s) for the suggested Test System(s). For example, one might need 10^n full energy ramps at rate X Ts^{-1}, 10^m simulated beam-induced quenches, 10^p cool down-warm up cycles with interspersed magnetic, mechanical and electrical measurements, in situ magnetic field measurements, quench propagation across all boundaries, etc., etc. Estimate the time required to carry out each of the suggested major design validation tests. It seems reasonable to assume that a major system test bed facility needs to be in operation throughout Ph I and Ph II of the SSC and that it is practical and desirable to move the system test bed to the SSC construction site at the end of the first year after NTP. Criticize that assumption and the consequent conclusion that the test facilities under discussion in your report need to be available until the end of the first year after NTP even though the first round of design validation tests are to be completed at the end of 1987.

3. A description with rough specifications of the major facilities needed to carry out the suggested tests. To be included are equipment, housing needs, personnel work space, refrigeration, cryogenic distribution, power supplies, utilities and personnel and equipment safety systems. Any significant dependence of facility needs on magnet style should be described and cost differences estimated.

4. A list for both BNL and FNAL of the relevant facilities that exist and a critical evaluation of their suitability for the task at hand including a description of needed modifications, if any. Also, for both FNAL and BNL, list additional facilities that would have to be purchased or built to carry out the test program. For both potential sites estimate the cost to designated SSC R/D funds for modification of existing facilities and for bringing them into operation in readiness for the tests as well as the cost to SSC R/D funds to provide and bring into operation any additional facilities that woud be required.

5. An estimate for both sites of the manpower required to prepare the facilities for the tests and to operate the facilities during the test. The estimate shoud be broken down in terms of physicist, engineer, technician, and other manpower. Assess the availability of the needed manpower at each of the sites.

6. Discuss other technical and economic factors which may affect the cost and availability of needed resources on the needed time scale and compare the two sites with respect to these factors.

Name: Fiscal and Management Review Panel

Leader: R. Neal

Members:

T. Elioff
R. Matyas
R. Yourd

Name of Initiating Workshop (if any): None

Meetings:

October 19, 1984 / LBL
October 27, 1984 / FNAL
November 2, 1984 / BNL
November 14, 1984 / TAC
November 21, 1984 / LBL

Charge: Recommend a uniform monthly accounting and technical reporting scheme to be used by the laboratories participating in SSC Magnet R&D.

Reports generated:

Final draft of the report completed November 21, 1984.

Name: Technical Magnet Review Panel (Interim)

Leader: A. Tollestrup (Chair)

Members:

T. Elioff
F.R. Huson
P. Limon
R. Lundy
R. Neal
P. Reardon
C. Taylor
R. Watt
R. Yourd

Name of Initiating Workshop (if any): None

Meetings:

October 17-18, 1984/LBL
October 25-26, 1984/FNAL
October 31 - November 1, 1984/BNL
November 12-13, 1984/TAC
November 19-20/LBL

Charge: (1) To delineate for each design type that minimal set of technical data which are needed for the design type selection process and which can only be obtained from models and prototypes. (2) To review critically and report progress, from October 1983 to date, of each of the three major design types. (3) To review critically plans for FY 1985 in light of (1) and, as appropriate, suggest changes which may enhance their effectiveness. (4) To write a report setting forth the results of (1), (2), and (3) in a systematic fashion.

Reports Generated:

Interim Report was issued November 1984

Other information:

New panel is being re-formed. Meetings are scheduled as follows:
July 1-2, 1985/TAC
July 12 - 13/LBL
Final report due July 25, 1985

Name: Technical Magnet Review Panel (new)

Leader: A. Tollestrup (Chair)

Members:

F.R. Huson
R. Lundy
P. Reardon
H. Hirabayashi
C. Taylor
R. Watt
R. Yourd

Name of Initiating Workshop (if any): None

Meetings:

July 1 - 2, 1985/TAC
July 12 - 13, 1985/LBL

Charge: (1) Review magnet and cable development programs at BNL, FNAL, LBL and TAC. (2) Write a report evaluating the technical status of dipole and quadrupole magnet design and development work for the 1 in 1 and 2 in 1 low and high field magnet styles. For each style enumerate the R/D remaining before each style can prudently be carried to the full scale prototype stage. This enumeration should include an estimate of the time and manpower effort needed to complete the pre-prototype R/D. The report should include a detailed account of model tests for the various designs. (3) Evaluate and report on the status of superconducting cable development and enumerate further development objectives which could reasonably be expected to be complete in time to have a beneficial impact on SSC magnet cost, reliability and ease of operation. The report should be complete by July 25, 1985.

Reports Generated:

Final Report due July 25, 1985

Name: Magnet Selection Advisory Panel

Leader: F. Sciulli

Members: (see attached list)

Name of Initiating Workshop (if any): None

Meetings: Scheduled for August 25-30, 1985.

Charge: (see attached text)

Reports Generated: None to date.

MAGNET SELECTION ADVISORY PANEL

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CHARGE TO THE MAGNET SELECTION ADVISORY PANEL

A number of Basic Magnet Types have been considered for possible SSC service. They include mechanically linked dual aperture magnets which may or may not be thermally or magnetically linked (2-in-1) and mechanically, magnetically and thermally independent single aperture magnets (1-in-1). Both high field (6T or more) and low field (about 3T) versions of these types have been studied and developed to a greater or lesser extent. After considerable study of the many possible combinations, five have emerged as most likely to provide economical and reliable options of the SSC. These five are: I. a low field, mechanically and thermally linked, magnetically independent 2-in-1 type; II. a high field, mechanically, thermally and magnetically linked 2-in-1 type; III. a high field 1-in-1 type with cold iron; IV. a low field 1-in-1 type; V. a high field, warm iron 1-in-1 type.

During the last quarter of Fiscal Year 1985, one of these Basic Magnet Types will be selected for final prototype development by the Director of the Central Design Group. In aid of this selection the Advisory Panel will submit a report to the Director containing the Panel's recommendation in the form of an ordered list of these five Basic Magnet Styles. The rationale for this recommendation shoud be given in detail. If no clear choice emerges this sould be clearly stated and justified.

In making its recommendation the Advisory Panel will be guided by the Criteria set forth below, using technical materials supplied by the CDG and such other technical inputs as it may solicit at its discretion.

The report of the Advisory Panel is due by September 1, 1985.

Criteria

In its deliberations the Panel will consider the SSC to be a hadron collider designed ultimately to achieve 20 TeV per beam at a luminosity of $10^{33}\text{cm}^{-2}\text{sec}^{-1}$.

In rendering its judgement the Advisory Panel should consider the general implications of low field and high field and 1-in-1 and 2-in-1 features, as well as details of proposed mechanical, thermal and magnetic designs. Both system features and characteristics of the magnets considered as individual components need to be taken into account. While the dipoles are the major cost component of the magnet system, the quadrupoles and various correctors inherent to the various Basic Magnet Types must receive due consideration.

The Criteria to be used in making an overall recommendation are:

1. Relative capital cost of an SSC facility employing a particular Basic Magnet Design.
2. Workability of the Basic Designs presented.
3. Complexity of the overall magnet system inherent to the particular Basic Design.
4. Operational complexity of an SSC employing the particular Basic Design.
5. Relative flexibility of an SSC design employing the particular Basic Design.
6. Likely impact of the Basic Magnet Design on the SSC construction schedule.
7. R/D time and effort needed to develop the Basic Design.
8. Accelerator Physics considerations.
9. Other considerations deemed appropriate by the Advisory Panel.

Comments on the Criteria (Numbers below refer to the list above)

1. Cost figures will be developed by the CDG with input from the SSC R/D participants and from independent commercial firms experienced in manufacturing superconducting magnets. In calculating the overall SSC facility cost, the conventional construction costs developed by the CDG and its A/E consultants will be used. The Reference Designs Study will be a primary reference. In computing magnet costs, the CDG will select the aperture to be used with each Basic Magnet Type based on accelerator physics considerations and the best information available on the likely field errors for each Basic Magnet Type.

2. Workability or practicality refers to the manufacturability and potential reliability of a particular design, taking into account needed tolerances, material specifications and assembly procedures. Model tests by the developers will provide concrete evidence in this area.

5. Relative flexibility is with regard to: a) possibilities for staging the SSC to speed up first physics use while reducing spending rates if necessary; b) operations such as injection, beam adjustments during collision, repair of magnets; c) concommitant site restrictions.

6. Particular impacts might be lengthened construction time for larger circumference, needs for special portals or on-site factory facilities for particular magnet designs, duration of manufacturing time for various magnets.

8. Accelerator Physics issues would have to do with inherent properties of low and high field rings and coupled or uncoupled beam channels. One would expect vacuum chamber impedance, surveying, magnet shuffling, radiation protection and other considerations to play a role.

Information to be Supplied by the CDG to the Advisory Panel

1. Report of the CDG Cost Estimating Task Force.
2. Report of the Task Force on Operations and Commissioning.
3. Report of the Aperture Task Force.
4. Drawings, specifications and model test results, where available, representing the current state of development of each of the Basic Magnet types.
5. Report of the Technical Magnet Review Panel.

Name: Cost Estimating Task Force

Leader(s): T. Elioff & R. Yourd (co-chairs)

Members:

K. Mirk
C. Goodzeit

Consultants:

J. Carson
N. Engler
F.R. Huson
W. Schneider
E. Kelly
General Dynamics (R. Baldi)
Westinghouse (L. Young)

Name of Initiating Workshop (if any): None

Meetings: Tentatively scheduled for July and August 1985.

Charge: To perform a detailed review of costs for all magnet design styles for the SSC.

Reports Generated: None to date.

Name: Business Affairs and Management Advisory Panel

Leader: R. Matyas

Members:

H. Doney
F. Mattmueller
R. Williams
J.D. Jackson, Ex Officio Member
D.P. Kreitz, Ex Officio Member

Name of Initiating Workshop (if any): None

Meeting Dates:

March 15, 1985/URA, Washington, D.C.
April 11-12, 1985/CDG, Berkeley
May 29, 1985/Cornell University, Ithaca

Charge:

To advise and assist the CDG Directorate on establishing a framework for independent operations at the permanent site, utilizing state-of-the-art methods, equipment, and procedures. The desirable timetable would have the CDG capable of independent operations not later than September 30, 1986.

Reports Generated:

Interim Report due to CDG Director -- June 1985
Final Report due -- December 1985

Name: Task Force on Detector R&D for the SSC

Leader: M.D.G. Gilchriese

Members:

B. Cox
M.D.G. Gilchriese
H. Gordon
P. Grannis
D. Hartill
J. Jaros
P. Kunz
S.C. Loken
D. Nygren
A. Seiden
M. Shochet
F. Paige

Name of Initiating Workshop (if any): None

Meetings:

May 9, 1985/FNAL
May 19, 1985/SLAC

Charge to the Task Force: (see attached text)

Reports Generated:

Preliminary Report, May 23, 1985

May 1, 1985

Charge to the Task Force on Detector R&D for the SSC

The Task Force will advise on the detector R&D needed to assure the timely construction of detectors capable of exploiting the luminosity and energy of the SSC at turn-on. In addition, the Task Force should estimate the manpower requirements, costs, and time scale of this R&D. The Task Force should also recommend the procedures to be followed to accomplish the tasks.

1. There should be a preliminary report on the R/D objectives, manpower requirements, costs, and time scale in time for the May 24 HEPAP working group meeting at SLAC. If there are particularly pressing problems needing funding in FY86, these should be identified for HEPAP.

2. It is expected that some part of the 1986 Snowmass Summer Study will be devoted to detector problems. The Task Force is requested to provide recommendations on the optimum way to structure this effort.

3. Finally, recommendations are requested regarding the scope and costs of the SSC detector R&D to be done in FY87.

4. What role, if any, should the SSC Central Design Group play in facilitating this detector R&D?

APPENDIX B.

REPORTS

APPENDIX B1. CDG REPORTS

Number	Date	Author	Title
SSC-1	10/84	T. Elioff	Monthly Report Oct.-Nov. 1984
SSC-2	11/84	A. Chao	SSC Aperture Workshop Summary
SSC-3	12/84	J. Peterson	Aperture Task Force Report
SSC-4	1/85	T. Elioff	Monthly Report - Dec. 1984
SSC-5	1/85	P. Limon	Workshop on SSC Commissioning and Operations
SSC-6	1/85	M. Furman	Simple Method to Symplectify Matrices
SSC-7	2/85	J. Peterson et al.	Magnetic Errors in SSC
SSC-8	2/85	D. Douglas	Interpolation of Off-Energy Matrices
SSC-9	2/85	D. Douglas	Options to Make PATRICIA Symplectic
SSC-10	2/85	T. Elioff	Monthly Report - Jan. 1985
SSC-11	2/85	J. Peterson	Aperture Task Force Report
SSC-12	2/85	J. Sanford	Scope of Work for A/E Services
SSC-13	3/85	T. Elioff	Monthly Report - Feb. 1985
SSC-14	3/85	S. Myers	Overlap Knock-Out Resonances in the SSC
SSC-15	4/85	J. Sanford	Site Parameters Document
SSC-16	4/11/85	A. Chao C.W. Leemann	More on the Overlap Knockout Resonances in the SSC
SSC-17	4/12/85	A. Chao J. Peterson	Eddy Current in the SSC
SSC-18 LBL-18903(3)	4/85	D. Douglas E. Forest	A Method to Render Second Order Beam Optics Programs Sympletic
SSC-19	4/85	E. D. Courant D. R. Douglas A. A. Garren D. E. Johnson	SSC Test Lattices
SSC-20	4/85	S. Peggs M. Furman A. Chao	A Possible Screening Procedure for Random Multipole Field Errors Before Tracking Studies
SSC-21	4/85	S. Heifets	Random Sextupoles in the SSC Lattice
SSC-22	4/22/85	D. Edwards	Aperture Task Force Interim Report - Aperture Criterion Group
SSC-23	5/85	D. Douglas	Ion Stability in Bunched Electron Beams
SSC-24	5/85	B. T. Leemann D. R. Douglas E. Forest	Tracking the SSC Test Lattices
SSC-25	5/85	J. Bisognano	Collective Effects and the Design of the SSC

Number	Date	Author	Title
SSC-26	4/85	T. L. Collins	On Choosing an Aperture
SSC-27	4/19/85	M. Harrison	Tevatron Operational Experience and Implications for SSC Aperture
SSC-28	4/85	M. Furman A. Chao	Effect of Long Range Beam-Beam Interactions on the Stability of Coherent Dipole Motion
SSC-29	4/85	E. Forest	Normal Form Algorithm on Non-Linear Symplectic Maps
SSC-30	4/85	E. Forest	Equivalence of Michelotti's Normal Form and the Map Normal Form as Used By the MARYLIE Code
SSC-31	5/85	A. Chao	Accelerator Physics Studies for the SSC
SSC-32	5/85	E. Forest	Algebraic Theory of Beam-Beam Interactions in the Lens Model
SSC-33	5/85	M. Tigner	Where Is the SSC?
SSC-34	5/85	J. R. Sanford	Civil Systems Aspects of the SSC
SSC-35	5/85	P. Limon	Accelerator Systems of the SSC
SSC-36	5/85	S. Peggs	The Dependence of Single Particle Stability on Net Chromaticity in CESR, Near $Q_h = 9 + 1/3$
SSC-37	3/85	T. Elioff	Monthly Report - March 1985
SSC-38	4/85	T. Elioff	Monthly Report - April 1985
SSC-39	5/85	T. Elioff	Monthly Report - May 1985
SSC-40	6/85	K. Steffen	Preliminary Lattice Proposal for Polarized Beam Acceleration in SSC

SSC Special Reports

Number	Date	Author	Title
SSC-SR-1001	10/84	W. Hassenzahl	Report of the Task Force on SSC Magnet System Test Site
SSC-SR-1002	3/85	T. Elioff	Program Plan
SSC-SR-1003	3/85	T. Elioff	Management Plan
SSC-SR-1004	4/1/85	R. Yourd et al.	SSC Reference Design Magnets Style "D" Cost Design
SSC-SR-1005	4/15/85	D. Groom et al.	Report of the Task Force on SSC Commissioning and Operations
SSC-SR-1006	7/1/85	W. Hassenzahl et al.	Report of the Task Force on Quench Protection and Power Supply Operation A. Quench Protection B. Power Supply Operation
SSC-SR-1007	6/25/85	M. McAshan et al.	2 K Magnet Operation Task Force Report
SSC-SR-1008	4/7/85	A. D. Krisch	Proceedings of the Meetings on the

UM HE 85-08		et al.	SSC Between Representatives of Industry and High Energy Physics Held at the University of Michigan on December 6, 1984, and January 7, 1985
SSC-SR-1009	5/23/85	G. Gilchriese et al.	Preliminary Report from the Task Force on Detector R&D for the SSC

SSC Notes

Number	Date	Author	Title
SSC-N-1	4/18/85	T. E. Toohig	Land and Shielding Requirements from the HEB: Impact of Conventional Facilities
SSC-N-2 TM-1299	3/85	T. E. Toohig	SSC Relative and Comparative Tunnel Costs
SSC-N-3	4/23/85	T. E. Toohig	Notes from a Telephone Conversation with John Elias: Radiation Levels in the Tevatron Tunnel
SSC-N-4 TM-1306	4/22/85	T. E. Toohig	Field- and Energy-Independent Normalization of the SSC Collider Ring Costs
SSC-N-5	4/85	J. Peterson	SSC Aperture Task Force Coordination Meeting, 24 April 85 at CDG/LBL
SSC-N-6	4/22/85	T. E. Toohig	Land Acquisition Requirements for the SSC
SSC-N-7	3/28/85	J. Peterson A. Chao	How Much Error in Circumference Difference Between The Two Rings Can We Tolerate?
SSC-N-8 TM-1289	11/23/84	T. E. Toohig	Observations on LEP with a View to SSC
SSC-N-9	5/15/85	T. E. Toohig	Magnet Length and Conventional Facilities
SSC-N-10	4/85	J. D. Cossairt	Design Considerations for Personnel Access Penetrations for the SSC
SSC-N-11	5/21/85	S. Marks J. Peterson	Memo on Error Analysis of Superferric Magnet
SSC-N-12 TM-1316	6/24/85	K. Koepke	A Simulation of Quenches in SSC Magnets with Passive Quench Protection
SSC-N-13	6/28/85	D. Neuffer	First Estimataes of Allowable Field Non-Linearities

APPENDIX B2. BNL REPORTS

SSC Technical Note Number	Date	Author	Title
1	7/20/83	M. Barton	Possible Use of Window Frame Magnets for SSC
2	9/9/83	M. Puglisi	The SSC Resonant Cavity Design Criteria
3	10/10/83	J.G. Cottingham	Accelerating the Quench Propagation in Long SSC Magnets
4	10/10/83	R.C. Fernow	Coil Design for the Prototype SSC Dipole
5	10/26/83	G. Parzen	Random Error Field Multipoles in SSC Magnets
6	11/16/83	R. LeRoy	Finie Element Analysis of SSC Prototype Clamping Shell
7	12/20/83	S.R. Plate	The Case of the Missing Pole Piece Laminations
8	1/13/84	H.J. Halama	Ann Arbor SSC Workshop Summary Report on Vacuum System, Ann Arbor, Mich. Dec. 11-17, 1983
9	2/6/84	D.P. Brown	The Case of Hot Tin Magnets
10	2/27/84	A. Ghosh W.B. Sampson G. Stenby A.J. Stevens	Radiation Exposure of Bypass Dipoles
11	2/24/84	A.F. Greene H.G. Kirk	Differences in Harmonics for Concave and Convex-Wound CBA Coils
12	3/21/84	G. Ganetis A.J. Stevens	Results of Quench Protection Experiment
13	4/18/84	E.H. Willen	SSC Magnets with Niobium-Tin
14	5/17/84	R. Fernow G. Morgan	Coil Design for the LBL-SSC Prototype Dipole (SSC-B61)
15	5/30/84	R.I. Louttit	Comparison of Heat Loads CBA-SSC
16	6/21/84	E.D. Courant	Chromaticity Adjustment in SYNCH Program
17	7/27/84	G. Morgan	Calculation of Superconductor Magnetization Effects in Magnets Using GFUN
18	8/29/84	J.C. Herrera	Characteristics of an SSC (pp) (Transparencies for U.S. 1984 High Energy Particle Accelerator School held at Fermilab, August, 1984)
19	10/8/84	R.C. Fernow G.H. Morgan	Coil Design for the 40 mm Collared SSC Dipole (SSC-C5)
20	10/30/84	H.J. Halama	Some Comments on the SSC Bore Tube
21	11/8/84	D.P. Brown K.C. Wu	Cooldown Calculations for SSC Magnets

SSC Technical Note Number	Date	Author	Title
22	1/29/85	D.C. Wu	Low Temperature Heat Shield for the SSC Magnet Type D
23	2/12/85	G.H. Morgan	The 1-in-1 SSC Dipole with C5 Coils
24	3/13/85	D. Brown	Cryogenic Operational Implications of Cyrogenically-Coupled Magnets
25	3/13/85	K.C. Wu	Recoolers for the SSC Reference Design D

APPENDIX B3. FERMILAB REPORTS

Number	Date	Author	Title
TM-1213	9/15/83	F.R. Huson	20 TeV Colliding Beam Facilities
TM-1214	9/21/83	F.R Huson	Potential 20 TeV Site in Illinois
TM-1232	11/83	S.C. Snowdon	Combined Function Magnets Profile Design
TM-1239	1/84	K.Y. Ng	An Estimate of the Longitudinal and Transverse Impedances for the Superconducting Super Collider
TM-1246	2/84	S. Ohnuma	How Much Random Sextupole Field Can We Have in the Presence of Beam-Beam Interactions?
TM-1247	3/84	S. Ohnuma	Width of Non-Linear Resonance
TM-1249	3/84	E.A. Treadwell	Pumping Rates for Water Drainage in the Main Ring Tunnel: Scale Considerations of the SSC
TM-1260	7/83	R.R. Wilson	A Tevatron Improvement Program
TM-1285	11/84	J. O'Meara	Water Cooling Considerations for the SSC
TM-1289	11/84	T.E. Toohig	Observations on LEP with a View to SSC
TM-1292	12/84	T.E. Toohig SSC Study Group	A Preliminary Design for a 20 TeV Collider in a Deep Tunnel at Fermilab
TM-1294	1/85	B.C. Brown	A Naive Comment on Changing SSC Persistent Current Sextupole Thru Metallurgical Changes in the Superconductor
TM-1299	3/85	T.E. Toohig	SSC Relative and Comparative Tunnel Costs
TM-1300	3/85	A.D. McInturff	An Aperture Study
TM-1306	3/85	T.E. Toohig	Field-Independent Normalization of SSC Collider Ring Costs
FN-396	1/84	R.P. Johnson	The Tevatron as an SSC Prototype: Experience Versus Predictions
FN-440	4/84	Jorge Morfin	Leptoproduction at an SSC Fixed Target Facility
Conf-85/14	1/85	S. Loken J.G. Morfin	A Fixed Target Facility at the SSC
Conf-85/15	1/85	J.G. Morfin J.F. Owens	Measuring Structure Functions at SSC Energies
Conf-85/33	2/85	B. Cox F.J. Gilman	Standard Electroweak Interactions and Higgs Bosons

APPENDIX B4. LBL REPORTS

Number	Date	Author	Title
SSC Note-1 LBL-16034	8/83	A. Garren	20 TeV Collider Lattices with Low-β Insertions
SSC Note-2	9/83	A. Garren M. Cornacchia F. Dell	Chromatic Properties and Tracking Studies of a 20 TeV pp Collider
SC Note-3 LBID-795	9/83	C. Leemann	Beam-Beam Tune Shift for Bunched Beams Crossing at an Angle
SSC Note-4 LBID-796	9/83	M. Cornacchia	Discussion on the Choice of Working Point for s Six-Fold SSC Lattice
SSC Note-5 LBID-797	9/83	A. Garren	6.5 Tesla SSC Lattice
SSC Note-6 LBID-802	10/83	A. Garren	5 Tesla SSC Lattice - Approximate Parameters
SSC Note-7 LBID-809	11/83	D. Douglas	TABLOT and NUPLOT, Two Graphics Programs for Tune Computations
SSC Note-8 LBID-811	10/83	L. Smith	Non-Linear Stop Bandwidths
SSC Note-9 LBL-16019	8/83	E.R. Close D.R. Douglas R.C. Sah	Survey and Alignment for a 20-TeV on 20 TeV Collider
SSC Note-10 LBID-810	11/83	M. Cornacchia	Estimates of Some Tracking and Stability Requirements in the SSC
SSC Note-11 LBID-827	12/83	B. Leemann	A Fast Extraction System for the 6.5 Tesla SSC Lattice
SSC Note-12 LBL-17020	12/83	D. Douglas	Tune Shift Due to Systematic Errors in Bend Magnets
SSC Note-13 LBID-833		C. Leemann	Beam-Beam Forces for "Non-Round" Beams and Multipole Expansion of Long Range Forces
SSC Note-14 LBID-834		C. Leemann	Control of IP, Estimate of Tolerances
SSC Note-15 LBID-836	11/83	M.S. Zisman M. Cornacchia	Preliminary Design Implications of SSC
SSC Note-16 LBL-17052	12/83	C. Leemann	Choice of IP Geometry and Beam Parameters for the SSC
SSC Note-17 LBL-17253	1/84	R. Ruth	Single Bunch Instabilities in an SSC
SSC Note-18 LBL-17233	1/84	M. Puglisi	Preliminary Considerations on an RF System for an SSC
SSC Note-19 LBL-17234	1/84	M. Puglisi	Coaxial Cavity Parameters Evaluation

Number	Date	Author	Title
SSC Note-20 LBID-869		D.B. Hopkins M. Puglisi	Design Considerations for SSC RF Cavities
SSC Note-21 LBL-17254	1/84	B.T. Leemann	Injection, Extraction and Beam Abort System for the SSC
SSC Note-22 LBL-17260	1/84	M. Zisman et al	SSC Closed-Orbit Correction
SSC Note-23 LBID-874	5/85	M. Cornacchia	Discussion of Some Sextupolar Effects of Persistent Currents in the SSC
SSC Note-24 LBL-17283	1/84	A. Garren	A 6.5 Tesla SSC Lattice Example
SSC Note-25 LBID-911	6/84	D. Douglas	The Collins' Scheme for the Local Correction of Chromatic Abberations Due to Insertion
SSC Note-26 LBL-17805	1/84	C. Leemann	Considerations Regarding the Choice of Beam Parameters and IP Configurations for the SSC
SSC Note-27 LBID-912	4/84	P.D. Meyers	SSC Magnet Alignment and Aperture
SSC Note-28	10/84	D. Douglas R. Servranckx	A Method to Render Second Order Beam Optics Programs Symplectic
SSC Note-29 LBL-18026	6/84	M.S. Zisman	Preliminary Design Implications of SSC Fixed-Target Operation

APPENDIX B5. TAC REPORTS

Number	Date	Author	Title
	5/85	E. Zaidman et al D. Neuffer	Study of the Plasma Fiber Accelerator
	5/85	S. Heifits et al	Beam Tracking and Stability Analysis for the SSC
	5/85	S. Heifits D. Neuffer	Lattices for the Superferric Super Collider
	5/85	S. Pissanetzky Wm. Schmidt	Design of the Dipole Magnet for the "C" Version of the Superconducting Supercollider 20 TeV Twin-Beam
	5/85	P. McIntyre D. Neuffer Wm. Schmidt	The Three Ring Circus
	5/85	F.R. Huson et al	Superferric Magnet Option for the SSC

Appendix C

Industrial Involvement

APPENDIX C.

Industrial Involvement in SSC R&D

Industrial participation and interest in the SSC in its R&D phase ranges from expressions of eventual interest once the project is approved through detailed inquires into possible participation in the R&D efforts to actual involvement as a contractor or supplier of components or materials. Summarizing such diversity is difficult. No thoughtful analysis has yet been attempted to gauge the level of overall interest or to determine (apart from the obvious) those sectors of private industry most likely to have eventual involvement.

The existing facts are listed below in the following order:

1. Superconducting Magnet Technology

    (a) Superconducting strand and cable
        (i) Suppliers
        (ii) Possible participants
    (b) Suppliers of magnet components
    (c) Suppliers of cryostat components
    (d) Suppliers of tooling

2. Large Electrical Equipment

3. Meetings, Congresses, and Conventions

4. Architecture and Engineering

    (a) Present contractors
    (b) Respondents to the CBD Announcement for A/E Work

1. SUPERCONDUCTING MAGNET TECHNOLOGY

(a) Superconducting Strand and Cable

(i) Suppliers

Amax Specialty Metals Corporation
Refractory Division
460 Jay Street
Coldwater, Michigan 49036
(Subcontractor for extrusion of superconductor billets)

Intermagnetics General Corporation
1875 Thomaston Avenue
Waterbury, CT 06704
(Wire procurement and superconductor R&D)

New England Electric Wire Corp.
Lisbon, NH 03585
(Cable manufacturing and development)

Oxford Superconducting Technology
600 Milik Street
Carteret, NJ 07008
(Wire procurement)

RMI Company
P.O. Box 574
Ashtabulah, OH 44104
(Subcontractor for extrusion of superconductor billets)

Small Tube Products
P.O. Box 1674
Altoona, PA 16603
(Subcontractor for copper components for superconductor billets)

Supercon, Inc.
830 Boston Turnpike Road
Shrewsbury, MA 01545
(Wire procurement and superconductor R&D)

Teledyne Wah Chang
P.O. Box 460
Albany, OR 97321
(NbTi alloy procurement)

(ii) Possible participation

BBC Brown Boveri & Company, Ltd.
Oerlikon Works, P.O. Box 8242
8050 Zurich, Switzerland
(Submission of proposals for cable manufacturing)

The Furukawa Electric CO., Ltd.
9-15, 2-chome, Futaba
Shinagawa-ku
Tokyo 142, Japan
(Manufacturing of wire samples for evaluation)

Hitachi Cable, Ltd.
Tsuchiura Works
3550 Kidamari-cho
Tsuchiura-shi
Ibaraki-ken 300, Japan
(manufacturing of wire samples for evaluation)

Kawecki-Berylco, Inc.
Division of Cabot Corporation
Box 1462
Reading, PA 19603
(Prospective manufacturer of NbTi alloy)

LDM
Postbus 42
Drunen, Holland
(Potential source of hydrostatic extrusion services)

Magnet Corporation of America
197 Bear Hill Road
Waltham, MA 02254
(manufacturing of wire samples for evaluation)

National Standard CO., Ltd.
Arran Road, North Muirton
Perth, Scotland
(Potential source of hydrostatic extrusion services)

Outokumpu OY
Copper Products Division
SF-28100 Pori, Finland
(inquiry about participation)

Vacuumschmelze GMBH
Postfach 2253
Gruner Weg 37
6450 Hanau 1, West Germany
(manufacturing of wire samples for evaluation)

(b) Suppliers of Magnet Components

Active Fabricators
7850 Quincy St.
Willowbrook, IL 605521
(Kapton channel or caps for coil insulation.)

Advance Electrical Sales
1661 Industrial Way
Belmont, CA 94002

Advance Manufacturing Group
Multiwire Division
Kollmorgen Corp.
10 Andrews Road
Hicksville, NY 11801
(Application of syperconducting wire for trim coils to plastic sheet)

Alpha Products, Inc.
5570-T W. 70th Place
Chicago, ILL 60638
(Lamination Stamping)

American Metals Services
P.O. Box 250
Miami, Fla 33152
(Suppliers of Aluminum for AL Collars)

Armco Steel
Middletown, OH 45043

Armco Steel
575 Valley Forge Plaza
1150 First Avenue
King of Prussia, PA 19406
(Nitronic 40 stainless steel for collars; low carbon steel for yokes.)

Beacon Chemical CO.,
125 Mac Questen Pkwy. So.
Mt. Vernon, NY 10550
(Epoxy for assembly of yoke laminations)

Chicago Fineblanking Corp.
2068 Foster Ave.
Wheeling, Ill 60090
(Fineblanking)

Comanche Steel
805 Hannah Ave.
Forest Park, ILL
(Steel strips)

Copper & Brass Sales
415 State Parkway
Schaumburg, ILL 60196
(Suppliers of Copper & Aluminum)

Dek Plastics
3480 Swenson St.
St. Charles, Ill 60174
(RX-630 Molding)

E.H. Canis & Sons
400 Oser Avenue
Hauppaguge, NY 11787
(Kapton tape, shrink tubing, Teflon film)

Eason & Waller
2214 W. Palm Lane
Phoenix, Ariz 85009
(4 Axis G-10 Machining)

E.I. DuPont de Nemours & CO
Wilmington, Delaware 19898
(Kapton film for coil insulation.)

Essex (United Technologies)
P.O. Box 1510
Fort Wayne, Ind 46801
(Materials slitting, Superinsulation Blankets,
Kapton for Dry Windings and Magnet Wire)

General Electric CO.
1310 W. 22nd St. Suite 1107
Oakbrook, ILL 60521
(Kapton for Dry Winding)

General Electric CO.
Motor Magnet Wire Operation
Bldg. 109
Schenectady, N.Y. 12345
(Kapton)

H & J Tool & Die CO.
1565 Ocean Avenue
Bohemia, NY 11716
(Die stamping of collar and yoke laminations)

Imperial Plastics Ltd.
2611 S. 21st Ave.
Broadview, Ill 60153
(RX-630 Molding)

Joseph T. Ryerson & Son, Inc.
16th & Rockwell Sts. Box 8000-A
Chicago, IL 60680
(Steel suppliers & fabricators, Alum. suppliers)

LTV Steel
Two Continental Towers
1701 Gold Road - Suite 600
Rolling Meadows, IL 60006-4275
(Suppliers of Low Carbon & Stainless Steels)

3M
225-4N-05 3M Center
St. Paul, Minn 55144-1000
(B-Staged Kapton for Dry Winding)

Metalstamp Inc.
305 Earl Street
Shorewood, ILL 60436
(EDM Magnet End Plates)

MS Tool CO.
115 Elizabeth Dr.
Arlington Hts., IL 60005
(Experimental Parts)

Northern States Metal Corp.
51 N. Main St., Box 666-U
W. Hartford, CT. 06107
(Extrusions)

Permacil
650 Woodfield Dr., Suit 210
Schaumburg, IL 60195
(B-Staged Kapton for Dry Winding)

Phelps-Dodge
941 N. Plumgrove Rd.
Schaumberg, IL 60195
(Copper Wedges)

Plainfield Tool & Eng. Inc.
P.O. Box 326
10 East Main St. Rt. 126
Plainfield, IL 60544
(Laminations)

Raynor, Inc.
P.O. Box 458
Westminster, MA 01473
(Yoke half-shells)

Reichhold Chemicals Inc.
8420 Fawncrest Place
Ft. Wayne, Ind 46815
(Molding Compounds)

Rogers Corp.
2001 W. Williams Field Rd.
Chandler, AZ 85224
(B-Stage Kapton Molding Compounds)

Rummel Fibre
82 Progress St.
Union, N.J. 07083
(G-10 Tubing)

Shaped Wire Inc.
3655 Illinois Ave.
St. Charles, IL 60174
(Copper Wedges & SS Keys)

Spaulding Fibre
1300 So. 7th St.
DeKalb, IL 60015
(Suppliers of G-10 Tubing)

Tempel
5990 W. Touhy Ave.
Niles, IL 60648
(Lam. Stamping House)

Ullrich Copper
2 Mark Rd.
Kenilworth, N.J. 07033
(Copper Wedge Extrusions)

Wagner Fineblanking
4611 N. 32nd St.
Milwaukee, Wi 53209
(Fineblanking)

(c) Suppliers of Cryostat Components

Aluminum Company of American (Alcoa)
P.O. Box 7500
Lafayette, Indiana 47903-7500
(Alum. Extrusions)

ARMCO
333 N. 6th St.
St. Charles, Ill. 60174
(Fiberglass Post Fabrication)

Bloomer-Fiske CO.
2300 W. 47th St.
Chicago, Ill. 60609
(Steel Forming & Rolling)

Calflex
26111 Evergreen Suite 220
Southfield, Mi. 48076
(Bellows Manufacturers)

Cryogenic Consultants, Inc.
1176 North Irving Street
Allentown, PA 18103

Cryolab
4175 Santa Fe Road
San Luis Obispo, CA 93401

C.V.I., Incorporated
P.O. Box 2138
Columbus, OH 43219

E/M Lubricants, Inc.
P.O. Box 2200, Highway 52 N.W.
West Lafayette, Ind. 47906
(SSC Post Thread Lub.)

Essex (United Technologies)
P.O. Box 1510
Fort Wayne, Inc. 46801
(Materials slitting,
Superinsulation Blankets,
Kapton for Dry Winding
and Magnet Wire)

Flexonics Inc.
300 East Devon Ave.
Bartlett, Ill. 60103
(S.S. Bellows)

Gardner Products
254 N. Water St.
Batavia, Ill. 60510
(SS Thin Shields)

G.E. Mathis CO.
6102 S. Oak Park Ave.
Chicago, Ill. 60638
(Bump Forming 20' Vacuum Vessels)

Ideal Tool
5615 S. Claremont
Chicago, Ill. 60636
(Planing of vacuum vessel,
heavy machining)

Medco
340 E. Howard St.
Des Plaines, Ill. 60018
(4 Axis Machines,
G-10 Machining, Flanges)

Metal Bellows
1075 Providence Highway
Sharon, Ma. 02067
(S.S. Bellows)

Metal Fab Corp.
P.O. Box 2611
Ormond Beach, Fl. 32075
(Bellows Manufacturers)

Metal Lab
7316 Durand Ave.
Sturtevant, Wi. 53177
(Vacuum Degassing)

Metalized Products
73 East St.
Winchester, Mass. 01890
(Superinsulation Suppliers)

Nicofibers
Ironpoint Road
Shawnee, Ohio 43782
(Fiberglass Separator for
Insulation Blankets)

Plymouth Tube
P.O. Box 11
Winfield, Ill. 60190
(SS Extrusions)

Precision Extrusions
727 East Green Street
Bensenville, Il. 60106
(Mfr. of Extrusions &
Alum. Tubing)

Ultra Specialties
1360 Howard St.
Elk Grove Village, Ill. 60007
(General Machine & Fab.)

Walco Tool
P.O. Box 220B R.R. #3
Lockport, Ill. 60441
(General Machine & Fab.)

Western Pneumatic
P.O. Box W
Kirkland, Wa
(Tube Mfr.)

(d) Suppliers of Tooling

American Grinding
2000 N. Mango
Chicago, Ill. 60639
(Collaring Press,
Ground ready made tables)

Danco Tool
Wheatland & Mellon Sts.
Phoenixville, Pa 19460
(Diemakers & Lamination
Stamping House)

DeKalb Precision
2031 Sycamore Rd.
DeKalb, Ill. 60115
(General Machine & Fab.)

K.C. Glader
6056 Gross Point Rd.
Chicago, Ill.
(Close Tol. Stl. Strip)

Lesco Tool and Die
1929 Miller Street
P.O. Box 8096
Houston, TX 77288

Meyer Tool and Mfg., Inc.
9221 South Kilpatrick
Oak Lawn, IL 60453

Numerical Precision Inc.
2200 Foster Ave.
Wheeling, Ill. 60090
(4 Axis Mills)

2. LARGE ELECTRIC EQUIPMENT

Firms interested in large scale involvement in the SSC project (some already involved modestly):

Ansaldo spa
Via A. Pacinotti 20
16151 Genova, Italy
(Inquiry about magnet manufacturing)

BBC Brown, Boveri, Inc.
1460 Livingston Avenue
North Brunswick, N.J. 08902
(Inquiry about magnet manufacturing)

Brown, Boveri & Cie
Postfach 351, GK/MS 3
6800 Mannheim 1, West Germany
(Participation in manufacturing plan and
cost estimates; inquiry about magnet manufacturing
in the U.S.)

General Dynamics
(Magnet construction for TAC; cryostat
development with LBL; cost estimates
for SSC-CDG)

Hitachi Works, Hitachi Ltd.
3-1-1 Saiwai-cho
Hitachi-shi
Ibaraki-ken, Japan
(Inquiry about magnet manufacturing)

Toshiba Corporation
1-6, Uchisaiwai-cho
1-chome, Chiyoda-ku
Tokyo 100, Japan
(Inquiry about magnet manufacturing;
starting assembly of model magnets)

Westinghouse
(Cost estimates for SSC-CDG)

3. MEETINGS, CONGRESSES AND CONVENTIONS OF INDUSTRIAL CORPORATIONS INTERESTED IN SSC TECHNOLOGICAL DEVELOPMENT AND NEEDS

(a) 5th Annual Meeting, Fermilab Industrial Affiliates, May 21-22, 1985. Attended by 70 participants. A listing of these participants is available on request.

(b) Intense Briefing on Large Scale Superconducting Magnet Technology, Fermilab, February 19-20, 1985. This briefing was attended by 38 participants. A complete list of these participants is available on request.

4. ARCHITECTURE AND ENGINEERING

(a) Present Contractors

CER Corporation
2225 East Flamingo
Suite 300
Las Vegas, Nevada 89109
($320 K, 6 months)

RTK
Joint Venture
1800 Harrison Street
Oakland, CA 94623-2321
(expected to be approximately
$6M, 2-1/2 years)

(b) Respondents to CBD Announcement for A/E Work

Parsons, Brinckerhoff, Quade & Douglas, Inc.
1625 Van Ness Avenue, 4th Floor
San Francisco, CA 94109-3678

Ralph Parsons CO.
100 W. Walnut Street
Pasadena, CA 91124

Morrison-Knudsen
Two Morrison-Knudsen Plaza
P.O. Box 7808
Boise, ID 83729

Braddock, Dunn & McDonald
Alburquerque, Nm
(Vacuum Cryogenics Controls)

Urbahn/Lynn Associates
300 Park Avenue, South
New York, NY 10010
(Architects)

Joseph R. Loring CO.
(Engineers)

Rutherford & Chekene
(Geotechnical)

James Wilton
Jacobs Associates
500 Sansome
San Francisco, CA

Professor Garniss Curtis
Department of Geology & Geophysics
499 Earth Sciences Building
University of California
Berkeley, CA 94720

Jose Garcia, President
Sol-Arc CO.
2040 Addison Street
Berkeley, CA

Philip Banta
UC Berkeley

Charles J. Nafie, Jr.
Boston, MA
(Planner)

Howard, Needles, Tammer & Bergendoff
9200 Ward Parkway
P.O. Box 299
Kansas City, MO 64141

Sverdrup/Jacobs Jt. Venture
801 North Eleventh Street
St. Louis, MO 63101

Sverdrup & Parcel Assoc., Inc.
417 Montgomery Street
San Francisco, CA

Jacobs Engineering Group, Inc.
251 So. Lake Avenue
Pasadena, CA 91101

Princeton Plasma Physics Laboratory
Princeton University
P.O. Box 451
Princeton, NJ 08544

Fluor Engineers, Inc.
Advanced Technology Division (ATD)
333 Michelson Drive
Irvine, CA 92730

Daniel International

Fenix & Scisson, Inc.
1401 So. Boulder
Tulsa, OK 74119

Los Alamos Technical Associates
Los Alamos, NM

URS/John A. Blume & Associates Engineers
130 Jessie
San Francisco, CA

EMF Group-Jt. Venture

Engineering Decision Analysis Corp.

MBT Associates

Forell/Elsesser Engineers, Inc.
539 Bryant Street
San Francisco, CA 94107-1270

Dames & Moore
445 So. Figueroa Street, Ste 3500
Los Angeles, CA 90071
(Geotech & EIS)

Lachel Hansen Associates
Golden, CO
(Tunnels)

George Nolte Associates
(Waste Treatment)

Gayner Engineers
821 Howard Street
San Francisco, CA 94103
(Mechanical Engineering)

The Engineering Enterprise
620 Bancroft Way
Berkeley, CA
(Electrical)

YEI
1485 Bayshore Blvd.
San Francisco, CA
(Substations)

Gus Atkinson
(Construction Management)

SWA
(Sasaki, Walker, Assoc.)
Sasaki Associates, Inc.
64 Pleasant Street
Watertown, MA 02172
(Planning and Landscaping)

DKS, Inc.
319-11th Street
San Francisco, CA
(Traffic Consultants)

Charles M. Salter Associates, Inc.
350 Pacific Avenue
San Francisco, CA 94111
(Acoustics)

Marshall Associates
(Food Services)

RTK-Jt. Venture
1800 Harrison Street
Oakland, CA 94623-2321

Raymond Kaiser Engineers
300 Lakeside Drive
Oakland, CA

Tudor Engineering CO.
149 New Montgomery Street
San Francisco, CA 94105

Keller & Gannon-Knight
1453 Mission Street
San Francisco, CA 94103

Wm. L. Pereira Associates
27 Sutter Street
San Francisco, CA
(Architects)

Earth Technical Corp.
(Geotechnical)

J. Warren & Associates
1800 North Charles Street, Ste 54
Baltimore, MD 21201
(Roads)

EBASCO-Jt. Venture

EBASCO Services, Inc.
Two World Trade Center
New York, NY 10048
(Sub. of Enserch Corp.)

Losinger
Switzerland

Westinghouse Elec. Corp.
Westinghouse Bds Gtwy Center
Pittsburgh, PA 15222

Rockwell Corp.
600 Grant Street
Pittsburgh, PA 15219

Stone & Webster Engineering Corp.
245 Summer Street
Boston, MA 02107

Amman & Whitney
Two World Trade Center
New York, NY 10048

Peter Tarkoy, Consultant
(Tunnels)

John Erlewine, Consultant
(Former G.M.--CH AEC Office)

Brown & Root Development, Inc.
P.O. Box 3012
Naperville, IL 60566
(Subs. of Halliburton CO.)

Alvord, Burdick & Howson
20 N. Wacker
Chicago, IL 60606
(Tunnels)

STS Consultants, Inc.
(Soil Test)

Chicago Bridge & Iron CO.
800 Jorie Blvd.
Hinsdale, IL 60521
(Cryogenics & Vacuum)

NUS Corporation
910 Clopper Road
Gaithersberg, MD 20760
(Environmental)

Black & Veatch Engineers-Architects, Jt. Venture
1500 Meadow Lake Parkway
Kansas City, MO 64114

Marshall & Brown, Inc.
Architects

Cryogenic Consultants, Inc.
1176 North Irving Street
Allentown, PA

Motor Columbus Associates
Switzerland
(Tunneling)

Boude C. Moore
Coronado, CA
(Vacuum)

Dames & Moore
Los Angeles
(Geotechnical)