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Report of the DOE Office of Energy Research Review Committee on the Site-Specific Conceptual Design of the Superconducting Super Collider

September 1990

U.S. Department of Energy
Office of Energy Research
Office of Superconducting Super Collider

EXECUTIVE SUMMARY

From June 25 to 30, 1990, an Office of Energy Research Review Committee (ERC) evaluated the technical feasibility, the estimated cost, the proposed construction schedule, and the management arrangements for the Superconducting Super Collider (SSC) as documented in the Site-Specific Conceptual Design Report (SCDR) and other materials prepared by the Superconducting Super Collider Laboratory (SSCL). The SSC facility will provide the key tool for the next step in the U.S. high energy physics basic research program — a proton-proton collider with a total center-of-mass energy of 40 TeV and high luminosity (10^{33} cm^{-2} s^{-1}). The SCDR reflects research, development and design activities undertaken since the 1986 SSC Conceptual Design Report, along with the characteristics of the SSC site in Ellis County, Texas. It incorporates the best judgement of the Universities Research Association (URA), the organization chosen by the U.S. Department of Energy to establish the SSCL and to execute the project.

The ERC concludes that the design set forth in the SCDR and related documents is technically sound and is scoped to meet the requirements of the U.S. high energy physics program well into the next century. The design of the SSC is based to a large extent on previous experience with storage rings and synchrotrons which use superconducting magnets, particularly the Tevatron in the United States and HERA, under construction in Germany. While, in some aspects, the SSC requires extension of this experience, there is no question that a facility with the SSC specifications is feasible.

As with past colliders, the ultimate intensity or luminosity of a specific design cannot be completely guaranteed in advance. However, the design provided by the SSCL reflects advanced design activities that address many accelerator physics issues not considered in the design of previous colliders and holds the promise of performance levels beyond the basic luminosity goal of the SSC. Hence, there is little doubt that a collider based on the present design would provide the scientific community with a facility of unique capabilities promising major discoveries at the forefront of knowledge. The current design is judged by the review committee to be based on reasonable conservatism and has taken into account both reliability and maintainability.

An essential ingredient, needed for this ambitious project to succeed in meeting its technical goals, is the commitment of a world-class scientific and technical staff whose skill, experience and dedication are matched to the challenge of the SSC. The present level of technical staffing (physicists and engineers), of both accelerator-experienced personnel and others in key areas such as controls programming, places severe limits on the amount and depth of work that can be accomplished in the near term. SSCL should make every effort to increase, as soon as possible, the present level severalfold in certain critical areas. Special action by the DOE may be required to assist the SSCL in accomplishing this essential goal.

The SSCL has documented an estimated total project cost (TPC) for constructing and commissioning an SSC facility of $6.57 billion in FY 1990 dollars, which includes $0.75 billion in contingency. Also included in this estimate is $0.98 billion for component R&D and preoperational commissioning of the facility, and $0.75 billion for fabrication of an initial complement of detectors for the SSC research program. Taking account of the schedule and the associated funding profile developed by the SSCL, and escalating costs using escalation rates provided by the DOE and OMB, resulted in a TPC of $7.8 billion in as-spent dollars.

The ERC finds, with the exception of a few underestimated items, that the SCDR base cost estimate (i.e., without contingency) in FY 1990 dollars is credible and generally consistent with the scope of the project. However, the procurement strategy developed by the SSCL and DOE for the collider dipole magnets does not take full advantage of the cost benefits of full and open competition. The committee recommends that alternative strategies be considered which enhance SSCL/industry technical interaction, relieve the manufacturer of uncontrolled risks, and provide for alternate and more competitive sources of procurement. However, it is critical to get the magnet industrialization process vigorously underway as soon as possible. Thus, the collider dipole magnet request for proposals should be issued as soon as possible, even in its current form, as long as it provides the latitude for a later change in production contract type.

The identification of the scope of the initial experimental program by the SSCL Program Advisory Committee is now in progress. However, based on preliminary considerations of proposed experiments, the ERC believes that the allowances provided in this estimate for experimental systems together with the anticipated significant level of non-Federal contributions for detectors can provide a balanced initial research program, albeit at a somewhat reduced scope from the desired initial set of detectors consisting of two large general-purpose detectors, one medium-sized special purpose detector, and some number of quite small specialized experiments.

The committee has identified a few items in the base estimate presented by the SSCL which it believes are underestimated and a few which are overestimated. The committee also notes that the level of contingency associated at this early stage with certain areas of the project is less than would be desirable to ensure successful completion of the project within the planned level of funding. The ERC base cost estimate for the total project is increased by $57 million (FY 1990), a one percent increase compared to the estimate presented by the SSCL. The associated contingency allowance is increased by $395 million (FY 1990), a 53 percent increase (from 13 percent to 20 percent) compared to the SSCL contingency. The major element of this increase was $290 million for the superconducting magnets to reflect concern about uncertainties and optimism in the cost estimate. The resulting TPC calculated by the ERC is $7.02 billion (FY 1990), seven percent higher than the SSCL TPC. Escalating to as-spent dollars, using the escalation rates provided by the DOE and OMB and the funding profile developed by the SSCL, results in a TPC calculated by the ERC of $8.4 billion. The committee also notes that the budget for support and operation of injector accelerator and collider sectors after they have been commissioned is not included in the TPC; nor are certain SSCL facilities and services not specifically related to the project (estimated by SSCL to be about $0.35 billion, as-spent). In view of these findings, the SSCL should consider possible scope changes and design optimizations and reconsider their contingency allocation and their estimated TPC.

The proposed cost-optimized construction project schedule leading to completion in late 1998 is considered by the committee to be possible, although it is very aggressive and, therefore, carries considerable schedule risk. The committee points out that this schedule results in a funding profile developed by the SSCL that rises rapidly to over $1.25 billion per year for FY 1992 through FY 1995. This schedule implicitly assumes that the required level and quality of technical staff is put in place quickly, that the R&D program proceeds on a success-oriented, fast-track schedule, and that the development of the currently undeveloped SSC site and of the associated support infrastructure proceeds rapidly. Thus, the SSCL estimate of the TPC probably represents a lower bound; the potential for significant increases in as-spent dollars is high if the schedule and funding profile proposed by SSCL are not achieved. The testing of industrially assembled superconducting magnets in the E1 complex in September 1992 represents a critical milestone which should be carefully monitored in order to gauge the project's early progress.

The management challenge facing the DOE, URA, and SSCL is to effectively blend the varied professional cultures of the SSC participants (DOE, DOD, universities, industry, national laboratories, foreign participants, high energy physicists, other scientists and engineers) into a hybrid that is stronger than any contributing element. The success of the SSC depends critically on how well these diverse elements can be integrated into a working team to provide the capability to carry out this project effectively, on time, and within cost. It is imperative that the assignment of tasks and responsibilities be made clear to all parties through a formal management system. Prompt formulation and documentation of the project execution strategy is critical to the success of the SSC.

Strong, effective, and appropriate management structures, including permanent staffing, documented procedures, and delegation of authority, are absolutely necessary for successful completion of this project within the timeframe and resources planned. URA should ensure that the most capable management team possible is put in place immediately within the SSCL. The Department of Energy should also ensure that its management and oversight personnel within the OSSC are of the highest quality and are given the necessary authority, particularly at the site-office level, to shorten the time required for the necessary administrative decisions and for a reduction in administrative paper requirements to ensure that the SSC project can proceed as planned.

Finally, the ERC was impressed with the substantial work accomplished since March 1990 by the SSCL in preparing for this review.

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Appendices

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2. INTRODUCTION

After it was established in early 1989, the Superconducting Super Collider Laboratory (SSCL) began to prepare a detailed site-specific SSC conceptual design, including cost and schedule estimates. As detailed in the SSC Site-Specific Conceptual Design Report (SCDR), this design builds upon the design in the March 1986 SSC Conceptual Design Report (CDR) and takes into account characteristics of the SSC site, results of continuing magnet R&D, and advances in accelerator design.

2.1 Charge to the Energy Research Review Committee

The DOE Office of Energy Research constituted a Review Committee (ERC) to thoroughly review and evaluate the this SSC site-specific conceptual design and charged it as follows:

> CHARGE TO THE ENERGY RESEARCH REVIEW COMMITTEE
> FOR THE
> SSC SITE-SPECIFIC CONCEPTUAL DESIGN
>
> The ERC should assess the technical design proposed; in particular, whether the design is consistent with the SSC performance objective. The ERC should carefully review the cost estimates for the conceptual design, understand in detail the basis for the estimates, note identified uncertainties, and judge the overall validity of the estimates. The realism of the proposed construction schedule and funding profile should be addressed. The manner in which the work will be accomplished, including how it will be managed, should be reviewed and assessed. Thus, in summary, the ERC is to review and assess the proposed SSC design and the credibility of the associated cost and schedule estimates, as well as the adequacy of present and planned management arrangements to accomplish the scope of work.

2.2 Membership of the Energy Research Review Committee

The ERC was chaired by L. Edward Temple, Jr., Director of DOE's Division of Construction Management Support, Office of Energy Research. The ERC was organized into eight subcommittees with members from the DOE national laboratories, the Corps of Engineers, the Bureau of Reclamation, universities, and private industry (including private consultants with specialized experience). In addition, the ERC included a team of observers and a team of support personnel from DOE, as well as a team of report coordinators. The ERC membership and subcommittee structure are listed in Appendix A.

In addition, DOE planned two other concurrent reviews of the site-specific technical design, schedule, and cost to be conducted in late June or early July. The first of these was the DOE Independent Cost Estimating (ICE) Review, which used support contractors and private industry to make an independent assessment of SSC costs and compare them with costs reported by SSCL. The DOE ICE group was to function independently of the SSC program office (OSSC) in ER and to provide the DOE Acquisition Executive an independent estimate of project costs. The ICE review was to include an assessment of the overall scope of the project, the estimated cost, and the proposed schedule as required for major DOE projects under DOE Order 4700.1 in support of the Energy Systems Acquisition Advisory Board process. It was to identify high-risk technical issues and ensure that a meaningful technical baseline was included in the project plan.

The second review was by the SSC Cost Estimate Oversight Subpanel of the High Energy Physics Advisory Panel (HEPAP), which was to provide an independent assessment of the SSC cost estimate. The subpanel was to evaluate the appropriateness of the cost estimating methodology, the completeness and the credibility of the cost estimates, the realism of the proposed schedules and funding profiles, and the degree of risk involved in completing the SSC within the estimated cost, including the proposed contingency. HEPAP reports to the Secretary of Energy through the Director of the Office of Energy Research.

Members of the ICE review team and of the HEPAP subpanel are also listed in Appendix A. Members of both groups participated in the review of the SCDR.

2.3 The ERC Process

In April 1990, James F. Decker, Acting Director of the Office of Energy Research, formally requested in a memo to L. E. Temple (Appendix C) that a peer-review team be established for the purpose of reviewing the technical content, the cost estimates, and the schedule estimates of the SSC site-specific conceptual design. The results of the review, along with those of the ICE and HEPAP subpanel review, were to be used to establish the

SSC technical, cost, and schedule baselines and to support budget requests for FY 1991 and later years.

Planning for the review actually began earlier in the year, and four coordinating meetings with the SSCL were organized by OSSC in the period from February to May 1990. These meetings resulted in a mutually agreeable agenda for a review that would thoroughly evaluate the total scope of the SSC project and agreement on the scope of documentation required for such a review. Appendix C lists the final agenda for the review.

The ERC held an organizational meeting at the DOE, Germantown, Maryland, on June 15, 1990. The review took place at the SSCL from June 25-30, 1990. The first day was devoted to overview presentations to the entire ERC by the SSCL staff. The second and third days were devoted to detailed presentations to subcommittees and to interactions between subcommittee members and about 160 members of the SSCL staff (the superconducting magnet subcommittee met for two additional days). The next three days were divided between further presentations and interactions, as needed, ERC deliberations, and report writing. The report coordinators and support staff took two additional days to complete the draft report for mailing to ERC members on July 2, 1990. After ERC review of the draft, the report was put into final form at DOE headquarters during the period from July 11–17, 1990.

Comparison with past experience was a primary method for verifying requirements, scope, and cost. Existing accelerator laboratories and recent construction projects provide a relevant basis for comparative evaluation. In the United States, these include the Energy Saver and Tevatron projects at the Fermi National Accelerator Laboratory (Fermilab), the Stanford Linear Collider (SLC) project at the Stanford Linear Accelerator Center, and the Continuous Electron Beam Accelerator Facility (CEBAF), a new facility under construction near Newport News, Virginia. Recent projects overseas include Large Electron-Positron project (LEP) at the European Laboratory for Particle Physics (CERN) near Geneva and Hadron-Elektron-Ring-Anlage (HERA), which is still in progress at the Deutsches-Elektronen Synchrotron (DESY) in Hamburg. Throughout the ERC's deliberations, various comparisons were made with these facilities to evaluate the SCDR scope and cost estimates.

2.4 Background

The concept of a multi-TeV accelerator was first publicly discussed more than 10 years ago. Two workshops sponsored by the International Committee on Future Accelerators, one at Fermilab in 1978 and one at CERN in 1979, examined various possibilities for very high energy machines, including proton-proton colliders in the 20-TeV per beam range. The SSC has its origins in a 1982 summer study sponsored by the Division of Particles and Fields (DPF) of the American Physical Society. This study and workshops on detectors and accelerators held in 1983 at Lawrence Berkeley Laboratory (LBL) and Cornell University, respectively, provided critical technical input to a HEPAP recommendation for the "immediate initiation of a multi-TeV high-luminosity proton-proton collider project with the goal of physics experiments at this facility at the earliest possible date."

The proposed facility was designated the SSC. As a result of the recommendation, in the fall of 1983, the DOE and the directors of the U.S. high energy accelerator laboratories chartered a Reference Designs Study (RDS) with beam energy and luminosity goals specified. That study, which was completed in April 1984, drew upon the expertise of about 150 accelerator physicists and engineers from across the nation. Three different approaches to an SSC were studied, and it was concluded that each of them could form the foundation of a technically feasible collider of 20 TeV per beam.

In March 1984, the DOE assigned oversight responsibility for the national SSC effort during the R&D and preconstruction phase to Universities Research Association (URA). By the fall of 1984, URA had formed the SSC Central Design Group (CDG) to carry out its responsibilities of directing and coordinating the national R&D work and put its headquarters at LBL, with Maury Tigner of Cornell University as director. The CDG technical staff members were drawn from high energy physics, accelerator, and technical groups from universities and national laboratories across the country. In June and July of 1984, a second DPF summer study examined the reference designs and the SSC suitability for physics experiments. The summer study reaffirmed the primary parameters of the RDS (20 TeV per beam at 10^{33} cm^{-2} s^{-1} luminosity) as important for meeting the physics goals. By the summer of 1984, extensive work on model magnets for the SSC was already underway at Brookhaven National Laboratory (BNL), Fermilab, LBL, and the Texas Accelerator Center.

The principal activities for fiscal year 1985 were, first, conducting a diversified effort on model magnet and cryostat R&D in order to provide the technical basis for selection of one of the five superconducting magnet designs then under study and, second, beginning the SSC conceptual design based on that selection. Also important was the preparation of a siting parameters document that could provide a technical basis for eventual site selection by the DOE. These goals were accomplished and magnet selection was made in September 1985. Fiscal year 1986 focused on engineering developments to improve the cost effectiveness of the selected magnet style and to flesh out the conceptual design and cost estimate expressed in the SSC CDR issued in March 1986.

In January 1987, after extensive reviews of the SSC project, the DOE and the Reagan Administration supported the project and recommended it to Congress with technical, cost, and schedule baselines based on the 1986 CDR. The DOE initiated the process of site selection by issuing an Invitation for Site Proposals (ISP) in the spring of 1987. This document contained the latest design concepts, descriptive information about the accelerator and research facilities, and lists of site requirements. States submitted more than 40 site proposals to the DOE, thus setting the stage for site selection. A special committee assembled by the National Academies of Sciences and Engineering made a recommendation to the DOE about a select group of "best qualified sites." From this list, the DOE chose the Texas proposal with the site encircling Waxahachie, about 30 miles south of Dallas in Ellis County (Fig. 2.1).

Concurrently with the extensive site-selection efforts, the DOE sought the services of a contractor to manage the design, construction, and the research program for the SSC. It was announced in January 1989 that URA, in conjunction with its partners EG&G and the Sverdrup Corporation, had been selected. URA announced that it had chosen Roy Schwitters from Harvard University as the director of the emerging SSCL. The first members of the new laboratory began work in the south Dallas area, about a 20-minute drive from the SSC site, in March 1989. By the end of the summer, more than 300 persons were working on the accelerator design, component development, and launching the new organization. Now, about 600 staff members, visitors, and consultants are working at laboratories and offices at SSCL.

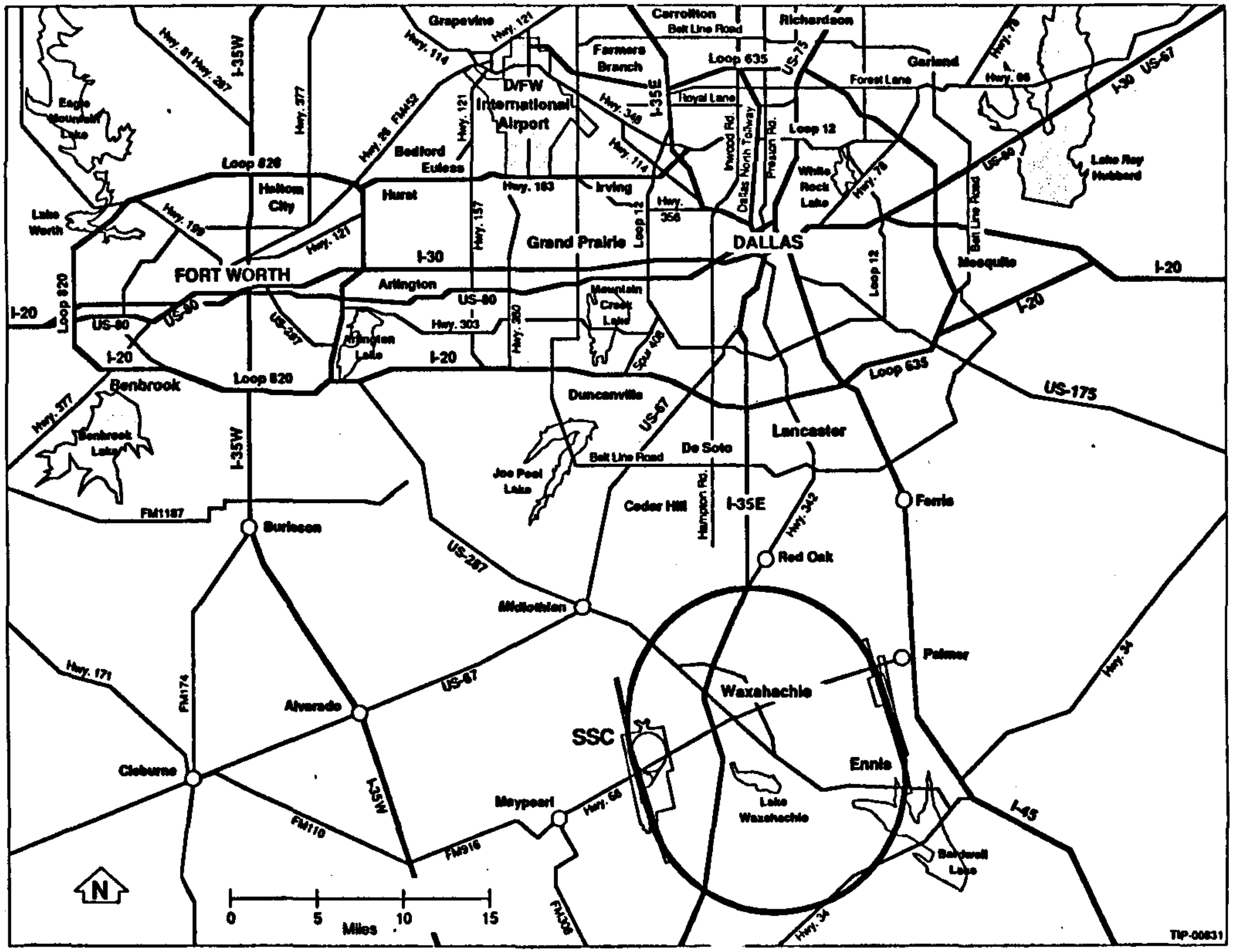

Figure 2.1. Location of the SSC site in Ellis County, Texas, south of the Dallas-Fort Worth metropolitan area.

In September 1989, preparation began of an environmental impact statement (EIS) to supplement the EIS of December 1988, written before the final site selection. It is expected that the supplemental EIS will be completed in the last quarter of 1990.

The involvement of industrial partners in the operation and management of the SSCL is unique in high energy physics. In addition to EG&G and Sverdrup, assistance with systems integration is provided by the Lockheed Corporation. In March 1990, the consortium of Parsons-Brinckerhoff/Morrison-Knudsen was chosen as the contractor (AE/CM) to carry out the detailed design and construction of conventional facilities in collaboration with SSCL staff. The Texas National Research Laboratory Commission (TNRLC) represents a second innovative form of participation in the SSC project. The TNRLC was established by the Texas legislature in 1985 as a nine-member commission, initially to prepare the Texas SSC siting proposal and now to facilitate the progress of the construction project. The TNRLC is a state agency reporting to the legislature and eventually will have authority to spend approximately $1 billion in support of the SSC, including an estimated $700 million on site development and $100 million on research. The first bond issue of $250 million has recently been approved by the Texas legislature. The TNRLC is also the official channel for acquisition of the land required by the SSC, a process that is just beginning.

The SSCL is organized into six divisions: (1) Accelerator Systems, (2) Magnet Systems, (3) Physics Research, (4) Conventional Construction, (5) Technical Services, and (6) Administrative Services. The Project Manager and the Technical Director manage the technical and conventional construction of all accelerator and magnet systems and conventional support facilities. The divisions directly responsible for the design and construction of the technical components and the conventional facilities report to the Project Manager. The SCDR represents the project-oriented efforts of the divisions. The Physics Research Division defines requirements for experimental support facilities, coordinates the research program, and manages some aspects of general Laboratory support, such as computing.

With the selection of the site near Dallas and the assembling of the design team, one of the first efforts was determining the conceptual design features of the SSC. For months, scientific, technical, and administrative personnel in the SSCL studied the design and research objectives of the SSC, using the 1986 CDR as a starting point for these examinations. Many new considerations that arose over the intervening years were addressed in detail.

The SCDR was prepared to describe the current conceptual design for the accelerator and research facilities at the SSCL. This design starts from the 1986 CDR and draws upon the device developments, technical studies, and workshops that have been held in the intervening years. More importantly, the SCDR reflects the design choices, technical evaluations, performance objectives, and judgements of the staff of the SSCL.

The conceptual design for the SSC continues to evolve from the ongoing work of the scientific, engineering, administrative, and support staff at the new laboratory. A primary concern is the adaptation of the developing design to the characteristics of the Ellis County, Texas site. In parallel with the acquisition of information and data on the physical, geological, cultural, and human-made features of the site, extensive thought is being given to the design of the accelerator, technical, and research features of the SSC. The SCDR conveys the information that was assembled at the time that the document went to press (June 1990). Work is continuing on all aspects of the design. As a consequence, the design presented by the SSCL during the June ERC review was different in some aspects from that in the SCDR. The SSCL used the phrase *point design* to describe the design presented. A point design is understood to be a "snapshot" of the evolving design taken for the purpose of evaluating cost and schedule for such a review.

The full design represented in the SCDR describes the long-range objectives of the SSC Laboratory. Initially, a somewhat reduced set of facilities will be constructed.

The SSC complex, as presented in the SCDR, consists of five cascaded accelerators, beginning with the 600-MeV linac and leading to the 20-TeV collider. The linac, a 0.25-km-long linear accelerator, is the first machine in the chain. It produces and accelerates negative hydrogen ions to 600-MeV kinetic energy. The second stage of acceleration is the low energy booster (LEB), a rapid-cycling synchrotron (a nearly circular accelerator) with an 0.54-km circumference, which first converts the negative ions to protons and then boosts the energy from 600 MeV to 11.1 GeV. In the next stage, the medium energy booster (MEB), which has a circumference of 3.96 km, boosts the energy of the protons from 11.1 GeV to 200 GeV. All three of these initial stages of acceleration use conventional room-temperature magnets and acceleration systems. The final energy boost, from 200 GeV to 2 TeV (2000 GeV), is accomplished by the high energy booster (HEB), which has a circumference of 10.89 km. The HEB, like the 87.12-km collider rings, uses superconducting magnets cooled to liquid-helium temperatures by a helium liquefier/ refrigerator located at the HEB service area. All of these accelerators are housed in underground enclosures that are interlocked against access and monitored from the main control room.

The experimental detectors will be housed in underground enclosures at the interaction points. The largest of these detectors will weigh up to 60,000 tons and require an enclosure approximately 40 m wide by 110 m long by 35 m high. Except for the matter of scale, the technical facilities for the SSC are similar to those at existing DOE and foreign accelerator laboratories, so the experience of those laboratories can be used with confidence to guide the design of the SSC facilities.

The performance goals for the SSC are shown in Table 2.1. The energy and luminosity specifications for the collider are based on extensive studies of physics goals and accelerator and detector technologies. The tradeoff between energy and luminosity was recently reviewed in considerable detail by the Ad Hoc Committee on SSC Physics, convened by the Director of the SSCL, and by a subpanel of HEPAP. Both groups reaffirmed the original design beam energy and luminosity.

Table 2.1

Primary SSC Design Objectives

Proton beam energy	20 TeV
Luminosity	10^{33} cm^{-2} s^{-1}
Number of interaction regions	4 (8 possible)

While the performance objectives remain as they were in the 1986 CDR, certain of the system parameters have been altered to meet those goals. These do not represent conceptual innovations but rather are evolutionary refinements based on improved understanding and appreciation of problems inherent in a system of such complexity and magnitude. Continuing studies of beam dynamics and experience with current accelerator systems have produced more thorough knowledge of the behavior to be expected in the SSC. These have led to modification of some design parameters, as discussed in Section 4.

3. SCIENTIFIC NEED AND TECHNICAL BASIS

3.1. Scientific Need

Elementary particle physics, the science of the ultimate constituents of matter and their interactions, has undergone a remarkable development during the past two decades. A host of experimental results made accessible by the present generation of particle accelerators and the accompanying rapid convergence of theoretical ideas have brought to the subject an unprecedented coherence. This clarity, however, brings into sharp focus fundamental limitations in our current understanding that raise fresh possibilities and set new goals for advancing the understanding of nature. The progress in particle physics has been more dramatic and more thoroughgoing than could have been imagined only 15 years ago. Many of the deep issues then current have been addressed, and many of the opportunities then foreseen have been realized. This progress and the profound questions emerging from it bring particle physics to an intellectual turning point comparable to the synthesis of classical physics in the late nineteenth century that preceded the discovery of relativity and quantum mechanics.

Forty years ago, ordinary matter was thought to consist of protons, neutrons, and electrons. Experiments probed the structure of these particles and explored the forces that bind them into nuclei and atoms. In the course of these experiments, over a period of 20 years, physicists discovered more than 100 new particles, called hadrons, that had many similarities to protons and neutrons. None of these particles seemed more elementary than any other, and by the mid-1960s there was little understanding of the mechanisms by which they interacted.

Since that time, a radically new and simple picture has emerged (Fig. 3.1) as a result of many crucial experimental discoveries and theoretical insights. It is now clear that the proton, neutron, and other hadrons are not elementary, but are composite systems made of yet more fundamental particles called quarks, much as an atom is a composite system

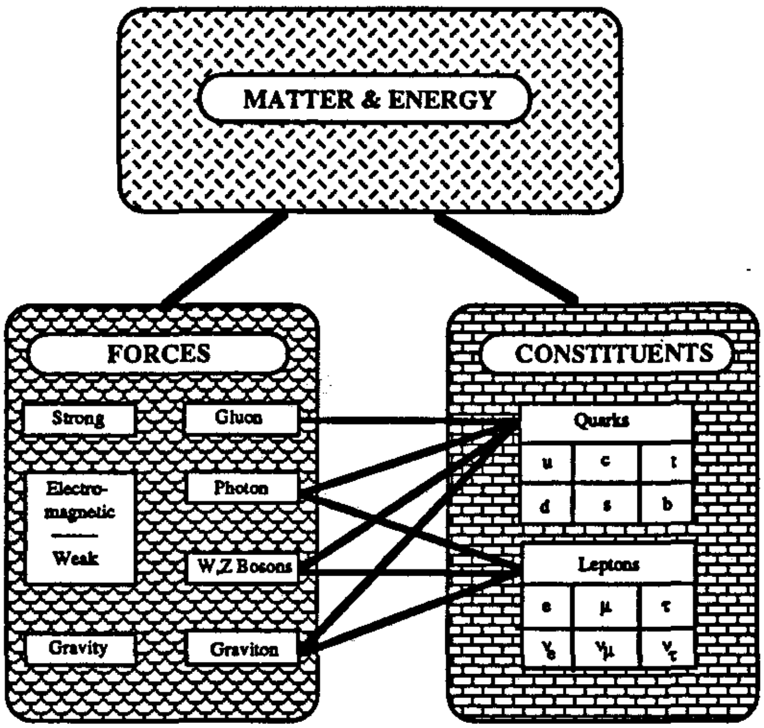

Figure 3.1. Nature derives enormous complexity from the six quarks and six leptons now thought to be the fundamental constituents of matter and from the four forces that govern their interactions. The small number of fundamental forces—gravitation, electromagnetism, the weak interaction responsible for certain radioactive decays, and the strong force that binds atomic nuclei—are shown along with the particles that "carry" each force. As depicted by the solid lines connecting the quarks and leptons to the carriers of each force, the strong force that binds quarks together does not affect leptons at all. Both quarks and leptons are acted on by the three other fundamental forces.

made up of electrons and a nucleus. The existence of five kinds of quarks has been established, and experimental evidence for a sixth species is actively being sought. Unlike the proton and neutron, the electron does appear to be an elementary constituent of matter, both structureless and indivisible. However, we now know that there are six kinds of electron-like particles called leptons. Both quarks and leptons appear to be grouped in three families of two members each. According to our present understanding, all matter is composed of quarks and leptons.

Nature derives enormous complexity of structure and dynamics from the six quarks and six leptons now thought to be the fundamental constituents of matter and from the forces that govern their interactions. All known natural processes may be understood as manifestations of a very small number of fundamental forces. For half a century, physicists have recognized four basic forces: gravitation, electromagnetism, the weak interaction responsible for certain radioactive decays, and the strong force that binds atomic nuclei. An important difference between quarks and leptons is that one of these four interactions, the strong force that binds quarks together to form hadrons, does not affect leptons at all. Both quarks and leptons are acted on by the three other fundamental forces.

Over the past 25 years, great progress has been made in understanding the nature of the strong, weak, and electromagnetic forces. The description of weak and electromagnetic forces has been unified by a theory whose predictions have been verified by many inventive experiments, culminating in the Nobel Prize-winning discovery of the W and Z particles in 1983. These carriers of the weak force are analogs of the photon, the carrier of the electromagnetic interaction, whose existence was postulated early in this century and established experimentally in the 1920s. In addition, there is indirect but persuasive evidence for particles called gluons, the carriers of the strong force. The strong, weak, and electromagnetic interactions are all described by similar mathematical theories called gauge theories.

The quark model of hadrons and the gauge theories of the strong, weak, and electromagnetic interactions organize our present knowledge and provide a setting for going beyond what is now known. For example, we do not know what determines such basic properties of quarks and leptons as their masses. Nor do we understand fully the origin of the differences between the infinite range of the electromagnetic force and the very short range of the weak interactions, which act only on subatomic scales. Existing methods for dealing with these questions involve the introduction of many unexplained numerical constants into the theory—a situation that many physicists find arbitrary and, thus, unsatisfying. Physicists are actively seeking more complete and fundamental answers to these questions.

Another set of questions goes beyond the existing synthesis. For example, how many kinds of quarks and leptons are there? How are the quarks and leptons related, if they are related? How can the strong force be unified with the electromagnetic and weak forces? Then there are questions related to our overview of elementary particle physics. Are the quarks and leptons really elementary? Are there yet other types of forces and elementary particles? Can gravitation be treated quantum-mechanically as are the other forces, and can it be unified with them? More generally, will quantum mechanics continue to apply as we probe smaller and smaller distances? Do we understand the basic nature of space and time?

Given this list of questions, it is not surprising that there are many directions of theoretical speculation departing from the current paradigm. Many of these speculations imply important phenomena at energies that are beyond our present reach. Although theoretical speculation and synthesis are valuable and necessary, particle physics cannot advance without new observations. In the recent past, crucial observations have come from a variety of sources, including experiments at accelerators and nuclear reactors, nonaccelerator experiments (cosmic-ray studies and the search for proton decay), and deductions from astrophysical measurements. *All our current ideas, embodied in the Standard Model, point to 1 TeV, an energy equivalent to approximately 1000 proton masses, as the mass scale on which new phenomena can be expected. A detailed examination of a great variety of conjectured extensions of the Standard Model shows that the SSC is the instrument of choice for exploring this new domain.*

With the identification of quarks and leptons as elementary particles and the emergence of gauge theories as descriptions of the fundamental interactions, physicists possess today a coherent point of view and a single language appropriate for the description of all physical phenomena. This development has made particle physics a much more unified subject, and it has also helped physicists to perceive common interests and to make common cause with other specialties, notably astrophysics and cosmology, condensed matter physics, atomic physics, intermediate energy nuclear physics, and mathematics. Among many examples, one important by-product of recent developments in elementary particle physics has been a recognition of the close connection between this field and the study of the early evolution of the universe from its beginning in a tremendously energetic primordial explosion called the Big Bang. Particle physics provides important insight into the processes and conditions that prevailed in the early universe. Deductions from the current state of the universe can, in turn, give us information about particle processes at energies that are too high to be produced in the laboratory--energies that existed only in the first instant after the primordial explosion. *The SSC will simulate and allow detailed study of the state of matter that existed in the initial 10^{-15} of a second following the Big Bang.*

The experimental measurements and discoveries that shaped the recent revolution in particle physics were made possible by exploiting new accelerator and detector technologies that permitted the exploration of new energy domains. Accelerator advances included the invention of colliding-beam accelerators (colliders) in which counter-rotating beams of high energy particles collide head on and the introduction of large-scale, energy-efficient, high-field superconducting accelerator magnets. Each sortie into a new energy regime, each improvement in our ability to search for rare processes, and each increase in sensitivity for their detection has led to new insights and, often, to the discovery of unexpected and revealing phenomena.

Experimental pursuit of the most important fundamental questions raised by the recent revolutionary developments in elementary particle physics and related fields requires energies higher than those provided by any accelerator now in operation or under construction anywhere in the world. The SSC is a unique scientific instrument to lead the quest for a deeper understanding of the natural world. This major new accelerator complex would be based on the accelerator principles and technology that have already been developed in connection with the construction of colliders at Fermilab (the Tevatron) and at DESY (HERA) and on extensive work on superconducting magnets in the U.S. and overseas during the past 20 years. The proposed SSC would have an energy about 20 times that of the Tevatron collider now in operation at Fermilab. The high energy of the SSC is needed to answer some of today's pressing questions in elementary particle physics. In addition, such a large increase in energy will open up new and uncharted territory. Historically, such openings led to revolutionary advances for entire fields of science.

Mankind is tantalizingly close to a profound new understanding of the fundamental constituents of nature and their interactions. The Standard Model, based on quarks and leptons, organizes current knowledge and defines the horizon of particle physics at constituent energies of about 1 TeV and the horizon of cosmology at times of about 10^{-15} second. The SSC would provide a direct gateway to and beyond the 1-TeV scale where important new discoveries await about the unification of the forces of nature, the patterns of the fundamental constituents of matter, and the origin of the universe.

3.2. Technical Basis

The central purpose of the SSC is to produce reactions among the elementary constituents of matter at the highest possible energies. To accomplish this, two proton beams, each with an energy of 20 TeV, will be guided in opposite directions around a racetrack path and brought into collision at four interaction points in such a way as to produce a luminosity of up to 10^{33} cm^{-2} s^{-1} at each collision point. At the interaction points (four to be operational initially, eight possible) detectors are placed to record and analyze the reaction products. The overall configuration of the facility is shown in Fig. 3.2.

The SSC is made up of a variety of technical components and conventional facilities. The system of superconducting collider magnets that bend and focus the proton beams, the refrigeration system needed to cool those magnets, the attendant injector system that boosts the proton beam energy in stages, the particle detectors that will yield the physics data, and the monitor and control systems form the principal technical components of the SSC. Of these, the collider magnet system is dominant in bulk and in cost. The principal conventional facilities associated with the SSC include the tunnels housing the main accelerator systems; the experimental halls housing the detectors; the laboratory, industrial, warehouse, and support buildings; and the utility services for the facility. Section 4 contains an overview of the conventional facilities.

The injector system consists of a H^- ion source and linear accelerator, followed by three booster synchrotrons. The linear accelerator brings the protons up to 600-MeV kinetic energy. The cascade of boosters then accelerates the protons successively to 11.1-GeV, 200-GeV, and 2-TeV energies. The final booster is a synchrotron with superconducting magnets; the others have conventional copper and iron magnets, which permit rapid cycling.

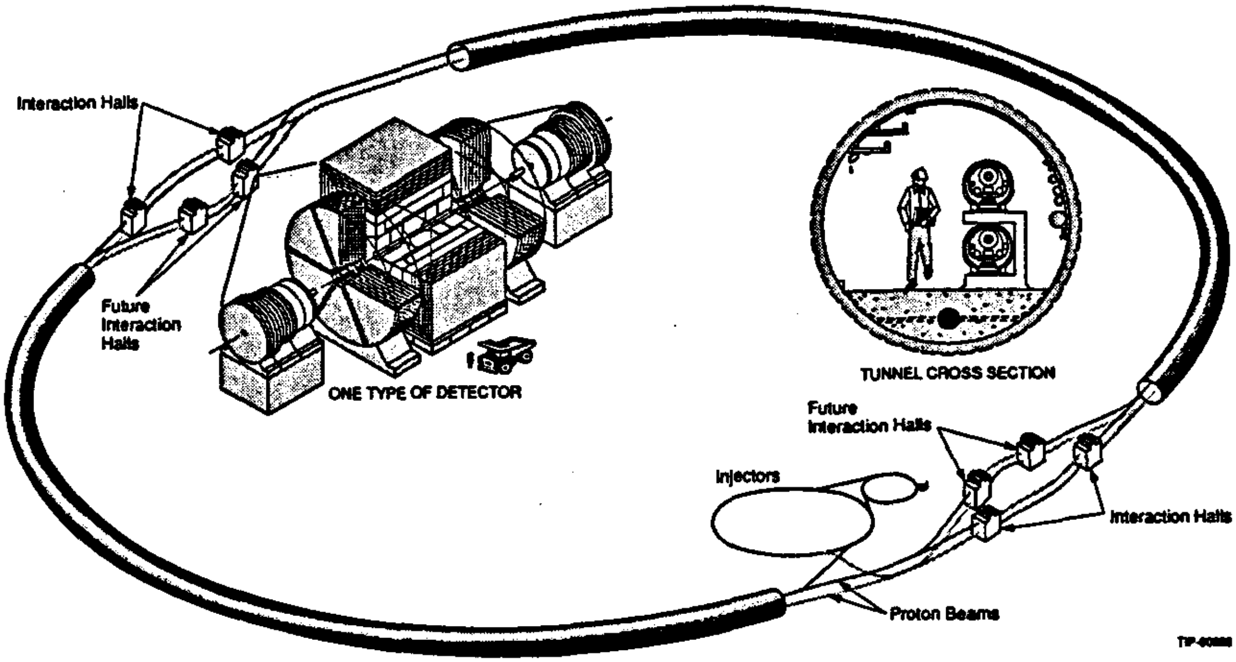

Figure 3.2. Schematic layout of the SSC showing the injector system, the collider rings, and initial (4) and future (up to 4 additional) experimental halls.

The largest synchrotron of the injector system is comparable in size, complexity, and number of components to the Fermilab Tevatron. The SSC main collider rings are much larger. Because of the choice of a higher magnetic field for the bending magnets (6.6 tesla compared with 4.4 tesla for the Tevatron), the circumference of the SSC is about 13 times that of the Tevatron, even though the energy is 22 times larger. The general nature of the technical components of the collider rings is the same in both machines. The dipole bending magnets, for example, are 6-m long in the Tevatron, with an inner coil diameter of 75 mm. Despite the factor of 2.5 greater length and 50 percent higher field, the stored energy per SSC dipole magnet is only a factor of two greater than for a Tevatron dipole magnet because of the smaller coil diameter of 50 mm. Similar comparisons can be made for other technical components. The Tevatron, with its successful proof of the technology of superconducting magnets in a modern accelerator, provides a benchmark for the extension to SSC energies.

The SSC collider ring is 87.12 km in circumference. In the curved parts, a large percentage of the orbit length is occupied by the dipole bending magnets. The inner body of the superconducting magnets is thermally isolated from its outer casing so that it can be maintained at its operating temperature of 4.35 K (-269 degrees Celsius) without undue refrigeration power being required. Design calculations and measurements of the SSC prototype magnets show that the electric power required to operate the refrigerators of the SSC will be about 38 MW, comparable to that being used to operate the largest existing accelerators, which is possible because of the much lower losses in each of the large number of SSC magnets.

As with the Tevatron magnets, the working fluid of the refrigeration system is liquid helium, which is the only substance that maintains its fluid properties at the needed operating temperature. Cold liquid is introduced from refrigerators into the arrays of magnets at ten locations around the ring, cooling the superconducting coils as it flows through. At the end of a magnet string, the helium is recooled in order to maintain a nearly uniform magnet temperature. At each refrigerator, the helium is restored to its initial condition. About 2.4 million liters of liquid helium are stored in the refrigeration system during operation. Although an impressive amount of liquid helium, this is still only about 1/30 of recent U.S. annual usage. Moreover, only a small fraction of the helium inventory is lost each year during operation.

In addition to the bending magnets, the continuous cryogenic envelope surrounding the beam vacuum chambers contains focusing (quadrupole) magnets and special orbit and focusing correctors along with various pressure, thermal, and electrical measurement and control devices. The cryogenic envelope contains valves and heat exchangers needed for the vacuum and refrigeration systems. Linking all these with the injectors and refrigeration equipment and permitting the monitoring and control of the entire system is a network of computers connected by a broadband communication network that forms the collider control system.

The SSC accelerator physics issues are considered in depth in the SCDR. While building on previous studies including the 1986 CDR, no qualitatively new accelerator physics issues were identified. However, during the past 2 years, studies on several critical parameters have been carried out in much more detail than before. For example, the important parameter of the magnet aperture has been studied in detail together with the lattice design in order to maximize the overall reliability and to minimize the overall risk. Also, the energy of the final booster has been increased from 1 to 2 TeV in order to reduce the technical risk associated with perturbing fields at low injection energy into the collider. Various arrangements of the interaction regions were also studied and a particular clustered arrangement selected for this site-specific conceptual design. These and other technical topics were addressed by the SSCL and reviewed by various ERC subcommittees, whose findings comprise Section 10 of this report.

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4. OVERVIEW OF DESIGN AND FEASIBILITY

4.1 Description of Facility

The SSCL has adopted, as overall guidance, the goal of constructing a reliable facility that can be rapidly commissioned and has the potential for future upgrading. The SSC is being designed as a 20 TeV on 20 TeV proton-proton collider with a luminosity of 10^{33} cm^{-2} s^{-1}. Provision for a future luminosity upgrade to 10^{34} cm^{-2} s^{-1} is included in the design. Each proton beam is guided around the desired orbit through an evacuated tube by superconducting dipole electromagnets while being focused by superconducting quadrupole magnets. Two rings of magnets are located one above the other in an underground tunnel. With the maximum design magnetic field in the dipole magnets of 6.6 tesla, the storage rings have a circumference of approximately 87 km (54 miles). Eight interaction points (four initially developed) where the beams intersect are clustered in two regions, one on the west side of the rings and one on the east side. Each cluster contains one utility straight section for major supporting equipment and one diamond-shaped bypass for the interaction regions (IRs). The detectors to be installed in the IRs depend on the specific proposals made by candidate experimental collaborations. For planning purposes, a model has been adopted, consisting of two large general-purpose detectors and two medium-sized more specialized detectors. The injector system consists of an H^- source and a 600-MeV linear accelerator, followed by three booster synchrotrons of energies 11.1 GeV, 200 GeV, and 2 TeV. A plan view of the facility is shown schematically in Fig. 4.1.

4.1.1 Technical Facilities

The principal technical components of the SSC are the injector system, the collider (with its associated superconducting magnet and cryogenic systems), and the experimental facilities.

A cascade of accelerators forms the injector complex (Fig. 4.2) needed to produce the high quality beam with rms normalized horizontal and vertical emittances of 1 π mm-mrad. Each accelerator is operated to minimize dilution of transverse phase space from the source to the collider rings of the SSC. The first member of the injection chain is the 600-MeV linac, which consists of an H^- source, a radio-frequency quadrupole (RFQ) accelerator, a drift-tube linac, and a coupled-cell linac (CCL). The injection linac provides a beam of 600-MeV H^- ions through a transfer line to the low energy booster (LEB). The LEB is a separated-function, room-temperature synchrotron with a circumference of 540 m. The LEB takes the H^- beam from the linac transfer line, foil strips the ions of electrons to form protons, and accelerates the protons to a kinetic energy of 11.1 GeV at a repetition rate of 10 Hz. Operation will be below the transition energy (12.7 GeV, $\gamma_t = 14.5$) throughout the acceleration cycle in order to avoid potential problems associated with a transition crossing. The medium energy booster (MEB) is also a conventional synchrotron, with a circumference of 3960 m, and has a cycle time of 4.5 sec. The MEB

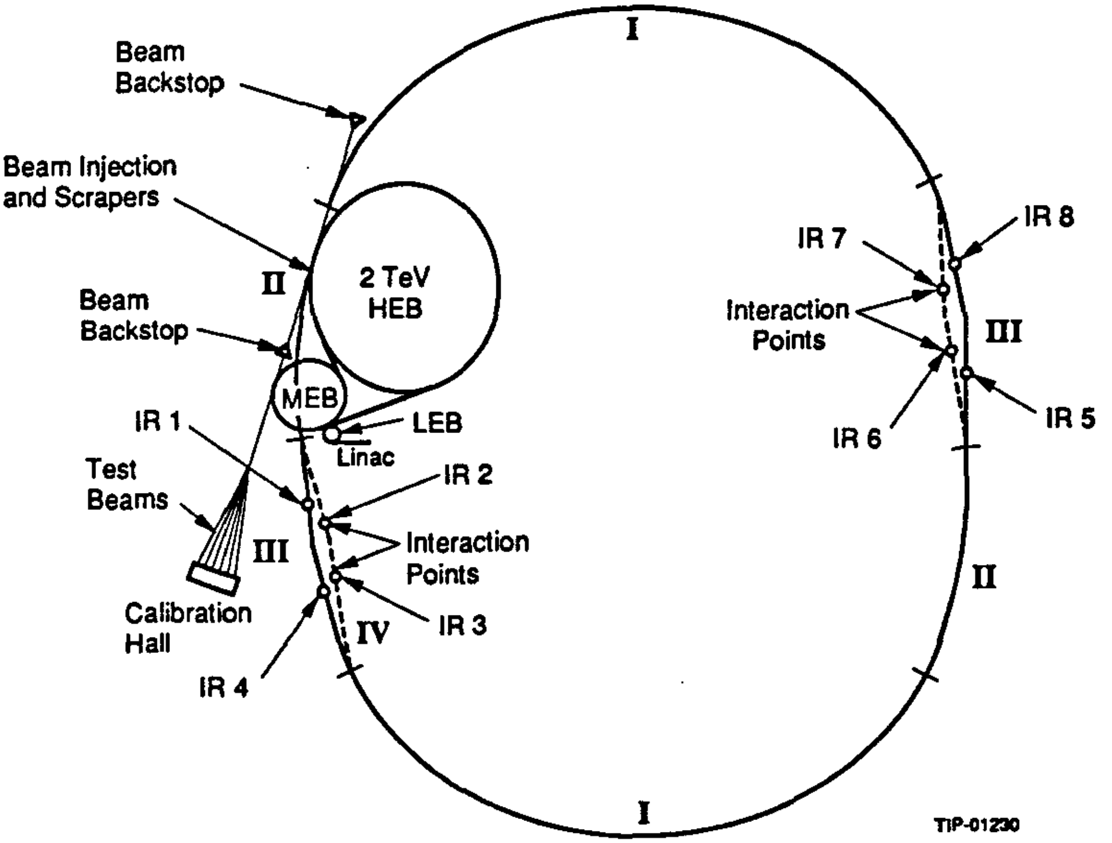

Figure 4.1. Overall arrangement of SSC collider system showing the injector system [linac, low-energy booster (LEB), medium-energy booster (MEB), and high-energy booster (HEB)], along with the collider, interaction points, and test-beam area.

accelerates the beam from 11.1 GeV to 200 GeV for injection into the high energy booster (HEB), requiring the beam to cross the transition energy (14.0 GeV, $\gamma_t = 15.9$). The HEB is a superconducting accelerator similar in scope to the Fermilab Tevatron. Protons are accelerated to 2 TeV in the HEB for injection into the main collider rings. The HEB ring has a circumference of 10.89 km and a cycle time of 4.5 minutes. The superconducting magnets are similar in design to the collider magnets with a bore of 50 mm and a peak dipole field of 6.5 tesla.

Each collider ring is filled with 8 beam batches from the HEB at 2 TeV. Batches are loaded alternately in one collider ring, then the other. To accomplish this, the polarity of the HEB is reversed between batches. The total filling process will require more than 70 minutes. During injection and the 1500-sec acceleration ramp from 2 TeV to 20 TeV in the

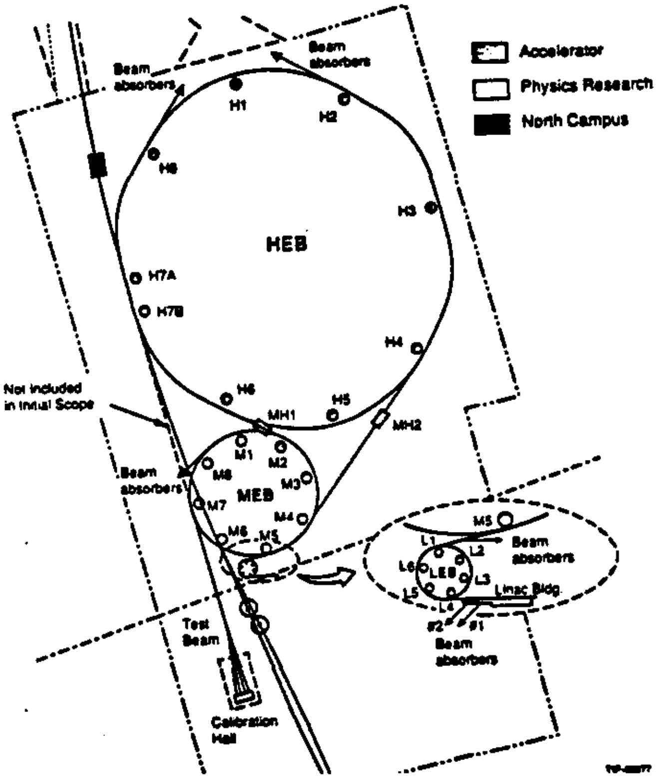

Figure 4.2. Detailed layout of SSC injector system. Having been accelerated to 200 GeV by the linac, LEB, and MEB, alternate batches of protons are accelerated in opposite directions in the HEB to the collider injection energy of 2 TeV. Batches in the clockwise direction enter the lower collider ring, whereas counterclockwise batches enter the upper ring.

collider rings, beam-beam collisions are avoided by separating the beams near the crossing regions. The magnets are ramped linearly in time, requiring an energy gain of 3.5 MeV per turn. To stabilize transverse and longitudinal emittance growth from intrabeam scattering, the longitudinal emittance is increased by controlled injection of rf noise into the 360-MHz, 20-MV peak-voltage acceleration system. The total time necessary to fill the collider, accelerate to 20 TeV, and bring the proton beams into collision may add up to about 2 hours, a fraction of the expected useful-luminosity duration of more than one day.

The SSC collider lattice incorporates three types of modules: arcs, bypasses, and utilities. There are two arc modules, one in the north and one in the south regions of the ring. Each arc consists of 196 cells that are 180 m long with a 90-degree betatron phase advance per cell. Five bending magnets are placed between focusing and defocusing quadrupoles, and the corresponding magnets of the two rings are placed exactly above and below each other, so that the proton beams are separated by 800 mm. The bypass and the utility modules are each 4140 m long and are arranged in two clusters joining the arc modules as shown in Fig. 4.1. Each leg of the diamond-shaped bypasses can accommodate two IRs. Two high-luminosity ($\beta^* = 0.5$ m) and two intermediate-luminosity ($\beta^* = 10$ m) IRs are initially provided in the outer legs of the diamonds, with expansion possible to a full complement of eight IRs. The beams cross at a small angle, typically 75 μrad, which is variable between 0 and 150 μrad. The two utility modules have adequate space for injection and abort systems and the eight rf cavities. In the future, the east utility region can also be converted to an IR with a horizontal beam crossing.

Among the collider systems, the superconducting magnet system is dominant in both bulk and cost, with more than 8600 dipoles, 1700 quadrupoles, and 1900 spool pieces, which contain correction windings and other instrumentation. The arc magnets have a one-in-one (one beam tube and coil assembly in one thermally insulating cryostat), collared-coil, cold-iron design. Some special magnets for the IRs, where the two beams are close together, have common cryostats for the two proton beam lines or are fully two-in-one with a shared iron yoke.

A cross section of the SSC dipole magnet assembly is shown in Fig. 4.3. At its center is the evacuated beam tube of 32.3-mm inner diameter. This tube has a high-conductivity inner liner to minimize beam-wall interaction. There is a two-layer main coil of superconducting NbTi cable with interspersed copper wedges that adjust the current density for a uniform magnetic dipole field across the beam tube aperture. This coil is held in place by laminated stainless steel collar halves that are keyed together after compression. The inner coil diameter is 50 mm. A yoke of laminated low-carbon steel surrounded by a stainless steel skin completes the inner assembly. The dipole magnet is rated at 6.6 tesla and comes in two effective lengths of 15.2 and 12.7-m. In the CDR, the dipole magnets came in a single 17-m length with an aperture of 40 mm. The aperture was increased to 50 mm to improve the field quality and to make collider operation more reliable. Quadrupole magnets are similarly constructed with a 40-mm aperture and require a gradient of 206 tesla/m. Spool pieces in the arcs are about 5 m long and have separate windings that provide dipole, quadrupole, and higher order corrections.

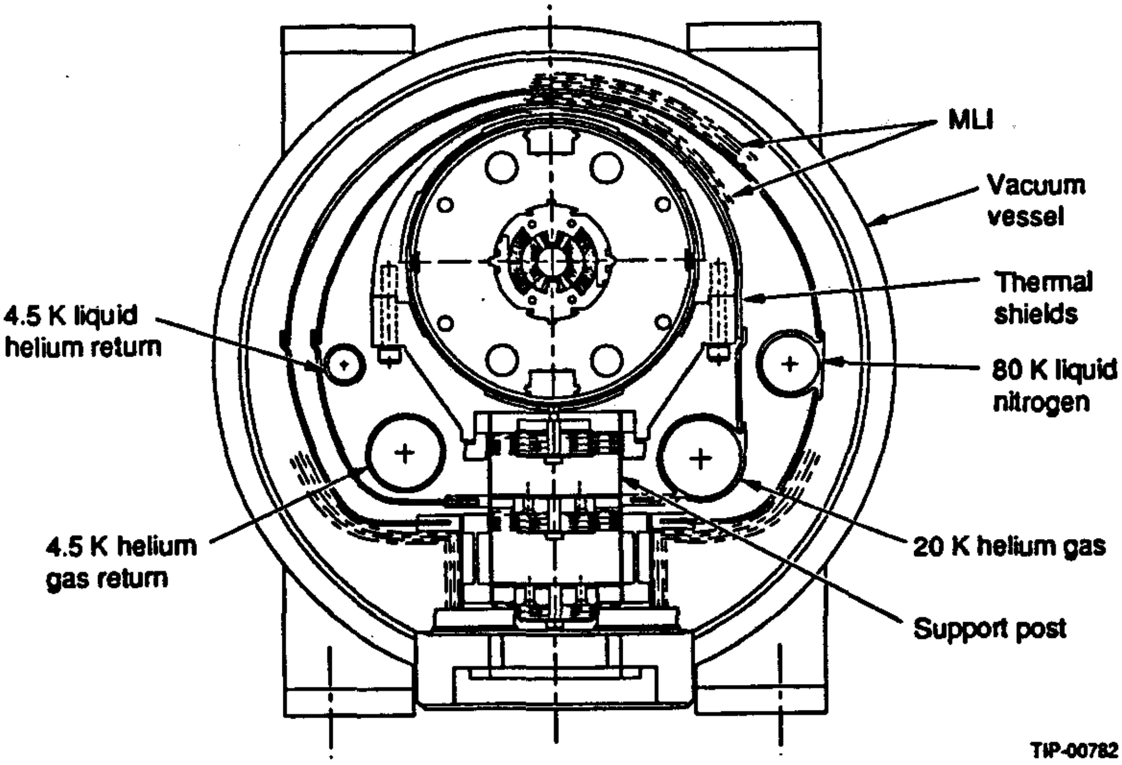

Figure 4.3. Cross section of a collider superconducting dipole magnet in its cryostat. The major components are the superconducting coils made of NbTi in a copper matrix, the collar that holds the coils rigidly in place under the large magnetic forces, and the cold-iron yoke. This "cold mass" is mounted in a cryostat and cooled by liquid helium to 4.35 K.

An extensive cryogenic system is required to maintain the magnets at the design temperature of 4.35 K or less. For cryogenics the machine is divided into ten sectors, four in each arc and one in each cluster. Two additional refrigerators cool the HEB. Each refrigerator has about the same cryogenic load (5.2 kW at 4.15 K). The total electrical power requirement for the 12 refrigeration plants is 45.6 MW (installed capacity is 125 percent of anticipated load at the design luminosity). The refrigerators supply 290 g s^{-1} of helium at 4.15 K and at 4 atmospheres pressure. The cryogenic system of each sector is independent, but each is connected to the next through the magnets to assist one another in cooldown or to take over for a malfunctioning refrigerator.

4.1.2 Parameters List

The design goal of a 20-TeV pp collider storage ring that can achieve a high peak luminosity with a small number of interactions per bunch-bunch crossing, which is required for the experiments now foreseen, sets limits on the various accelerator parameters. In addition, the underlying accelerator physics restricts the range of performance for a storage ring. Table 4.1 is a summary of selected accelerator (injector and collider) parameters obtained by the SSCL from an optimization over these constraints and those specific to the site. Flexibility in choice of crossing angle, bunch spacing, and other parameters is maintained for adjustments during operation. The value of the normalized emittance is based on extrapolation of experience at CERN and Fermilab, and the minimum value of β^* is set by the maximum practical quadrupole gradient and aperture. The bunch spacing of 5 m results from a compromise between optimizing the event rate per bunch crossing, synchrotron radiation power emitted, and reducing the bandwidth required for the bunch-by-bunch feedback system. The head-on beam-beam tune shift per crossing at full energy and normal operating scenarios ($<10^{-3}$) is well below values tolerated at the CERN Super Proton-Antiproton Synchrotron (Sp$\bar{p}$S) collider and the Fermilab Tevatron.

Table 4.1

SSC Accelerator Parameters

	Collider	HEB	MEB	LEB	Linac
Kinetic energy	20 TeV	2 TeV	200 GeV	11.1 GeV	0.6 GeV
Momentum	20 TeV/c	2 TeV/c	200 GeV/c	12 GeV/c	1.2 GeV/c
Mono/bipolar	(2 rings)	bipolar	monopolar	monopolar	mono-directional
Superconducting/normal	SC	SC	normal	normal	normal
Peak dipole field (T)	6.55	6.47	1.7	1.23	-
Circumference (km)	87.12	10.89	3.96	0.54	-
Bunch spacing (m)	5	5	5	5	-
Harmonic number	17,424×6 $(2^4 3^2 11^2)6$	2178 $(2\ 3^2\ 11^2)$	792 $(2^3\ 3^2\ 11)$	108 $(2^3\ 3^3)$	
Emittance for collider operation (π mm-mrad, rms, normalized)	1.0	0.8	0.7	0.6	<0.5
N for collider operation	0.75×10^{10}	1×10^{10}	1×10^{10}	1×10^{10}	-
N_{tot} for collider operation	1.3×10^{14}	2×10^{13}	7×10^{12}	1×10^{12}	-
Cycle time for collider operation		4.5 min	4.5 s	0.1 s	
Emittance for test beam operation (π mm-mrad, rms, normalized)	-	4	4	4	-
N for test beam operation	-	5×10^{10}	5×10^{10}	5×10^{10}	-
N_{tot} for test beam operation	-	10^{14}	3.5×10^{13}	5×10^{12}	-
Cycle time for test beam operation	-	5.5 min.	5.5 s	0.1 s	
Half-cell length (m)	90	38.9	19.8	5.0	-
Cell phase advance (deg)	90	90	60	112	-
Tune (horiz)	123	34.4	16.6	16.8	-
Chromaticity (inj)	-173	-48	-18	-25	-
Gamma T	105	29.2	15.9	14.5	-
Effective lengths of dipoles (m)	15.2/12.7	15.2	7.6	2.4	-
Effective lengths of quads (m)	5.2	1.2	2.0	0.85	-
Number of dipoles (15.2m/12.7m)	7956/504	432	328	84	-
Number of quads (standard/other)	1664/360	278	200	108	-
Field gradient quads (T/m)	206	206	17.4	16.5	-
ß max (m)	1.82	3.0	3.8	1.0	-
Energy gain/turn (MeV)	3.5	0.8	1.5	0.6	-
RF voltage, max (MV)	20	1.6	2.3	0.7	-
RF frequency (MHz)	360	60	59.9	47.5-59.8	-
95% bunch area (ext) (eV-sec)	4.4	0.66	0.076	0.038	-

4.1.3 Summary of Major Changes from 1986 CDR

While the design objectives remain as they were in the 1986 CDR, certain of the system parameters have been altered to meet those goals. These do not represent conceptual innovations but rather are evolutionary refinements based on improved understanding and appreciation of problems inherent in a system of such complexity and magnitude. Continuing studies of beam dynamics and experience with current accelerator systems have produced more thorough knowledge of the behavior to be expected in the SSC. These have led to modification of some design parameters as discussed below:

1. Injection Energy

The extent of the good-field region within the magnet aperture required to accommodate particle motion in the collider is largest during injection into the collider ring from the previous element in the accelerator cascade, the HEB. Operating reliability is optimized if the energy of the injected beam and the field in the bending magnets are maximized. To that end, the design injection energy has been increased to 2 TeV from the 1 TeV of the CDR. At this energy, particle orbits are much less sensitive to effects of magnetic-field imperfections. Most troublesome are the time variations of dipole-field distortions due to persistent currents in the superconductor as revealed by recent data.

2. Focusing

Focusing magnet elements have been strengthened to reduce the effective local betatron-oscillation amplitude (betatron function), as well as the off-energy beam excursions (dispersion function). Again, the object is to reduce the aperture required to accommodate the particle orbits and, in so doing, reduce the effects of magnetic-field imperfections. This design improvement brings a reduction in the half-cell length from 114 to 90 m, which has a small effect on the gross shape of the machine and causes a small increase in its circumference.

3. Magnet Components

According to the CDR, as a result of studies of alternative designs of superconducting bending (dipole) magnets and R&D efforts over the years, "a high-field, one-in-one (one beam tube and coil assembly in one thermally insulating cryostat) was preferred as the basis for the SSC conceptual design and for further development into the actual SSC magnet." This recommendation followed model-magnet test results showing that "the magnet performance can be predicted reliably, that model SSC magnets achieve the necessary peak field strengths and have adequate field quality for accelerator operation, that the magnet fabrication techniques assure reproducibility from magnet to magnet, and that these techniques are ready to be transferred to industry." Since then a baseline design has been adopted. The fundamental design parameters remain: an operating field of 6.6 tesla at a temperature of 4.35 K with 6.5 kA current. A vigorous R&D program continues at BNL, Fermilab, and LBL to refine the basic concept, demonstrate performance characteristics, and improve technical understanding of the variables that affect and control the performance. Particular attention has been given to mechanical and structural features. In the progression to a mature design, to be ready for production in 1992, a newly imposed field margin of 10 percent and a larger (50-mm) aperture are specified to ensure reliable operation at 20 TeV.

4. Interaction Regions

As many as eight detector stations may eventually be available for experiments at the SSC. The detectors in use at colliders continue to grow in complexity and technical sophistication, as well as in sheer bulk. Intensive studies of detector requirements have produced design concepts that, while still evolving, have advanced to a stage where the scope of their assembly and operating hall needs can now be specified much more reliably than when the CDR was issued. Furthermore, the geological and topographical constraints of the site are known, which leads to a better specification of the halls and experimental support facilities than was possible before. Two of the model detectors require halls that are significantly larger than the previous rough estimates: one has grown in volume by roughly a factor of two, the other by a factor of five. Those two large, multipurpose, full-solid-angle detectors will be assembled in place on the beamline.

5. Proton Beam Bypass

To obviate the need for separate detector assembly halls, alternate beam routes (bypasses) have now been planned for two IR clusters. Earlier, it had been planned to assemble the detectors underground behind shielded doors and move them into place, a ponderous process given their weight (up to 60,000 tons). Detectors will be constructed in place on the beam line in the operating halls. In time, this arrangement will allow continued delivery of beam to functioning experiments while another is being repaired or modified while still in position on another leg of a bypass. Decoupling detector construction, repair, and maintenance from collider operation improves the overall operating efficiency both of the collider and its detectors. The bypasses have caused a small increase in the circumference of the collider rings. It is now planned to construct the bypass tunnels as a future expansion of the initial SSC scope.

6. Test and Calibration Beams

Arguments are so compelling for test and calibration beams and associated support facilities that they hardly need repeating here. Detectors at SSC will almost certainly exploit new technologies that are not well established. Indeed, in some cases, operating conditions at SSC preclude direct extensions of current techniques. Perceived needs, as well as the use of test beams at current hadron colliders, have reinforced the tentative conclusion that beams of extracted protons should be provided by the HEB and MEB. Plans have been developed for slow extraction of the circulating proton beams, which can then be split and directed to different targets. The positioning and layouts of the beams have been changed in the interest of convenience and economy. Requirements for the secondary beams have been made more demanding than before. Studies of calorimetry—especially by the UA2 group at CERN and the CDF group at Fermilab—have shown that the response of such devices to particles in the multi-GeV energy range depends sensitively on the response at energies as low as 1 GeV. Calibrations must be made with both incident hadrons and electrons. Provision has been made for intense beams of particles in the energy range from 1 GeV to the maximum available from the HEB. Initially, the test-beam particles will be produced by 200-GeV protons from the MEB.

7. Detection Apparatus

The CDR contained only minimal discussion of detectors and the associated accommodations and support facilities. Although it is still premature to make firm, detailed plans for experimentation at the SSC, experience has been accumulated and ideas have evolved so that major detector components can now be identified. In addition, the SSCL has received an initial set of Expressions of Interest (EOIs) from experimental collaborations; these EOIs contain outlines of proposed detectors and experimental programs. In part based on accumulating experience and in part on these EOIs, a plausible scenario for the initial complement of detectors has been identified in the SCDR.

Experience with the large detectors—especially UA1, UA2, and CDF—has aided in the identification of particularly useful detector capabilities. Results of studies aimed at developing conceptual designs are documented in reports of proceedings of a series of workshops and conferences at which the characteristics of detectors needed for a full, varied experimental program at the SSC were outlined. Attention has focused on processes—for example the production and decay of Higgs particles and heavy vector bosons—that are particularly important for the discovery and study of the new phenomena expected to occur at the TeV-energy scale. To some extent, SSC detector components are fairly straightforward extensions of current apparatus scaled in size to allow measurement of much higher energy particles. The scale and scope of the apparatus are dominated, however, by the need to detect individual leptons (muons and electrons) and jets of particles that carry at least one-fourth of the few-TeV energy in very dense events. Furthermore, careful study has been made of the substantial radiation doses that the apparatus must tolerate, which are expected to be much larger at SSC than those at currently operating colliders.

By far the largest, most complex, and, therefore, most expensive detectors are those intended to explore the highest energy scale at the highest available luminosity.

Although quite varied technological approaches to achieve those goals continue to be pursued, the resulting conceptual designs are of comparable scope with similar components. All feature segmented sampling calorimetry over the full solid angle by means of roughly a 30-m thickness of alternating active and passive layers to determine electron and hadron-jet energy. Those layers are arrayed about an inner region, approximately 4 m in diameter and 8 m long, that is fitted with track-sampling devices within a magnetic field of about 2 tesla and yields values of particle momenta and interaction position. The tracking volume must be adequate to record sufficiently long track lengths for momentum determination within a solid angle chosen to yield acceptable detection rates for the processes of interest. Surrounding the calorimetry apparatus is about 3 m of iron, in some designs magnetized, instrumented with interleaved track samplers in which hadrons are stopped, allowing the transmitted particles to be identified as muons. A few specific design realizations currently under study are discussed in a companion document to the SCDR. For estimating requirements for space and utilities, two large detectors similar to those contained in the EOIs have been used as models for two of the IRs in the SCDR. Two other IRs would be occupied by more specialized, medium-sized detectors in the SCDR preliminary scenario.

In addition, the SSC puts more severe demands on detection apparatus than previous particle accelerators. The extremely high interaction rate, together with higher multiplicities, requires correspondingly faster readout and trigger electronics in addition to background-radiation-tolerant components. Dense events will require finer-grained calorimetry and higher resolution tracking devices. To handle the massive amount of data generated, both on-line and off-line, fast, versatile computers and better computation methods are needed. To these ends, the SSC has supported R&D programs at a number of institutions.

In summary, Table 4.2 lists some of the major parameter changes between the SCDR and the CDR for the collider and for the injector accelerator system (HEB, MEB, LEB, and linac).

Table 4.2

Accelerator Parameters in 1986 CDR and 1990 SCDR

	CDR	SCDR
COLLIDER		
Circumference (km)	82.9	87.12
Utility straight	2 on west	1 east - 1 west
Bypass	no	2-upgrade potential
IRs	4 + 2 potential	4 + 4 potential
Collision hall size		increased
Half cell length	96 m	90 m
Cell phase advance	60 deg	90 deg
Injection energy	1 TeV	2 TeV
Aperture (dipole)	40 mm	50 mm
Fill time (both rings)	40 min	70 min
HEB		
pc (GeV)	1000	2000
Circumference (m)	6000	10890
Aperture	50 mm	50 mm
Polarity	bipolar	bipolar
SC/normal	SC	SC
Cycle time	1 min	4.5 min
MEB		
pc (GeV)	100	200
Circumference (m)	1900	3960
Transition crossing	no	yes
Cycle time	4 s	4.5 s
Test Beams		
Test Beam	one (1 km), minimal	three (3.7 km)
Energy	1 TeV	200 GeV (2 TeV upgrade potential)
LEB		
pc (GeV)	8	12
Circumference (m)	250	540
Transition crossing	no	no
Cycle time	0.1 s	0.1 s
Linac		
pc (GeV)	1.22	1.22
Length (m)	125	148
Upgrade potential	no	yes

4.1.4 Conventional Facilities

The conventional facilities consist of all tunnels, enclosures, buildings, and related structures required to accommodate the SSC technical systems, experimental facilities, and auxiliary support functions. Infrastructure items, such as power, utilities, and site preparations, are included.

The SSC site is about an hour's drive south of Dallas-Fort Worth in a gently rolling landscape (see Fig. 2.1). The site has geological characteristics that are well suited to tunnel boring. The state's proposal for the Ellis County site suggested an orientation of the collider ring that was based on the description of the SSC in the Invitation for Site Proposals. The final position of the collider ring was determined after taking into account a detailed, revised design of the collider lattice, the location of the injector complex and experimental halls, and the underground geology and important surface features. The SSC footprint—a detailed description of the orientation of the injector, collider rings, experimental areas, and surface buildings—is summarized in Fig. 4.4. The land shown within the dotted lines will be acquired by the state of Texas under stratified fee; that is, the right to bore and instrument the collider tunnel will be obtained but surface rights will not. The land shown in the region enclosed by solid lines will be acquired under fee simple, which includes both surface and underground rights.

The relation of the collider tunnel to the geology and topography of the site is shown in Fig. 4.5. The collider tunnel is the largest conventional construction item. The collider tunnel will lie a minimum of 50 ft beneath the surface and is tilted 0.17 degrees to reflect the profile of the land. It will be excavated primarily by tunnel-boring machines. The finished internal diameter of the tunnel will be about 12 ft; the width at floor level will be about 10 ft. At many locations around the ring there will be alcoves and niches for cryogenic and electrical apparatus. Fig. 4.6 shows a cross section of the collider tunnel.

The collider ring consists of four main elements: the north arc, the south arc, the west complex, and the east complex. The arcs are subdivided into 5.4-mile-long sectors. Every sector will have a service area (E) at its center and an auxiliary service area (F) at its end, each covering about 50 acres. An E service area will support cryogenics in the tunnel, magnet power supplies, electrical power and control systems, personnel and equipment access, and various other utilities. A 55-foot-diameter shaft and a 30-foot-diameter shaft will be dug at alternate E areas. The E areas will also be used during the construction phase of the collider tunnel, and magnets will be delivered to these sites prior to installation in the tunnel. The F areas will provide support for tunnel ventilation, electrical power and control, and tunnel drainage. A 15-foot-diameter shaft will be located at each F area. Table 4.3 lists the major conventional construction parameters of the underground accelerator enclosures.

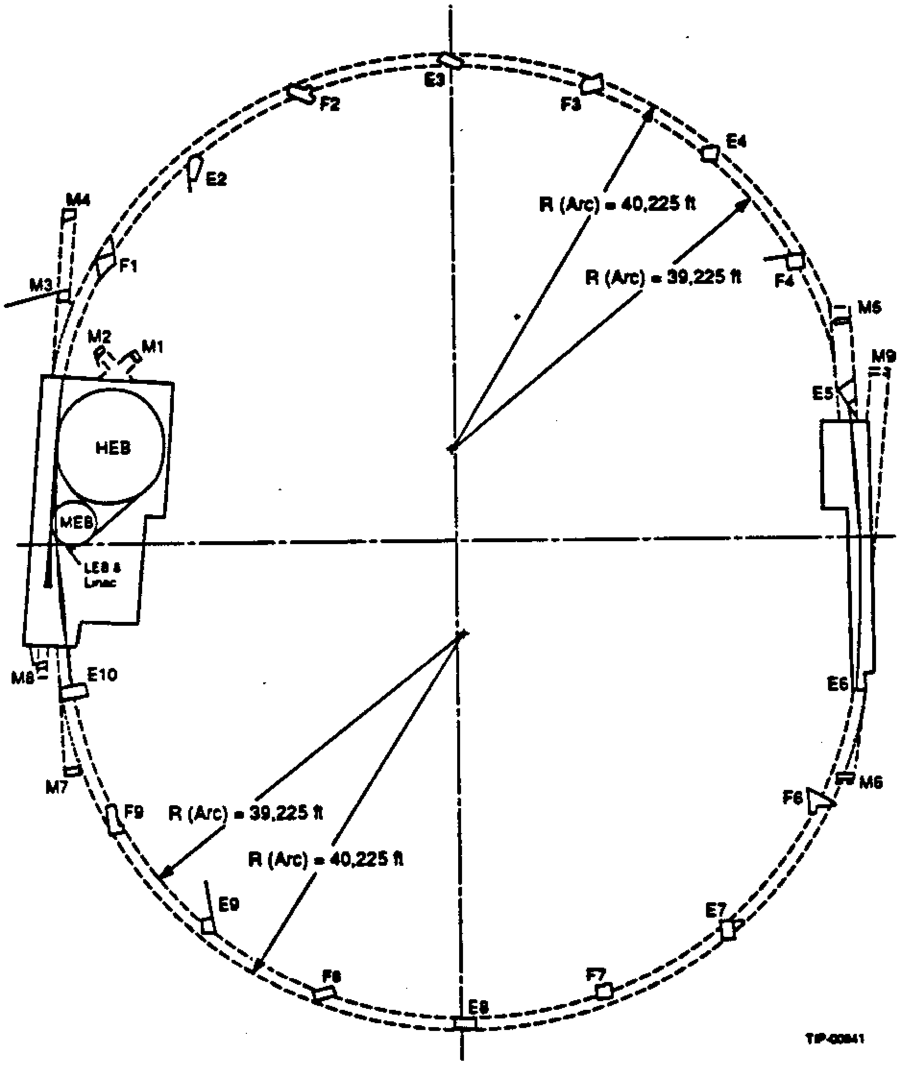

Figure 4.4. The SSC footprint. The land shown within the dotted lines will be acquired by the state of Texas under stratified fee; that is, the right to bore and instrument the collider tunnel will be obtained but surface rights will not. The land shown in the region enclosed by solid lines will be acquired under fee simple, comprising both surface and underground rights.

Table 4.3

Accelerator Underground Enclosures

Accelerator	Cross Section (ft)	Circumference (ft)	Construction Method (ft)
Linac	12 × 12	800	Cut and Cover-25 beam
LEB	12 × 12	1800	Cut and Cover-25 beam
MEB	10 Diameter	13,000	Tunnel
HEB	12 Diameter	35,700	Tunnel
Collider	12 Diameter	285,800	Tunnel (50 - 240 deep)

An underground test-beam facility providing for 200 GeV beams from the MEB includes 8800 ft of tunnel, underground magnet enclosures, connecting beam pipes, three underground target stations, surface-level utility buildings, and a test/calibration hall of approximately 30,000 sq ft.

The accelerator complex includes many surface buildings and access structures for personnel, technical components, and connection of utilities and services. Connecting to the below-ground systems housed in the tunnel is an array of electrical cables and mechanical pipes. At the surface and distributed around the ring are ten refrigerator facilities with large helium compressors. In the associated control room are the power supplies that provide the current to energize the superconducting magnets, as well as one of the nodes of the accelerator control system. There will be several transformers and heat exchangers in the area to provide the services required by the technical systems. At two locations around the large ring are major electrical substations connecting the accelerator complex to the power grid. Here power from overhead transmission lines is transformed to a lower voltage appropriate for the magnet power supplies and for distribution to substation locations in the accelerator complex. Other utilities, such as water and sources of fuel, will be provided as needed at the cluster areas and at the service areas around the ring. Table 4.4 lists the above-ground buildings associated with accelerators.

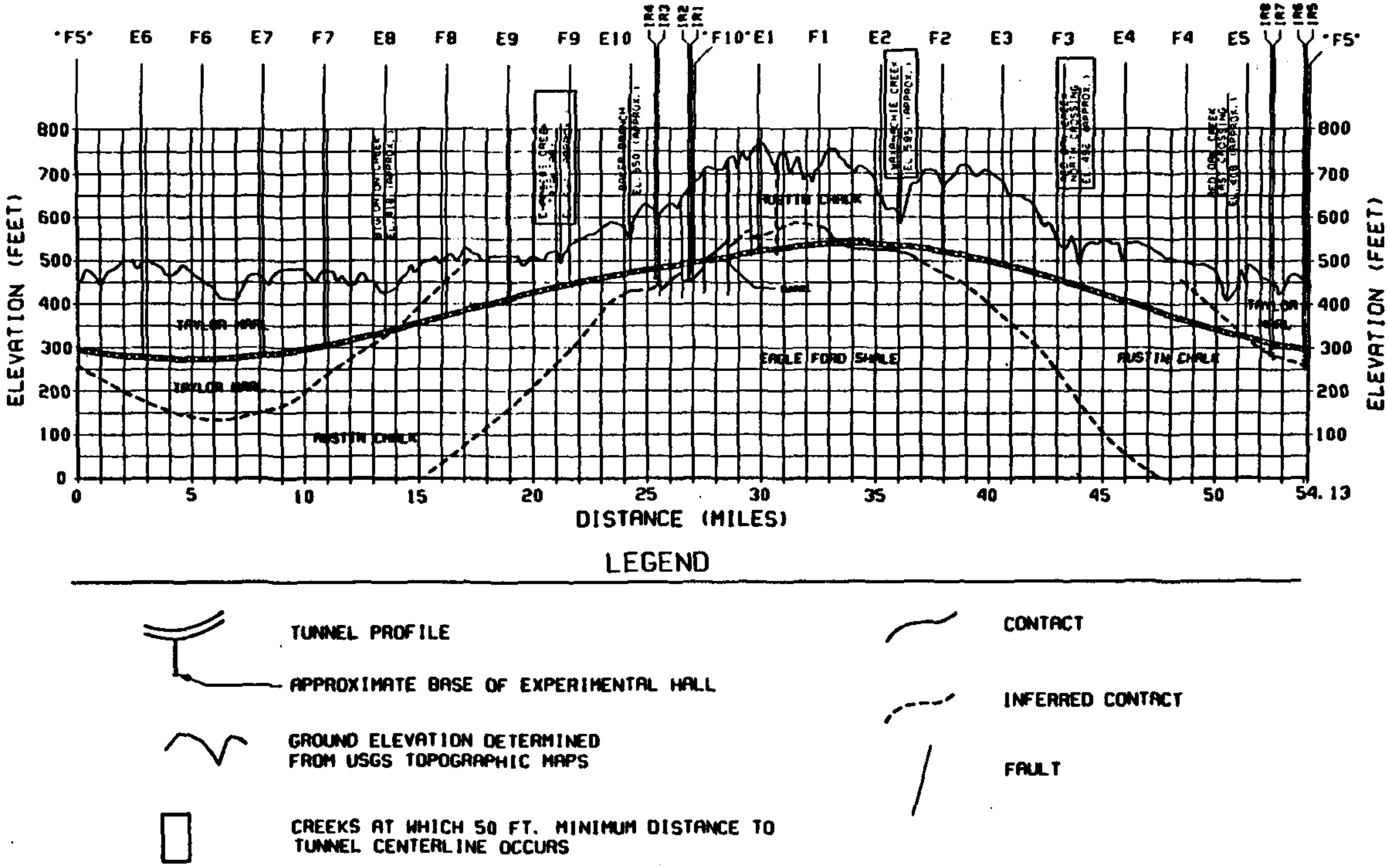

Figure 4.5. Schematic relationship of the collider tunnel to the geology and topography of the SSC site in Ellis County, Texas. The "E" and "F" notations indicate the location of the service areas shown in Fig. 4.4. "IR" refers to the interaction regions where detectors will be constructed.

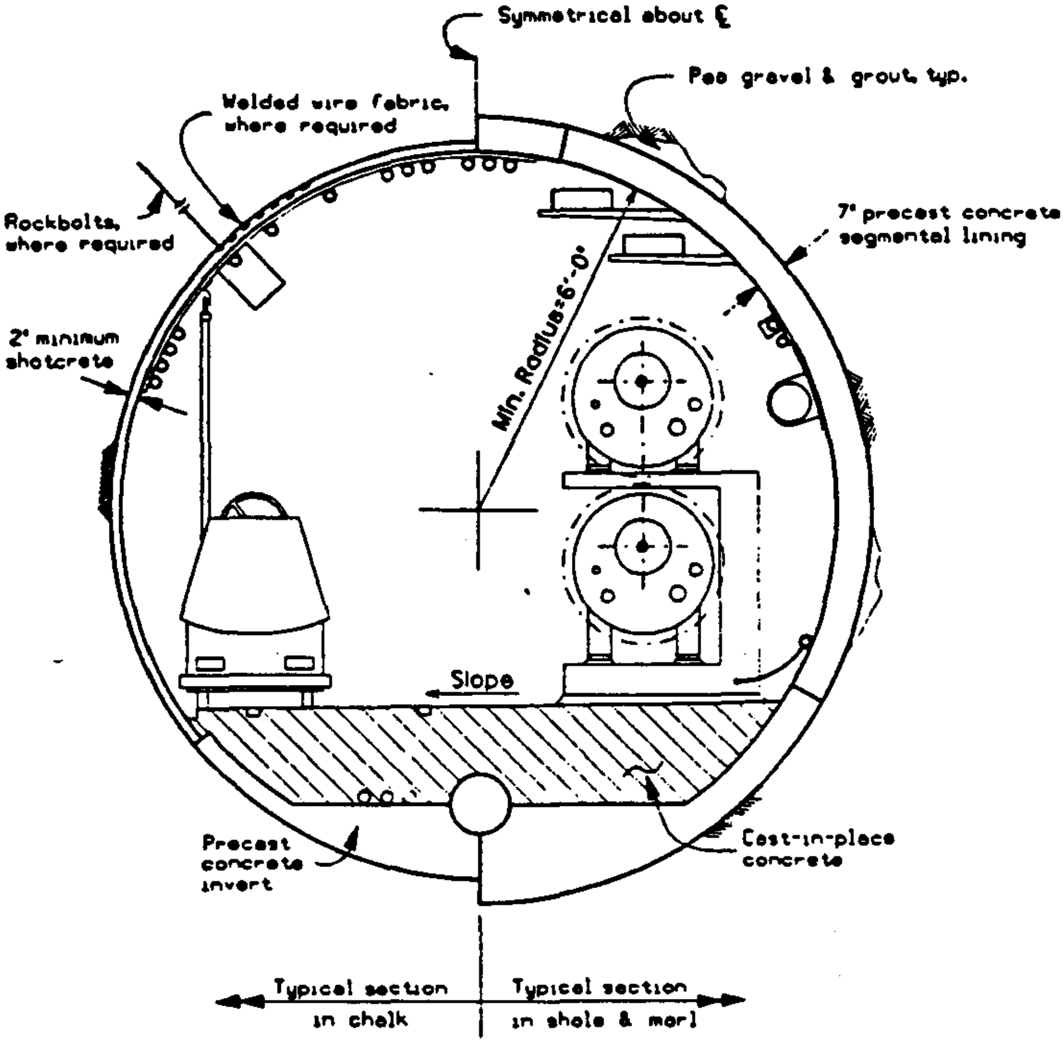

Figure 4.6. Cross section of the collider tunnel. Note that the tunnel-wall construction differs according to the local geological characteristics with the highly stable Austin chalk requiring a less rigid tunnel structure.

Table 4.4

Above-Ground Accelerator Buildings

Accelerator	Number of Buildings	Area (sq ft)
Linac	1	15,400
LEB	6	11,140
MEB*	11	31,600
HEB	11	51,775
Collider	20	212,750

*Includes the central utility plant, 3200 sq ft.

The size of underground experimental halls is determined by the size of the detector and by assembly and maintenance requirements. For each of the four detectors in the model, a preliminary study has been made that considers in detail the dimension, weights, and assembly procedures of the major detector components. Two varieties of large halls have been designed. Type A is the model for the northwest experimental IR (Fig. 4.7); Type B is the model for the southwest IR. Any of the large SSC detectors considered thus far can fit into one of these halls. Two smaller halls, comparable to underground halls at existing accelerators, have been designed for the east cluster. The initial complement of experimental halls will be constructed by cut-and-cover methods. These halls include heavy-crane coverage, one or more equipment access shafts, utility and personnel-access shafts, and the utility bypass tunnel around each hall. The utility bypass is not the same as the future second leg of the diamond that will be constructed for additional experimental halls. The basic dimensions of these halls are summarized in Table 4.5.

A variety of surface structures will support operations in the underground halls, provide assembly space for experimental apparatus, and house participants in the experimental program. Surface buildings associated with east and west clusters include headhouses with crane coverage, utility buildings, heavy work/assembly buildings, and administration/laboratory buildings. The west cluster, with 12 buildings, totals approximately 250,000 sq ft while the east cluster, with 11 buildings, totals 170,000 sq ft.

Table 4.5

Underground Experimental Halls

Hall	Detector	W × L × H (ft)	Crown to grade (ft)
IR1	LSD	92 × 262 × 95	114
IR4	L*	131 × 354 × 113	108
IR5	DO	75 × 161 × 79	110
IR8	BCD	59 × 197 × 66	96

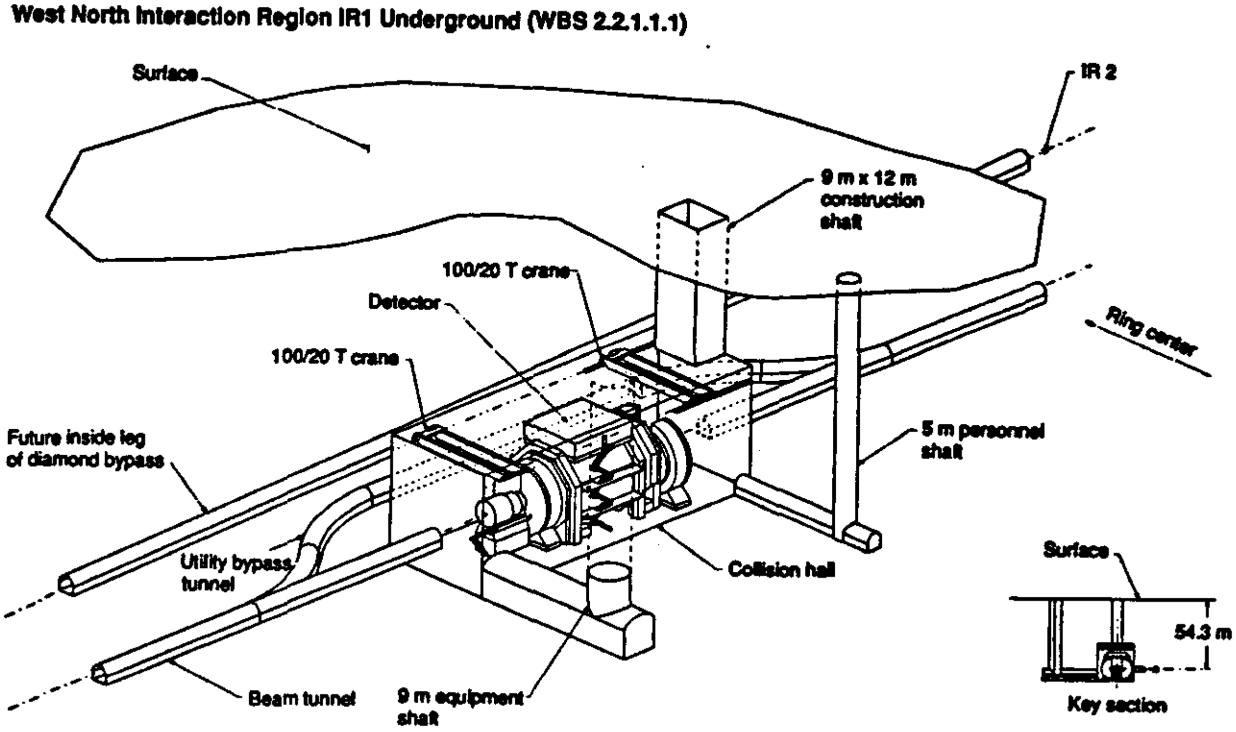

Figure 4.7. Isometric view of a Type A detector hall, specifically IR 1 in the west-north interaction region. This hall was designed to accommodate the Large Solenoidal Detector described by a potential experimental collaboration in one of the expressions of interest recently received by the SSC Laboratory. Expressions of interest represent the first formal step in defining the experimental program.

The west campus has been sited south of the linac and east of the IR 1 experimental area and includes office buildings, auditorium, and central services. Nearby facilities include an emergency services building, shops maintenance building, warehouses, and assembly buildings totaling approximately 640,000 sq ft (Fig. 4.8). The north campus on the west side of the site includes the magnet test laboratory, the magnet development laboratory, compressor building (combined with the nearby E-1 compressor), the string test facility (for testing superconducting magnets, both above and below ground), and the magnet acceptance and storage building, all adding another 235,000 sq ft of surface building area. The laboratory buildings will provide office and work space for the administrative and technical personnel. These buildings will contain the electronics development laboratories, control rooms, computing facilities, a cafeteria, meeting room, an auditorium, and other space for use by the staff of approximately 2700, including 500 visitors. Industrial buildings will house limited component-assembly activities and associated offices. Warehouses serve as receiving and storage facilities. The support buildings provide fire, site patrol, rescue, and maintenance services to the entire SSC.

The average utility requirements for the entire site (accelerators, experimental areas, and above-ground buildings) are estimated in the SCDR at 185 MW electrical power and 2241 g/min water.

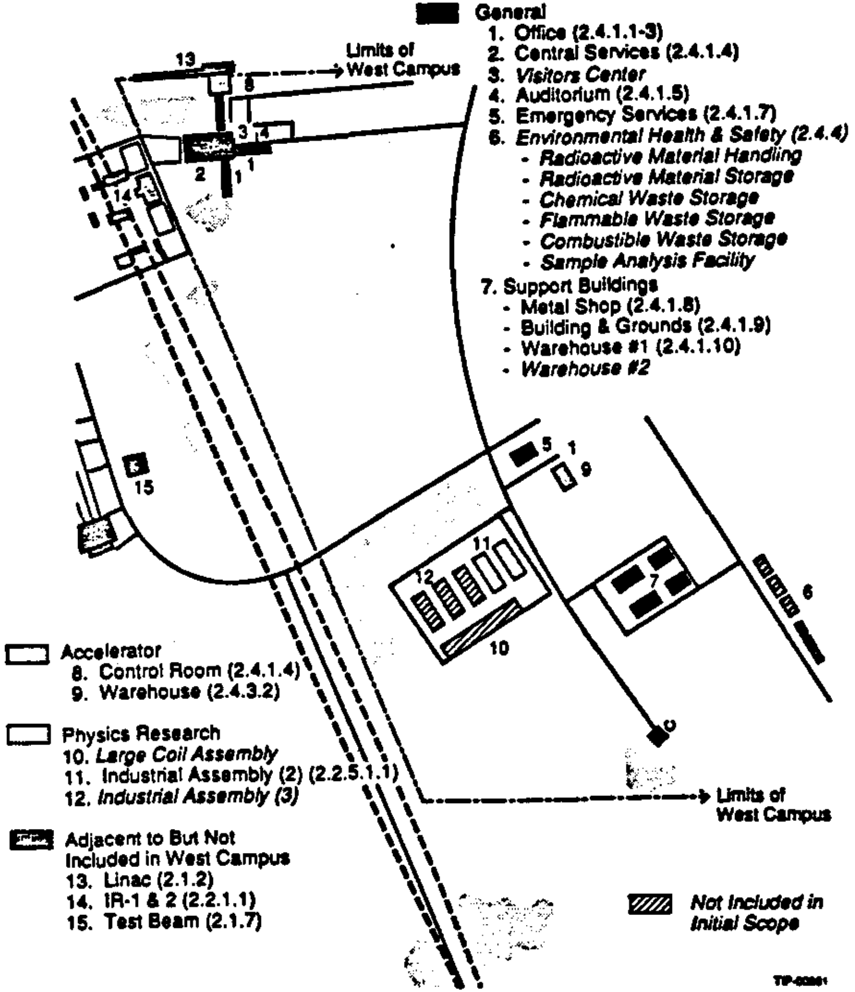

Figure 4.8. Surface facilities of the SSC West Campus. The campus has been sited south of the linac and east of the IR 1 experimental area. Buildings in the area total 640,000 sq ft.

4.2 Environment, Safety, and Radiation

For normal operation, the design of the SSC includes sensors to turn the beam off in case of malfunction and to inhibit operation if any potentially unsafe condition exists. The characteristics of the radiation produced by the beam are well understood from numerous experiments, extensive calculations, and experience at existing accelerators. Based on this understanding, designers have placed the collider tunnel under a minimum earth cover of 50 ft. With this cover, people in the vicinity are shielded to levels well below those set by applicable federal regulations. The beams extracted from the collider, either at the end of a routine run or by activation of the safety system, will be steered into isolated, massive abort dumps that will be sufficiently large to absorb the resulting radiation and thus protect the ground water.

The tunnels to house the collider ring and injector will be constructed by tunneling methods. With this method, the land above the tunnel will be left undisturbed except for the surface installations at 5-mile intervals along the collider. The auxiliary installations on the surface are sited to minimize their effect on the local environment. For the most part, the operations of these facilities will be monitored and controlled from the main control room at the campus, so there will be very little traffic and movement associated with them.

The SSC tunnel air must be monitored for possible oxygen deficiency or presence of toxic gases because of the long distances and small air volumes between access points and because of the possible but unlikely leakage of large quantities of liquid nitrogen or liquid helium into the tunnel. The access control system for the tunnel will prevent personnel access in the absence of a positive signal that circulation fans are on and that oxygen levels are adequate. In addition, personnel entering the tunnel will be required to have a personal rebreather pack with sufficient air capacity to reach an exit in case of an oxygen deficiency alarm. The SSC tunnel will be occupied only during installation, maintenance, and repair periods. It will be empty during normal accelerator operation. To protect personnel from the effects of noxious fumes under accident circumstances, the procedures established for a similar tunnel at CERN will be followed. The procedures carefully specify the safety characteristics of all materials to be installed or used in accelerator tunnels. In addition, existing vehicular, electrical, industrial, fire, and cryogenic safety codes will be used as appropriate in all laboratory areas, including the tunnels, following the practice at existing DOE accelerator facilities.

The campus/injector area will be similar to that at Fermilab. That facility has been operating continuously since 1972 at operating levels above those required for the SSC injector. All of the environmental sensitive aspects of their operations have been carefully monitored, with detailed annual reports submitted to the DOE. The Fermilab operations have never posed any radiological problems, even though the laboratory is unfenced and open to the general public. The SSCL will follow similar monitoring and reporting procedures.

4.3 Reliability

One design goal of the SSC is high operational availability for physics experiments (more than 80 percent). The SSC is comparable in complexity to recently constructed and operated particle accelerators, even though it is an order of magnitude larger in size. Only a moderate extrapolation of existing data is required to predict its availability. Furthermore, engineering techniques are now available to identify critical items and increase the reliability of components and systems of the SSC.

Reliability is determined largely by the quality of the design and is intimately linked with quality assurance (QA) and quality control (QC). Quality assurance begins with the detailed engineering designs and prototype testing that show whether the design is capable of meeting its reliability goals. Quality control is then required to see that the actual production meets the design standards. Although the bulk of QA/QC activities properly belongs to the detailed engineering design and construction phases of the project, the SSCL has already begun to address these issues in the conceptual design. This early start permits the SSCL to include the approximate cost and schedule implications in the SCDR.

Where data and procedures that are understood exist, modeling is performed to estimate system availability. Where no detailed data exist or where procedures are not well understood, scaling by size from existing facilities has been attempted. Where necessary, redundancy or other design changes are proposed to increase availability, and the additional cost was added to the cost estimate.

This process resulted in an overall availability goal for the SSC of 0.8 for the period after the facility is fully commissioned. This goal assumes that the operating schedule will involve cyclic periods of 10 days of high energy physics research and 4-day periods of maintenance and machine studies. The goals for the component systems of the SSC that determine the overall availability were set at a somewhat higher level than those of existing machines in anticipation of technological progress. Superconducting magnet reliability is discussed in more detail in Section 10.3. Table 4.6 compares the SSC availability goals with those achieved at Fermilab with the Tevatron.

Table 4.6

SSC Goals for System Availability

System	Availability Goal	Tevatron Availability*
Magnet System[1]	0.96	0.985
Power Supples and Quench Protection[2]	0.96	0.950
Cryogenic	0.98	0.990
Vacuum	0.995	0.995
Control and Instrumentation	0.98	0.990
RF	0.98	0.990
Injector Complex	0.95	0.985
Injection/Abort	0.985	0.950
Utilities	0.99	0.970
Safety and Interlocks	0.995	0.985
Overall Availability[3]	0.80	0.78

*Tevatron as collider

[1] After accounting for infant mortality, magnet failure probably scales with number of pulses

[2] Power-supply availability can be improved by battery back up and adding redundancy; availability scales with number of supplies

[3] Includes human errors

4.4 Evaluation of Feasibility

This section addresses the technological feasibility and overall reliability of the SSC over its projected lifetime. The project consists of four major components: (1) the four accelerators of the injector system (linac, LEB, MEB, and HEB); (2) the collider, including the array of superconducting magnets (dipoles and higher order multipoles) that account for approximately one-third of the total cost; (3) the initial complement of detectors that record the outcomes of collisions between protons in the IRs; and (4) conventional facilities, including the tunnels for the collider and the injector system, the underground caverns for the detectors, and other conventional above-ground structures. The feasibility, reliability, and cost of each major subsystem have been thoroughly reviewed by an ERC subcommittee and are treated in more detail in Sections 5 and 6, as well as in the subcommittee reports in Section 10. It is noted that the SSCL refers to the design presented in the SCDR as a point design, which is adequate for assessing feasibility, estimating costs, and setting schedules and provides the starting point for working out a more detailed engineering design.

4.4.1 Injector

The entire SSC concept relies heavily on the widely demonstrated scenario of a sequence of lower-energy synchrotrons injecting into the next-higher-energy machine, with an energy increase of roughly 10 to 20 at each stage. The cascade of machines proposed for the SSC injector system corresponds closely in concept and technology to the Fermilab injector system, whose successful functioning supports the feasibility of the SSC injector system. A major accelerator challenge is to design a sequence of machines with energies, circumferences, and other parameters that blend together to constitute an optimized injector system. There are no insuperable barriers to performing the optimization, provided that sufficient technical staff are available to do the necessary work.

4.4.2 Collider (Including Superconducting Magnets)

The feasibility of the collider depends on properly addressing a wide range of technical systems, including the storage ring, superconducting magnets, cryogenic systems, and instrumentation and controls, all for a machine operating at an energy 20 times higher than any before. Major changes in the design (doubling the injection energy to 2 TeV, increasing the dipole magnet aperture to 50 mm, and adopting a new lattice with a 90-degree phase advance and shorter cell length) increase the effective aperture for the beam and should make commissioning of the collider faster and upgrading to higher luminosity easier. Although further studies will be an important part of enhanced development of the SSC design, there is every expectation that the collider will perform well at its design energy.

The technical feasibility of the superconducting magnets is supported by the recent results of the SSCL program, which relies heavily on other DOE national laboratories (Fermilab, BNL, and LBL). While the most recent tests of collider dipole magnets with the 40-mm aperture of the original design have been successful, the decision to increase the aperture of the collider dipole magnets to 50 mm requires additional R&D on short and long (full-sized) magnets to verify performance. The somewhat more conservative nature of the new design adds to the confidence that the SSC magnets are technically credible. Additional R&D will also enhance future reliability and will result in an improved cost safety margin for this important item. Beyond technical feasibility, however, are issues relating to manufacture and procurement of approximately 8600 dipoles and 1700 quadrupoles with the required performance and quality and in a timely way, issues that are equally as important as technological feasibility.

The feasibility of the cryogenic plants is not in question. The refrigeration system is a mature design in which the cryogenic circuits are divided into units, each of which is well within the state of the art.

Systems integration and interfaces provide the major challenges for the instrumentation, diagnostics, and controls systems of the mammoth SSC complex, as the systems themselves are within the state of the art.

4.4.3 Detectors

The main challenge for SSC detectors is the extremely high rate (10^8 collisions per second) at which data are generated when the SSC is operating at its design luminosity. The detector system must first decide which events are worthy of recording, such as those having a high transverse momentum, often associated with new phenomena. Then, for the small fraction of interesting events, the system must accurately record the data with the required detail for later reconstruction of particle tracks and energy flow and for analysis. At this stage of the SSC project, it is too early for specific proposals with detailed performance specifications, and it is not yet possible to evaluate the technological feasibility of the SSC detectors. However, detector technology advances at an extremely high rate. Given the present state of the art, as indicated in the EOIs already received, there is reason to believe that the required capability will be in sight when detectors are being constructed, planned for the period from 1993 through 1998.

4.4.4 Conventional Facilities

Conventional facilities include both above- and below-ground structures. There is no feasibility question *per se* for above-ground structures because many similar structures exist and the Ellis County, Texas site poses no special challenges or hazards. The feasibility of underground structures is dependent on the geotechnical characteristics of the site. The collider ring will be dug by tunneling, a well-developed and widely practiced technique. Of the three geological media found at the SSC site, the Austin chalk that surrounds about 54 percent of the SSC tunnel is the most desirable medium for both tunneling and for the underground experimental areas, which will be excavated and covered over. Taylor marl surrounds the remainder (33 percent) of the collider tunnel. The Eagle Ford shale that intrudes into the western edge of the site (12 percent of the tunnel penetrates shale) is less desirable but still amenable to tunneling. The immense weight of the largest detectors (up to 60,000 tons) may require special attention toward maintaining the temporal stability of experimental hall floors on the west side of the collider.

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5. TECHNICAL SYSTEMS—SUMMARY EVALUATIONS

In addressing its charge, the ERC formed the subcommittees whose membership and structure are given in Appendix A. This section summarizes the findings of the subcommittees that addressed accelerator physics, superconducting magnets, conventional magnets, cryogenic and vacuum systems, other technical systems, and detectors. The full reports of these subcommittees comprise Sections 10.1–10.7 and 10.11 of this report.

5.1 Collider Accelerator Physics

The design of the SSC is based on previous experience with storage rings and synchrotrons. Its most striking feature, its physical size, does not invalidate the basic accelerator principles used for its design. Comparing the SCDR with the CDR of 1986 highlights the following substantial changes:

- The injection energy of the SSC has been doubled to 2 TeV.
- The dipole magnet aperture has been increased from 40 mm to 50 mm.
- A new lattice with 90 degrees betatron phase advance and shorter cell length has been adopted.
- The correction system is now based on lumped elements.
- The cycle periods of the SSC and HEB have been substantially increased.

Of these, the first three changes are specifically aimed at increasing the effective available aperture for the beam at injection. From an accelerator physics viewpoint, these changes will produce a collider that will be initially faster to commission and ultimately easier to upgrade to higher luminosities. In the subcommittee's opinion the most crucial and cost-effective design change has been the increase of the injection energy from 1 TeV to 2 TeV. This choice has resulted in a reduction of the magnitude of the multipole errors caused by persistent currents at injection and, as a consequence, greatly reduced the requirements of the corrector system. A new simplified corrector scheme based on lumped spool elements has now been proposed. This scheme has the advantage of simplifying the commissioning, tuning, and operation of the collider.

The increase of the dipole aperture also increases the dynamic aperture; however, with the increased injection energy and reduction in the cell length, it is the opinion of Subcommittee 1 that the 40-mm aperture with an appropriate multipole correction scheme could also provide adequate aperture for the design emittance. With the 2-TeV injection energy, the design luminosity of 10^{33} cm^{-2} s^{-1} should not be seriously jeopardized with 40-mm-aperture magnets. Some capability to improve luminosity beyond the design value would be lost, but a luminosity of 10^{34} cm^{-2} s^{-1} would not be out of the question.

The fifth change, made to reduce cost, may significantly impact the availability of the SSC for physics. This change nearly doubles the reloading time of the SSC, which the subcommittee estimates to be now between 140 and 215 minutes, including allowances for all the necessary operations. The cycle times could be reduced without major design change if experience shows that such a change is appropriate.

Although we believe that the SCDR design luminosity of 10^{33} cm^{-2} s^{-1} will be achieved, many of the implications of the detailed design choices for the new SSC lattice have not yet been fully studied. In the present design of the collider it appears that luminosities even higher than the design may eventually be attainable. The committee feels that this option should, if possible, not be excluded by design refinements.

Although analysis has shown that the intensity threshold for the transverse mode coupling instability is significantly above the design current per bunch, we believe that strict impedance monitoring and control should be exercised on all components installed in the collider rings. This impedance policing is necessary to ensure stability at the highest intensities.

To date, tracking simulations have concentrated on the dynamic aperture at injection with a simplified lattice. In particular, low-β insertions were not included. We believe that further tracking studies with low-β insertions in place and appropriately tuned at both 2 TeV and 20 TeV should be conducted.

The present scenario assumes a 40-mm-bore quadrupole magnet and a 50-mm-bore dipole magnet. For consistency, consideration should be given to increasing the quadrupole aperture to 50 mm in order to get a more efficient use of space and a smooth vacuum chamber.

The SCDR is a *conceptual* design report. The enormous task of producing the detailed *engineering* design, which will be used for component specifications and tolerances, will necessitate a substantial increase beyond the present numbers of accelerator physicists and engineers. Increased staff will enable, for example, a thorough study of all sources of emittance dilution throughout the accelerator, including power supply noise and transfer areas. Without this increase the project will encounter substantial delays.

The complete report of Subcommittee 1 (Accelerator Physics: Collider) is provided in Section 10.1 of this report.

5.2 Injector Accelerator Physics

The injector for the SSC collider rings accelerates protons from the gas bottle to 2 TeV by means of a linac and three synchrotrons. It is, as intended, a reasonable design on which to base a cost estimate. Furthermore, it is feasible in the sense that, if it were followed by a detailed engineering design and built without significant modification, it is likely, from an accelerator physics viewpoint, that performance goals would be met for beam brightness at 2 TeV to the collider rings and for beam intensity at 200 GeV to the test beam area.

The injector design is not yet optimized. Optimization should continue with all deliberate speed, focusing on the goals of providing significantly higher beam brightness to the collider as well as mitigating, ameliorating, circumventing, and/or arriving at the best compromise regarding the issues enumerated below. An aggressive approach to the design optimization can still allow the early schedule milestones to be met. A design which holds out the reasonable hope of significantly higher brightness would serve two purposes. It would furnish a significant safety factor on the SCDR design goal, which is prudent given the uncertainties involved in trying to predict accelerator performance, and, if achieved, it would provide the most reasonable upgrade path to significantly higher luminosities in the collider.

It is recommended that the designers should not assume *a priorii* that the optimization process will merely require fine-tuning of the SCDR design, but should instead start with a fresh look toward the possibility that an optimal injector might look rather different from that described in the SCDR. Since there may not be an adiabatic path from the present design to an optimized design, the design team should be encouraged to start with an open mind about the best way to accelerate a bright beam from the gas bottle to 2 TeV. Because optimizing the injector complex will not have a major impact on the total project cost, the designers should be allowed to proceed continuously to an optimized design, unfettered by external requirements to freeze the design periodically in order to produce further interim cost estimates. The issues, concerns, and recommendations of Subcommittee 2, to be included in the design optimization, are summarized at the end of this section and presented in detail in Section 10.2.

Few experienced accelerator physicists on the SSCL staff have been assigned to the design of the injector complex. SSCL management has successfully circumvented this limitation up to now by enlisting the experienced staff of other organizations such as BNL, LANL and Fermilab to assist with the design effort. However, this is clearly not ideal in the design stage and will become even less desirable in later stages of the project. A related issue is that, with the exception of the linac, no single individual in the organizational structure is responsible for a particular injector accelerator. It is recommended that a supervisor for each injector accelerator be appointed so that responsibility and authority for each subsystem can be identified.

The SCDR scenario for filling the collider would work but is slow and complicated. Most of the collider fill time results from the cycle time of the HEB, which is 515 seconds for one full bipolar cycle. This number was increased relatively recently to save money on rf, refrigeration, and power supplies for the HEB. At issue is whether the projected money saved would be well spent to increase the physics output of the facility and to speed up the commissioning and tuning processes.

The complexity of the filling scheme follows from the fact that the ratio between the total beam lengths in successive machines is not an integer. As a result, to achieve a total occupancy factor of about 92 percent of the available buckets, different numbers of bunches must be transmitted from one machine to the next on different cycles. It is recommended that, in subsequent design efforts, the possibility of adjusting the circumferences of the machines be examined toward the goal of simplifying the filling scenario by achieving an integral ratio of beam lengths in successive machines.

In addition to the optimization of the circumferences of the injector synchrotrons, the transfer energies and corresponding energy ranges should be reexamined. With modern lattice designs, the transition energy can be used as a variable to simplify rf requirements, to avoid beam dynamics problems or both, especially where compromises between adjacent machines are necessary. Since each booster in the injection chain has its own accelerator physics requirements, the optimization must be iterative, and tradeoff studies must be performed among all subsystems. Indeed, the SCDR injector design represents the work of largely independent groups who have not had the opportunity to interact and develop an integrated solution to the injector design.

The SCDR linac design will provide acceptable beam to the LEB and is adequate as the basis for costing and schedule planning.

While the LEB design is generally deemed to be adequate, the LEB is viewed as the highest-risk injector, especially in regard to beam brightness capability and ease of beam manipulation prior to transfer to the following machine. The two major concerns are a large transverse space-charge tune shift shortly after injection ($\Delta\nu_y = -0.34$) and the location of transition ($\gamma_t = 14.5$) slightly above the extraction energy ($\gamma = 12.8$).

The SCDR MEB is technically feasible. Important issues to be resolved in the MEB optimization include the transition crossing shortly above injection and uncertainty about the ability to extract slowly at full energy for test beams because of the strong sextupole component in the dipoles.

The SCDR HEB is a technically feasible, straightforward extrapolation of Tevatron and HERA experience. The dynamic aperture of the 50-mm-coil-diameter dipoles is marginal and represents a non-negligible technical risk; amelioration might involve larger coil diameter, correctors in the middle of half-cells, and/or higher injection energy. The bipolar operation appears to be a good idea, pending verification by magnetic measurements in this mode.

The associated beam transport lines needed for the facility have all been designed in a technically feasible manner and in adequate detail to support a realistic cost estimate.

5.3 Superconducting Magnets

The SSC contains over 11,000 superconducting magnets distributed among the collider dipoles, collider quadrupoles, and HEB accelerator magnets. All of these magnets are state-of-the art components that have been the subject of an intense development program for many years. The most critical of these magnets are the 7956 collider dipoles, each of which produces a 6.6-tesla field over a 15-m length, and the 504 similar dipoles, each of which has a 13-m effective length. In addition, there are quadrupole magnets for focusing of the beam in the collider and the HEB magnets. The superconducting correction magnets, located in the spool pieces, are discussed in Section 10.6.

While initial dipole developmental magnets did not meet the desired performance and trained excessively, more recent 40-mm-bore size magnets at Brookhaven and Fermilab have been quite successful when tested. However, the dipole bore size was recently enlarged to 50 mm, requiring further work to verify the new design. There is now an intensifying development effort to further improve the magnet performance, coupled with a somewhat more conservative design of the 50-mm dipole. Thus, there is confidence that the necessary magnets for the SSC are technically credible and will improve with further engineering development. The good performance of the most recent quadrupole model is heartening.

The magnet costs have been competently estimated from detailed parts lists and laboratory experience. However, the resultant estimated base costs are probably a lower bound. The margin to obtain a lower cost is nearly zero, while the potential for a significant cost increase is high. Accordingly, the industrial transfer process and the procurement method are extremely important. It is the opinion of the majority of the magnet subcommittee that the proposed leader-follower method limits competition and the opportunity for alternate fabrication methods. The projected costs do not adequately allow for the risks and profits expected in a fixed-price contract. Under the current strategy, the majority of the subcommittee recommended either a dramatic increase in the magnet procurement contingency or conversion to another type of contract for the bulk of the dipole manufacturing. A more flexible type of contracting would enhance the likelihood of achieving the projected magnet base costs. It would also improve technical communication between the SSC Laboratory and industry to correct any technical difficulties or to accommodate design changes. Even with enhanced communication and improved procurement methods, the subcommittee recommends increasing the overall magnet contingency from the present 19 percent to 34 percent to reflect the uncertainty and optimism in the cost estimates.

The subcommittee asserts that there is an absolute requirement to minimize, and preferably eliminate, design changes during magnet production if these contracts and the SSC program are to be completed within the cost and schedule envelope. This will require that, in the absence of major flaws that must be fixed, "improvements" after start of production will not be tolerated. Adequate attention must be paid by the Magnet Systems Division (MSD) and SSCL management to see that this rule is strictly adhered to.

The magnet schedule is very tight and certainly on the project critical path. In particular, the development schedule to produce the initial 12 prototype 50-mm-bore, 15-m collider dipole magnets with industrial participation at Fermilab is very short and dominated by the time required to make tooling. There is no float apparent in the schedules provided to the subcommittee, so careful attention and full resources must be applied to this SSC program critical path activity. The testing of these industrially assembled superconducting magnets in the E1 complex in September 1992 represents a critical milestone which should be carefully monitored in order to gauge the project's early progress.

A key element of the management of the critical path is the identification of the product managers who will be responsible for integrating the efforts at FNAL, BNL, and LBL, as well as the MSD matrix, from completion of the magnet design through industry production. It is essential that these positions be filled as quickly as possible. Although a matrix management arrangement is being used within the MSD, the magnet production managers should be permitted to have small direct staffs. The committee was pleasantly surprised at the current size and quality of the MSD staff. The first line supervisors are a highly qualified group.

Design criteria for the collider dipole magnets (CDM) are under development and partly specified in the Prime Item Development Specification (PIDS) sent to industry. Several of the items marked to be determined (TBD) should be filled in and marked as tentative numbers as soon as possible. Despite the considerable progress in the design, fabrication, and test analyses to reduce magnet training, a great deal of further work will be needed, particularly in the areas of stress and thermal analysis.

Materials tests now underway will be essential to a proper understanding of the coil behavior. These tests should be in all three principal directions, rather than simply azimuthal as is now done. The test program should be expanded to include cyclic lifetime tests for all critical components. The required number of excursions beyond the nominal operating point were not presented to the subcommittee. These must be defined early because of the strong impact on fatigue lifetime and structural design criteria. The latter have a direct impact on structural weight and cost.

The HEB magnet schedule and cryogenic design are extremely aggressive, with concomitant risk. There is a significant schedule risk due to the need to develop fine-filament (2.5-micron), high-current-density superconductor. These risks suggest that the cost contingency should be doubled in this area to about 40 percent. The subcommittee is encouraged that the HEB magnet project manager is in place, and that key problems of adapting the collider dipole magnet design to the HEB have been identified and seem manageable.

The baseline cryostat design is suitable for the CDM with opportunities for component and subsystem optimization during the industrial development phase. Support of the upper magnet from above would allow for a reduced vertical magnet centerline-to-centerline distance. Longer, straight (non-reentrant) support posts could thus be used. Both features could result in cost savings.

With the 10 to 12 magnet test stations planned, only 10 percent of the magnets can be cold tested in a routine manner during high-rate production. This situation could produce a serious risk of delaying and complicating the SSC initial operation. The HERA system experienced about one percent defects, which extrapolates to approximately one hundred magnet failures in the SSC. Complete cold testing of all magnets, therefore, seems justified on a cost and reliability basis. The SSC should consider developing full cold testing capacity for full-rate production.

The additional margin associated with changing to the 50-mm-diameter CDM is an obvious benefit. The change to a different Cu/SC ratio appears to be reasonable, but requires more time and effort to assess than available in this type of review. As a result an independent, more detailed, assessment by another group is recommended as soon as possible. It should also take into account the expected spread in cable performance based on critical property information taken to date.

Finally, it is imperative that the Magnet Division immediately start implementation of the Cost Schedule Control System (CS/CS) to aid them in managing their expanding effort. Performance, cost, and schedule responsibility should be delegated to the lowest possible level. Annual performance appraisals should address this responsibility to ensure that it is kept in mind by everyone participating in the design process.

See Section 10.3 for the full report of Subcommittee 3 (Superconducting Magnets).

5.4 Other Technical Subsystems

5.4.1 Conventional Magnets

The designs presented for conventional magnets in the SCDR for the LEB, MEB, test beams, and their associated transfer lines and abort systems are sufficiently developed for a detailed cost estimate to be made. The overall system as presented is not optimized, and future changes in these designs will evolve with additional engineering. However, it is felt that the costs presented are sufficient to cover these changes. Minor omissions from the cost base were found. The level of risk is modest in the components, which are based on designs built elsewhere. The method used by Subcommittee 4A (Conventional Magnets) to deal with uncertainties about industrial costs is discussed in the full subcommittee report in Section 10.4. The 0.6-T collider abort kicker is the only magnet that represents a significant increase in the state of the art. Some magnets, for example the MEB dipole and quadrupole magnets, are not optimum but are fairly good examples for cost estimation.

The subcommittee felt that the engineering done in the preparation of the cost estimate reflects an excellent standard from which the SSCL can proceed in the future. In spite of this, there is an urgent need, if the schedule is to be maintained, to proceed from the present design to a final engineering package. Since staffing at the SSCL in this area is sparse (most of the detailed designs and cost estimates presented were made at other laboratories), SSCL management is urged to aggressively seek additional experienced staff in this area.

The subcommittee felt some unease about the SSCL project management structure. The use of matrix management has been unusual in high energy physics construction projects, although high energy physics research and facility operations are often carried out utilizing matrix management principles. We are concerned that lines of authority might not be sufficiently clear for firm, effective, timely decisions to be made. Further, the accelerator physicists, including those responsible for the system, are isolated from the engineers and technicians who are charged with actually building the system; that is, the engineers and technicians report to a different person. DOE and SSCL are urged very strongly to expedite the appointment of a lead person for each accelerator in the injector chain as well as to recruit the needed engineering and technical staff.

5.4.2 RF, Power Supplies, and Linac

This subcommittee reviewed rf systems for all SSC accelerators, all magnet power supplies, and the linac. The subcommittee found that the scope, technical status, cost, and schedule of the systems reviewed are adequate for the current phase of construction of the project. Some of the designs are impressively advanced for the current stage of the project. These items are reviewed in more detail in the full subcommittee report in Section 10.5.

The designs and costs presented in the SCDR and associated documents extensively followed the experience at other laboratories, especially Fermilab's Tevatron. Since these designs are quite relevant to the SSC, the subcommittee recommends that the SSCL management continue to take maximum advantage of the availability of this information, and to supplement it with more recent developments when there is a clear advantage in doing so. The subcommittee was particularly impressed with the competence of the people making the presentations, both from the SSCL and from other laboratories that are collaborating with the SSCL. It is recommended that additional key people with both technical and managerial experience be brought on board as soon as possible, consistent with the SSCL's schedule and staffing plans. The areas of work reviewed by this subcommittee are being implemented through the interaction of groups of people responsible for each of the accelerators in the complex and groups of people having particular competence in each of the pertinent technical specialties; this is being done to avoid duplication of effort and to achieve standardization of subsystems to the extent practical. Clear definition of responsibility and authority is needed to ensure that construction proceeds smoothly.

It is noted that the SSCL is putting appropriate heavy emphasis on the most critical technical areas in the project, and has started significant R&D and design work in the areas reviewed by the subcommittee. This approach will help to maximize the likelihood that the design used will be free of defects, which is particularly important for components and subsystems which are replicated many times. For items with small multiplicities, the early start will ensure that functioning devices are available on the scheduled turn-on date. In view of the large staff and capital investment, a delay caused by a few missing or inoperative devices would be expensive.

The systems reviewed represent 4.7 percent of the TEC. The estimated costs and contingency are reasonable, with a few relatively small adjustments being recommended by the subcommittee. The various findings, evaluations, and recommendations given in the subcommittee's full report (Section 10.5) are summarized below.

- Primary emphasis should be placed on functionality, reliability, and holding any schedule delays within the available float.
- The planned collider rf system uses four cavities powered by the same klystron. Whether or not sufficiently small rf noise can be achieved by this technique needs to be explored. Similar considerations apply to the radio frequency quadrupole and first drift tube linac section.
- Simulations have shown that a small power supply ripple applied to the beam at a betatron sideband of the revolution frequency causes significant emittance dilution. The extent of this problem and methods of mitigating it merit further exploration.
- Transmission line modes on the power supply distribution system may be a problem and deserve investigation.
- Although the distribution of reliability allowances should be subject to ongoing optimization as a cost minimization measure, the current goal for the collider

power supply reliability translates to an unavailability allowance for each power supply of 0.000017 of the time. Methods of achieving this level of reliability require intensive exploration.

- Off-energy particles caused by beam loading transients, if not addressed, would cause objectionable beam spill in the LEB. The optimum method for mitigating this problem needs to be addressed.
- Whether or not an additional grounding system for the accelerator is required needs to be determined prior to freezing the civil construction design.
- The HEB and collider do not have distributed cooling water systems. The effect of this decision on component temperatures and reliability should be assessed.
- Detailed procedures for changing underground rf system components need to be worked out prior to freezing the associated civil construction design.
- The subsystems reviewed represent low risk if the SSCL's schedule for these subsystems is used to establish level of effort.

5.4.3 Cryogenics, Vacuum, and Related Components and Activities

The Subcommittee on Cryogenics, Installation, Commissioning, Operation, Vacuum, Survey/Alignment, and Spool Pieces agreed to the funds that had been included in the SCDR to implement the design and construction of these SSC components; however, the contingency estimates were considered to be understated, and the subcommittee suggested an increase of 5 percent of the base cost in this category.

Detailed discussion of the subcommittee's findings and recommendations is provided in Section 10.6 of this report. The most significant technical, cost and schedule findings are highlighted below.

5.4.3.1 Cryogenics

The refrigeration system is a mature design and has a high probability of meeting cost and schedule objectives.

The subcommittee is concerned about the ability to remove the heat generated during the 4-1/2 minute HEB cycle in view of the change in dipole bore size. We recommend that the change from a 70-mm bore to a 50-mm bore for the HEB dipole be revisited.

5.4.3.2 Installation

The site-specific needs are well developed with human resources and times adequately estimated. Equipment requirements have been fully identified.

5.4.3.3 Vacuum

The vacuum systems for all accelerators have been described to the level of detailed schematics, but not to the level of an engineering design. The subcommittee judged that this was sufficient for cost estimation. The subcommittee is concerned about synchrotron radiation effects, especially when considering luminosity upgrades, and it proposes studies relative to increasing the safety margin for the collider cold beam tube vacuum.

Efforts are encouraged to specify an SSCL-wide standard for interfacing to sensors and controls for vacuum systems, cryogenic systems, and other subsystems. Industry will need lead time to develop specific modules. Prototypes should be used at the ASST wherever possible.

5.4.3.4 Survey/Alignment

An early satellite survey gave an accuracy sufficient to locate the 44 penetration pipes. The SSC footprint does not include land in fee simple for these shafts. The subcommittee recommends that the SSCL resolve this dilemma speedily. The subcommittee endorses the developing plans to establish in the near future an SSC metrology group under a very experienced leader. The group would carry out the final precision survey tasks and establish a project-wide alignment data base.

5.4.3.5 Spool Pieces

A collider spool piece conceptual design was presented along with plans to proceed through prototypes that will be tested in magnet string tests. The spool pieces are the most complex cryogenic components, and, therefore, the subcommittee recommends that all spools be cold tested prior to installation in the tunnel.

5.4.4 Instrumentation/Controls, Computers and Related Subsystems

Subcommittee 4D examined the SCDR in the areas of controls, instrumentation and diagnostics, machine safety systems, and general laboratory computing. The subcommittee generally was impressed with the substantial planning that has been done, but in some areas was concerned about systems integration and interface issues. The subcommittee found scoping of the work to be appropriate and the cost estimates to be reasonable.

The subcommittee believes that the controls system scope and challenge are within the state of the art, and the project is achievable, with software timelines being the highest risk component. For a variety of reasons, the SSCL Controls Group is not yet making the technical decisions required for substantial progress. Primarily there is a lack of requirement definition and assignment of functional responsibility—presumably a responsibility of the Systems Integration Group. The staffing level of the group is low, and it appears that hiring the subgroup leaders soon will become a challenging task. These are believed to be the major issues behind a seemingly immature control system design. While this is not critical at the present time, additional attention by the Systems Integration Group and general support by management will be needed soon.

The Instrumentation and Diagnostics Group seems to be in very good form. While it also is hurt by the low level of Systems Integration Group input, the group is making excellent progress nonetheless, because of the strong leadership and good staff.

The machine safety system addresses personnel access to machine areas with potential radiation or electric shock hazards. Other safety issues, such as fire and oxygen deficiency, are addressed elsewhere. The functional requirements are well thought out, and the design is excellent. The cost estimate is good, but does require that transistor logic (rather than relays) be used in the system. It is conceivable that the safety review committees will not accept the transistor-logic approach; using relays would lead to increased cost and substantial functionality losses. This is another area where the subcommittee feels that the SSCL would be strengthened by the assignment of a permanent employee.

The general computing is on a good track. The group has made commendable use of the planning homework of the last few years. They are beginning to implement an up-to-date approach to the general laboratory computing and communications needs. Even so, in the areas of CAD, communications, and database support, there is some evidence of the types of systems integration problems observed elsewhere.

5.5 Detectors

The SSCL has presented a detailed set of plans for implementing an experimental program for the SSC. According to these plans, the first 3 years (1990, 1991, and 1992) will be occupied by the process of selecting the initial set of detectors, design of the detectors, and the submission of a detailed design report, and subsequent stage I and stage II approvals. The following 6 years (1993 through 1998) will involve the construction, assembly, and commissioning of the detectors. This schedule is very ambitious. However, with the involvement of a sizeable fraction of the U.S. high energy physics community, as well as substantial foreign collaboration, the goal of having operational detectors by SSC turn-on time should be achievable.

The process of selecting the detectors started with the submission of Expressions of Interest (EOIs). Fourteen EOIs were received in May 1990, involving over 300 institutions and over 1900 participating scientists. These EOIs will be discussed by the Program Advisory Committee (PAC) and, based on the PAC recommendations, the SSCL director will identify the scope of the initial complement of major detectors later in 1990. It is quite important that the selection of large detectors proceed expeditiously so that both serious detector design and the planning of experimental halls and support facilities of the SSCL can proceed. Both of these items are on the critical path to having operating detectors at SSC turn-on time.

The initial set of detectors has not yet been defined by the PAC. However, the SSCL did present some ideas on a desirable initial set of detectors. This set would include two large general-purpose 4π detectors, one medium-sized special-purpose detector, and some number of quite specialized small experiments. Two large general-purpose detectors are important to provide competition, complementary capabilities, and cross checks in major physics results. Some number of smaller experiments are crucial to provide breadth and diversity to the program.

The costs of the detectors are not well known at this time. Only rough estimates can be made until the initial detectors are chosen and their scope is defined. The cost estimates from recent detector cost estimating panels and the EOI's agree quite well, with one exception. These estimates include contingencies varying from 0 to 27 percent. It is the strong recommendation of the review committee that adequate contingency, which is of the order of 40 percent of the estimated detector costs, must be included in the planning for detector costs.

There is a fund of $842 million in as-spent dollars identified in the SSC TPC for detectors. It is reasonable to assume that there will be non-Federal contributions in addition to the U.S. funds. The amount of these non-Federal contributions is not known at this time with any certainty, but judging from the amounts discussed in the EOIs, a reasonable expectation is that the non-Federal contributions might be about half of the U.S. funds discussed above. With this assumption, one can compare the funding budgeted for detectors with the estimated detector costs. Even though these numbers have considerable uncertainties at this time, the following qualitative conclusions become apparent:

- A balanced initial physics program is possible with the $842 million identified in the SSC budget and the expected non-Federal contributions. However, to stay within this budget, the initial program will have to be less ambitious than the desired initial set of detectors discussed above. One would either have to have only one large 4π detector initially, or the two 4π detectors would initially have to have a scope reduced from that envisioned in the EOIs.

- The desired initial set of detectors discussed above, if scoped at the level envisioned in the EOIs, would require about 1-1/2 times as much as the $842 million budgeted for detectors, even with a very sizeable non-Federal contribution.

The SSCL has coordinated an extensive program of detector R&D in the high energy physics community. It has also made a detailed plan to prepare for the experimental program, including the experimental halls and support facilities, test beams, computing, management, and on-site support staff for the experimental program. The SSCL Physics Research Division is to be commended for this thoughtful and thorough planning, which seems sensible and appropriate for the present stage of the project.

The full report of Subcommittee 8 (Detectors) is provided in Section 10.11 of this report.

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6. EVALUATION OF CONVENTIONAL FACILITIES

In addressing its charge to thoroughly review and evaluate the material presented by the SSCL, the ERC formed the subcommittees whose membership and structure are given in Appendix A. This section summarizes the findings and recommendations of the Conventional Facilities Subcommittee. The full report of this subcommittee comprises Section 10.8.

6.1 Summary

There has been considerable effort by the SSCL to adapt the facility to the Ellis County site and to quantify, organize, and consolidate the conventional facilities requirements since the 1986 CDR. Of major impact was the increased circumference of both the HEB and the collider ring resulting from significant changes in the technical design of the machine. Additionally, a detailed study of the collider tunnel diameter with respect to the magnet size, the magnet supports, installation and servicing requirements, and other space allocation resulted in an increase of inside diameter (ID) from the 10 ft specified in the CDR to 12 ft in the SCDR. A significant number of niches to house power supplies and equipment were added around the collider's circumference. Another major change since the CDR was the decision to install fixed detectors in their permanent positions within the halls. The CDR proposed clustered interaction regions with the detectors conceived as movable units to be constructed in underground assembly areas separated from the adjacent collision halls by large movable shield doors.

Though produced with a limited staff and consultant base, the site-specific conceptual design for SSCL conventional facilities is adequate, reasonable, and well presented. SSCL materials covering the scope, constructibility, and cost of the collider tunnel (the ID of which was increased) were analyzed for labor and material breakdowns and the experience of construction contractors on similar, albeit smaller, projects. Materials on the experimental halls included detailed structural designs and proposed construction methods normally expected of post-Title I efforts, as well as some provision for resolving the problems thought to be associated with the Eagle Ford shale on the west side of the SSCL site, as described in Section 6.5. Because the major facilities are well conceived and the cost estimates approached Title I detail, the subcommittee is confident that the current scope of the point design, with a reasonable contingency, is feasible.

Geotechnical aspects of the Texas site have a direct impact on the constructibility, schedule, and cost of the underground conventional facilities. Exploration of the site geology and characterization of various rock formations in which the SSC will be built appear to be proceeding in a well-organized and comprehensive manner. The subcommittee was favorably impressed with the level of detail with which geotechnical aspects have been evaluated as a basis for conceptual design and cost estimation.

The main area of concern to the subcommittee is the geotechnical characteristics of Eagle Ford shale. Since approximately 12 percent of the collider tunnel circumference and, most importantly, the experimental halls in the west cluster are to be constructed through or immediately above this geologic zone, expeditious exploration and instrumentation of the shale strata is strongly recommended. While the scope of the SCDR point design does include some provisions for special construction of the west cluster experimental halls, the final geologic impact represents the most obvious risk factor in the conventional facilities scope.

The subcommittee made several specific recommendations, which are summarized here and discussed further below. The recommendations include:

1. Consider increasing the total estimated cost (TEC) for conventional construction by $63.5 million.

2. Augment the limited construction schedules to include integrated milestones and identification of critical activities, their durations, and floats.

3. Increase the staff of the SSCL Conventional Construction Division and appoint a permanent manager.

4. Proceed with early construction of the 55-ft-diameter shaft at the proposed E1 complex or the Large Diameter Drilled Hole (LDD) to obtain additional geotechnical data on the Eagle Ford shale areas of the site.

5. Give consideration to optimizing the location of the four detectors at the different IR regions in an attempt to mitigate the effects of Eagle Ford shale.

6. Consider increasing the contingency for the experimental halls to 30 percent and for underground tunnel construction to 25 percent to reflect the potential risk of underground construction.

7. Consider increasing the contingency for surface facilities by $1.7 million since actual space requirements will have to be confirmed.

8. Reinstate the diamond bypass tunnel at both the east and west IR clusters, if cost experience during construction permits.

9. Expedite negotiations with the AE/CM and issue a notice to proceed.

6.2 Total Estimated Cost

Recommendation: Consider increasing the TEC for conventional construction by $63.5 million.

The conventional facilities consist of all tunnels, enclosures, buildings, and associated structures required to accommodate the SSC technical systems, experimental facilities, and auxiliary support functions. Infrastructure items such as power, utilities, and site preparations are included in this category. The baseline scope of this SCDR was identified as a point design — a point of reference in the ongoing design development and optimization for the purpose of evaluating cost and schedule. The conceptual design of the conventional facilities, as stated in the SCDR and presented by the SSCL Conventional Construction Division (CCD), is adequate. However, because of the preliminary nature of the technical design and the potential risks associated with underground facilities, the subcommittee recommends an increase of $63.5 million (FY 1990) in the TEC for conventional construction, an increase of 5.3 percent. The SCDR base-cost estimate in FY 1990 dollars excluding contingency is $1.051 billion.

6.3 Construction Schedules

Recommendation: Augment the limited construction schedules to include integrated milestones and identification of critical activities, their durations, and floats.

The subcommittee is concerned that the construction schedules are based on a "point design" with no integrated critical-path schedule and, therefore, believes that the schedules are optimistic. Critical milestones for the start of construction are the AE/CM Notice to Proceed, Record of Decision (ROD) for the Supplemental Environmental Impact Statement (SEIS), and successful testing of industrially assembled magnets. The schedule dates for these critical milestones must be achieved for the construction schedule to be valid. Other key potential constraints are the stated funding profile, magnet delivery dates, and procurement schedules. Also, the number and level of milestones proposed is too limited.

6.4 Management

Recommendation: Increase the staff of the SSCL Conventional Construction Division and appoint a permanent manager.

The subcommittee believes that the management approach in preparing the estimates was exceptional. The contractor has taken a sound approach of basing the conceptual cost estimate on takeoffs rather than the conventional method based on square footage. The organization consists of a tiered approach that has been well tested on other large projects. There is a good working relationship between the contractor and the TNRLC. However, the subcommittee has concerns about management in the areas of CCD staffing, AE/CM mobilization, implementation of systems-engineering activities, and the coordination of infrastructure requirements with the TNRLC.

The subcommittee believes that current CCD staffing, including contractors, is insufficient, that immediate action to increase staffing levels is necessary, and that appointing a permanent CCD manager is absolutely necessary for successful completion of conventional construction. In order to manage the AE/CM work, a positive well-defined line of communication between the organizations needs to be established for transmitting firm design criteria and reviewing designs. The proposed CCD staff level of 25 persons appears marginal and may require a project management group in place of a matrix management system. Once the AE/CM is aboard and the interfaces established, a concentrated effort will be required to produce Title I and II documents for the initial facilities.

6.5 Geotechnical Data for Eagle Ford Shale

Recommendation: Proceed with early construction of the 55-ft-diameter shaft at the proposed E1 complex or the LDD to obtain additional geotechnical data on the Eagle Ford shale areas of the site.

The most serious concern regarding the underground conventional facilities arose from the unknown in-situ rock performance of the Eagle Ford shale that intercepts the collider tunnel and western experimental halls. The selection of each detector and its experimental hall will affect the final foundation design, particularly in Eagle Ford shale, where there is an immediate need for more data. Measurements of the response of *in-situ* Eagle Ford shale during the initial phases of construction will provide valuable input for design of the entire experimental hall structure, especially the foundations. Moreover, characterization of *in-situ* Eagle Ford shale behavior will provide crucial information regarding the potential foundation movements during and after detector construction. Because of the time and effort required to adequately analyze the behavior of the Eagle Ford shale by means of instrumented field measurements, the subcommittee strongly recommends early construction in the shale of the 55-ft -diameter shaft at the proposed E1 complex as an addition to the geotechnical exploration effort to obtain data on the shale response.

6.6 Underground Experimental Halls

Recommendation: Consider increasing the contingency for the experimental halls to 30 percent.

The large underground experimental halls require containment of very large detectors, the largest being in the range of 50,000 to 60,000 tons. Hall size can be compared to that of a football stadium, with the largest being 131 ft wide, 354 ft long, and 113 ft high. The current plan is to construct the halls using cut-and-fill techniques. Because the scope of the detectors is as yet unfixed and because of a lack of site data on the characteristics of Eagle Ford shale as a foundation medium, the subcommittee recommends that the current contingency be raised to 30 percent.

Recommendation: Consideration should also be given to optimizing the location of the four detectors at the different IR regions in an attempt to mitigate the effects of Eagle Ford shale.

It is important that the detectors be designed with due consideration of the geologic medium on and in which they will be founded. It will be advantageous to consider an optimal location for each detector that takes into account the properties of the rock formations and attempts to match detector design with geotechnical characteristics and prospective foundation performance. The detector designer must recognize the potential for long-term foundation movement, especially in Eagle Ford shale, and with geotechnical support, develop a detector that can accommodate long-term displacement either by releveling or other appropriate means of adjustment.

6.7 Collider Tunnel

Recommendation: Consider increasing the contingency for underground tunnel construction to 25 percent.

The subcommittee studied several aspects of the scope, constructibility, and cost of the collider tunnel, including labor and material and the experience of contractors on similar projects. The assumptions for tunneling, such as advance rates, crew size, etc., are representative of the site conditions to be encountered. The major cost component of underground construction is the main collider tunnel, including supporting shafts and the short areas off the tunnel referred to as niches. The subcommittee believes that the base estimate is reasonable, but, owing to the preliminary nature of the design, the contingency should be increased to 25 percent. The SSCL based its 20 percent contingency allowance on the expectation that designs of collider sections could be replicated. The subcommittee believes that replication will occur to a more limited extent and that other actions will have a greater influence on design and construction. The recommended 25 percent contingency accounts for potential design changes, potential varying costs of construction for the large amount of underground work, unknowns in geology, and constraints in the proposed schedule.

6.8 Surface Utilities and Infrastructure

Recommendation: Consider increasing the contingency for surface facilities to 15 percent.

The conceptual design for the surface facilities, such as office buildings, service or utility buildings, and industrial facilities was based on several detailed models of specific building types whose floor areas meet the estimated needs of the technical groups. Although the estimated space requirements were validated by comparisons with similar facilities at other accelerator laboratories, actual space requirements will have to be confirmed. The subcommittee feels that the overall scope, methodology, and cost estimate, with a small increase in contingency ($1.7 million), for surface facilities is feasible. The contingency for these facilities is associated with the as yet undetermined floor areas rather than unusual or undefined construction techniques.

6.9 Bypass Tunnel

Recommendation: Reinstate the diamond bypass tunnel at both the east and west IR clusters, provided that cost experience during construction permits.

Several significant facilities have been deleted from the SCDR baseline design and reserved as future projects in an effort to contain the TPC of the project, including the diamond bypass tunnels at the east and west IR clusters, which are an inherent feature of the SSC conceptual design. Their construction would enhance the collider performance and provide the operational flexibility both to construct detectors while commissioning the collider and to commission the collider without affecting the detectors. The estimated additional cost for tunneling these two bypasses is approximately $33 million, including mechanical and electrical systems. A smaller, additional amount will be needed for installation of the magnet facilities. The subcommittee recommends that the bypass tunnel at both the east and west IR clusters be reinstated in the scope if cost experience during construction permits it.

6.10 AE/CM

Recommendation: Expedite negotiations with the AE/CM and issue a notice to proceed.

The mobilization of the AE/CM is critical to attaining the early conventional-construction milestones of the project, including the prototype installation facility, the magnet development laboratory, the magnet test laboratory, and the ASST (string test facility). The schedule calls for the AE/CM to begin design in May 1990, but this date has now passed. Moreover, final contract negotiations, mobilization on site, establishing interfaces, integrating the firms of the joint venture, reconfirmation of the conceptual schedule and cost estimate, analyzing the existing body of design work, master site planning, and other early tasks will dilute the initial AE/CM productivity.

7. EVALUATION OF COST ESTIMATE AND CONSTRUCTION SCHEDULE

This section provides an overall review and evaluation of the SSC Site-Specific Conceptual Design Report (SCDR) and associated documents by the Energy Research Review Committee (ERC) with respect to the cost estimate, construction schedule, and management of the SSC. The primary objective of this part of the review was to assess the following:

- The cost estimate as presented with particular emphasis on the methodology used, completeness, and the assumptions underlying the estimate.
- The master schedule and its compatibility with the logical flow of work and the availability of human and fiscal resources.
- The overall state of readiness of the SSCL to manage the project.

Management considerations were a primary focus of the review by the ERC. The SSC represents a Department of Energy endeavor on a unique scale to establish a new national laboratory on a green field site. The organization of the SSCL must consider design, construction and commissioning of the SSC itself, and the necessary R&D associated with that activity, as well as a buildup of support and infrastructure capabilities to allow effective operation of the SSCL as required both during and after commissioning of the facility. Management issues at the upper organizational levels were the primary focus of the review by the Subcommittee on Management, Cost, Schedule, and Funding (see Section 10.9).

In considering management aspects of the SSCL, its organization was assessed with regard to staffing, staff responsibilities, interfaces and supervision, and work breakdown structure (WBS) responsibilities and authority, including the management responsibilities of the Directorate and the Project Manager's organization. The systems engineering function and the configuration management function were also addressed. The total estimated cost of the project was assessed by considering individual WBS cost elements, contingency allocation, a baseline funding profile presented by SSCL (and several alternative profiles), and the application of escalation.

The master schedule for the project was presented by the SSCL and the logic incorporated into this schedule was explained in detail. The development of this schedule and its buildup based on input from the various SSCL divisions was explained. The committee assessed the completeness of the schedule, the duration of activities, schedule logic, and the critical activities and the major milestones.

7.1 Cost Estimate

7.1.1 Methodology

A WBS encompassing all construction cost aspects of the conceptual design was developed by the SSCL to ensure that all elements of the SSC project were included in the design and costing process. The general philosophy of the SCDR cost estimate was to include all construction costs needed to bring the SSC to a state of operational readiness and to create a laboratory environment suitable for conducting high energy physics experiments at the facility. In addition to the construction cost of the technical systems and conventional facilities, the construction project includes:

- Required management and administration.
- Engineering, design, inspection and administration (EDIA) for technical systems.
- Architectural engineering/construction management (AE/CM) services for conventional systems.
- Allowance for contingency.

These elements comprise the total estimated cost (TEC). The SCDR cost estimate also includes costs for the R&D program for accelerator systems and components, particle detectors, computers, and commissioning activities. These costs, when added to the TEC, comprise the total project cost (TPC). Excluded from the cost estimate are site acquisition, primary power, and other utility distribution systems outside the site boundary which will be provided through the TNRLC. All costs were estimated by SSCL in FY1990 dollars and escalated to as-spent dollars based on a funding profile developed by SSCL and escalation rates provided by DOE and OMB.

Where possible, the cost estimates for the SSC components and systems were based on previous experience with similar accelerator systems and industry standard conventional construction practices. The cost estimate for the collider ring superconducting magnets, which are a major fraction of the total project cost, represents a considerable extrapolation from previous experience and, therefore, received more attention to detail in the evaluation. In the conventional facilities categories, the underground construction, including the tunnel and experimental halls, represents the largest portion of the total conventional systems cost. These estimates were derived by several AE firms, and the final estimate represents an SSCL composite. Variances at this conceptual stage are based primarily on engineers' assessments of the cost of constructing underground structures.

Cost estimates were based on vendor estimates (approximately 30 percent), engineering estimates with vendor and SSCL input (approximately 30 percent), and estimates by the SSCL based on experience and engineering standards (approximately 40 percent). In some cases consultants were used to verify cost estimates and to estimate specialty areas. Current local Davis-Bacon labor rates were used in the estimate where appropriate.

An EDIA estimate was developed for each technical and conventional cost element, based on an assessment of the complexity, uniqueness and criticality of each element. The resulting EDIA estimate of 16 percent of construction costs includes AE/CM activities, SSCL engineering and project management, and magnet vendor engineering. The EDIA cost was derived from estimated manhours, rates, and overhead estimates.

Contingency allowances were also developed for each of the technical and conventional cost elements. The contingency assigned for each WBS element was based on an evaluation of SSC requirements relative to the current state of the art, and on project uncertainties that could affect specific cost elements including potential technical, cost, and schedule changes. Contingency was not included for R&D and commissioning activities and for the allowance for the initial complement of detectors.

7.1.2 Cost Estimate Summary, Variances, and Conclusion

The SSCL, in its SCDR and associated materials, has documented their estimated TPC for constructing and commissioning the facility at $6.57 billion in FY 1990 dollars, which includes $0.75 billion in contingency. Included in this estimate is $0.98 billion for R&D on components and for the preoperational commissioning of the facility, and $0.75 billion for fabrication of an initial complement of detectors for the SSC research program. Taking account of the schedule and the associated funding profile developed by the SSCL and escalating to as-spent dollars using escalation rates provided by the DOE and OMB results in a TPC of $7.8 billion. This TPC in as-spent dollars as developed by the SSCL is presented in Table 7.1 and includes all costs expected in this project, with the following exceptions:

- Costs incurred in FY 1988 and FY 1989 totaling $132 million which, when added to the SSCL estimate, results in a TPC in as-spent dollars of $7.97 billion.
- Costs for the support and operation of injector accelerator and collider sectors after they have been commissioned and of certain SSCL facilities and services required during commissioning of the project (estimated by SSCL to be approximately $350 million as-spent).

The ERC subcommittees reviewed the SSCL-evaluated costs for their respective areas of expertise, and detailed discussions of their analyses are included in their individual reports in Section 10. ERC cost estimate assessments in FY 1990 dollars were compiled in the WBS format and rolled up to WBS level 3. Table 7.2 provides the comparison of the SSCL estimate and the ERC assessment. Table 7.3 provides a more detailed analysis and comparison of the SSCL estimate and the ERC assessment at WBS level 3. Table 7.4 provides a summary explanation of the variances, keyed to comment numbers in Table 7.3.

Table 7.1
SCDR Total Baseline Cost Estimate (As-Spent $K)

			Item Cost ($K)	Total Cost ($K)
A.	Engineering, Design, Inspection, and Administration (16% of item B*)			677,746
B.	Construction Cost		1,084,390	4,314,802
	Accelerator Systems	709,391		
	Experimental Systems	174,364		
	Site and Infrastructure	134,973		
	Campus	65,662		
	Technical Systems		3,230,412	
	Injector Components	358,107		
	Injector Superconducting Magnets	158,957		
	Collider Components	787,504		
	Collider Superconducting Magnets	1,925,844		
C.	Contingency (18.6% of above costs)			920,098
	Total Estimated Cost (TEC)			**5,912,646**
D.	R&D and Pre-Operations			1,082,023
E.	Experimental Systems			842,000
	Total Project Cost (TPC)			****7,836,669**

*Includes A-E/CM, SSCL Engineering, SSCL Project Management, and Superconducting Magnet Vendor Engineering

**Excludes FY 1988 and 1989 appropriations of $132.6 million

Table 7.2
Comparison of ERC and SSCL Cost Summary in FY 1990 and As-Spent Terms

	SSCL	ERC	Variance	
			Cost	Percent
FY 1990				
Base Estimate ($M)	5,814	5,871	57	1
Contingency ($M)	752	1,148	396	53
TOTAL (FY 1990 $M)	6,566	7,019	453	
**Total Rounded to FY 1990 $B*	*6.6*	*7.0*	*0.4*	*7*
As-Spent				
Base Estimate ($M)	6,916	6,983	67	1
Contingency ($M)	920	1,403	483	53
TOTAL (FY 1990 $M)	7,836	8,386	550	
**Total Rounded to As-Spent $B*	*7.8*	*8.4*	*0.6*	*7*

*Excludes FY 1988 and FY 1989 appropriations of $132.6 million.

Table 7.3

SSC SCDR
SUMMARY COST COMPARISON ROLLUP (FY90 $K)

17-Jul-90
09:28

Project Component	********** SSCL Estimate	***************			*********** ERC Estimate	***************					
	Base Estimate	Contingency %	Contingency Cost	Total Cost	Base Estimate	Contingency %	Contingency Cost	Total Cost	Variance Cost	Variance %	Comments
1.1 Accelerator Systems	1082170	17.59%	190319	1272489	1109145	21.84%	242215	1351360	78871	6.20%	
1.1.1 Management and Support	30230	8.00%	2418	32648	30230	5.00%	1512	31742	-907	-2.78%	(1)
1.1.2 Linac	37015	12.79%	4735	41750	36288	13.33%	4839	41127	-624	-1.49%	(2)
1.1.3 LEB	42351	14.87%	6296	48647	44072	20.64%	9097	53169	4522	9.30%	(3)
1.1.4 MEB	112501	13.76%	15478	127979	116861	21.86%	25550	142411	14432	11.28%	(3)
1.1.5 HEB	155432	17.47%	27153	182585	159382	24.10%	38418	197800	15216	8.33%	(3,4)
1.1.6 Collider	635975	18.91%	120232	756207	653055	22.75%	148552	801607	45400	6.00%	(3,5)
1.1.7 Test Beams	11231	21.12%	2372	13603	11822	22.09%	2612	14434	831	6.11%	(6)
1.1.8 Global Systems	57435	20.26%	11635	69070	57435	20.26%	11635	69070	0	0.00%	
1.2 Magnet Systems	1904207	19.33%	368171	2272378	1904207	34.56%	658171	2562378	290000	12.76%	(7)
1.2.1 Management and Support	26944	8.00%	2156	29100							
1.2.2 HEB Magnet Production	171052	19.73%	33754	204806							
1.2.3 Collider Magnet Production	1667590	19.49%	324968	1992558							
1.2.4 SSCL Test Facilities	38621	18.88%	7293	45914							
2.0 Conventional Construction	1051489	17.90%	188216	1239705	1069724	21.83%	233494	1303218	63514	5.12%	
2.1 Accelerator Facilities	635852	19.22%	122231	758083	635852	23.66%	150422	786274	28191	3.72%	(8)
2.2 Experimental Areas	126375	17.47%	22076	148451	126375	25.02%	31623	157998	9547	6.43%	(8)
2.3 Site and Infrastructure	110480	17.00%	18782	129262	110480	20.00%	22096	132576	3314	2.56%	(8)
2.4 Campus	54663	12.23%	6686	61349	54663	15.00%	8199	62862	1513	2.47%	(9)
2.5 Design & Construction Mgmt.	124119	14.86%	18441	142560	142354	14.86%	21154	163508	20949	14.69%	(10)
3.0 Project Management & Support	48691	12.91%	6288	54979	48691	10.34%	5035	53726	-1252	-2.28%	(1)
Subtotal (FY $90)	4086557	18.43%	752994	4839551	4131767	27.56%	1138915	5270682	431132	8.91%	(11)
Escalation	905991	18.44%	167104	1073095	916014	27.58%	252678	1168692	95597	8.91%	(11)
SUBTOTAL TEC (Construction) (As-Spent$)	4992548	18.43%	920098	5912646	5047781	27.57%	1391593	6439374	526728	8.91%	
4.0 R&D and Pre-Operations (FY $90)	975837	0.00%	0	975837	987477	0.94%	9302	996779	20942	2.15%	(12)
5.0 Experimental Systems (FY $90)	752120	0.00%	0	752120	752120	0.00%	0	752120	0	0.00%	(13)
Subtotal (FY $90)	1727957	0.00%	0	1727957	1739597	0.53%	9302	1748899	20942	1.21%	
Escalation	196066	0.00%	0	196066	196066	1.21%	2376	198442	2376	1.21%	(11)
SUBTOTAL (R&D/Pre-Ops/Exper Sys in As-Spent$)	1924023	0.00%	0	1924023	1935663	0.60%	11678	1947341	23318	1.21%	
TOTAL PROJECT COST (TPC) (As-Spent$)	6916571	13.30%	920098	7836669	6983444	20.09%	1403271	8386715	550046	7.02%	
Summary - TPC in FY $90:											
TEC (WBS 1.0 - 3.0)	4086557	18.43%	752994	4839551	4131767	27.56%	1138915	5270682	431132	8.91%	
WBS 4.0	975837	0.00%	0	975837	987477	0.94%	9302	996779	20942	2.15%	
WBS 5.0	752120	0.00%	0	752120	752120	0.00%	0	752120	0	0.00%	
TOTAL TPC (FY $90)	5814514	12.95%	752994	6567508	5871364	19.56%	1148217	7019581	$452,073	6.88%	
TOTAL TPC (As-Spent$)				$7,836,669				$8,386,715	$550,046	7.02%	
				$7.8 B				$8.4 B	$.6 B		

Table 7.4
Summary Explanation of Comments in Table 7.3

Comment	WBS	Project Component	Variance
(1)	1.1.1	Accelerator Management and support	Reduced contingency to reflect the confidence in the base estimate.
(2)	1.1.2	Linac	Revised the base estimate to reflect the proposed reduced scope of the rf system and increased the base estimate of the ion source based on recent experience.
(3)	1.1.3	LEB	Increased the base estimate for the power supplies, installation, and equipment cost and added conventional magnet shipping, which was omitted. Increased contingency to reflect the conceptual status of the estimate.
(3)	1.1.4	MEB	(same as 1.1.3)
(3) (4)	1.1.5	HEB	(same as 1.1.3) Plus: added Lambertson septum magnet costs omitted from estimates.
(3) (5)	1.1.6	Collider	(same as 1.1.3) Plus: increased the utilities installation cost.
(6)	1.1.7	Test Beams	Increased the safety system base estimate. Also, increased the magnet contingencies.
(7)	1.2	Magnet Systems	Increased contingency to reflect the superconducting dipole contracting uncertainties; additional cold testing; quadrupole bore diameter, which may increase; and the HEB magnets in which the bore diameter may increase and the wire filament size may change.
(8)	2.1	Accelerator Facilities	Increased contingency to reflect the potential risks in underground construction.

Table 7.4 (cont'd.)

Comment	WBS	Project Component	Variance
(8)	2.2	Experimental Areas	(same as 2.1)
(8)	2.3	Site and Infrastructure	(same as 2.1)
(9)	2.4	Campus	Increased the contingency a modest amount (3 percent). The reviewers assume a design-to-cost-estimate philosophy.
(10)	2.5	Construction Management	Increased the base estimate to reflect the complexity of this project.
(1)	3.0	Proj. Mgmt. and Support	Reduced contingency to reflect the confidence in the base estimate.
(11)		Escalation	Assumed at same ratio as the SSCL estimate.
(12)	4.0	R&D and Preoperations	Increased the base estimate to reflect additional ES&H manpower requirements.
(14)	5.0	Experimental Systems	No net change in the estimate.

In addition to the technical items and conventional facilities review by the individual subcommittees, the Subcommittee on Management, Cost and Schedule assessed the cost components of the WBS 3.0, Management and Support, following discussions with cognizant SSCL representatives. The subcommittee concluded that the direct SCDR management support costs and associated contingencies presented in the SCDR are reasonable, have appropriate bases, and present no undue cost risk.

The ERC finds, with the exception of the previously stated activities, that the SCDR base cost estimate (i.e., without contingency) in FY 1990 dollars is credible and generally consistent with the scope of the project. However, the procurement strategy developed by the SSCL and DOE for the collider dipole magnets represents a significant cost risk. The committee recommends that an alternative strategy be considered that enhances SSCL/industry technical interaction and relieves the manufacturer of uncontrolled risks, thereby reducing the procurement cost risk to the project and increasing potential competition. However, it is critical to get the magnet industrialization process vigorously underway as soon as possible. Thus, the collider dipole magnet request for proposals should be issued as soon as possible, even in its current form, as long as it provides for a later change in production contract type via a contract modification. The allowance provided in this estimate for experimental facilities together with the anticipated significant level of non-Federal contributions for detectors will provide a balanced initial program of research with the SSC.

The subcommittee also notes that the budget for support and operation of injector accelerators and collider sectors after they have been commissioned and of certain SSCL facilities and services required during the commissioning phase of the project (estimated by SSCL to be about $0.35 billion as-spent) is not included in the TPC. The subcommittee has assessed the justification for these costs and has found them to be reasonable. Funding is necessary for these costs.

The subcommittee has identified a few items in the base estimate presented in the SCDR which it believes are underestimated and a few which are overestimated. The subcommittee also notes that the level of contingency associated at this early stage with certain areas of this unique project is less than might be desirable in order to assure successful completion of this project within the planned level of funding. Compared to the estimate presented by the SSCL, the committee recommends that the base cost estimate for the total project be increased by $57 million (FY 1990) and the associated contingency allowance by $395 million (FY 1990). The resulting TPC suggested by the ERC is $7.02 billion (FY 1990). Escalating to as-spent dollars, using the escalation rates provided by the DOE and OMB and the funding profile developed by the SSC, results in a TPC calculated by the ERC of $8.4 billion.

7.2 Schedule and Funding

7.2.1 Assumptions

Several assumptions are made by the SSCL that the ERC believes are critical to attainment of the proposed schedule and funding profile. The key assumptions identified by the ERC generally relate to those activities that occur relatively early in the construction project and are identified below:

- SSCL staff of adequate quantity and quality will be recruited in a timely manner. In some technical areas a staff of exceptional quality is required very early in the project. Several lead positions will be filled soon with permanent personnel.
- Funding will be provided to match the funding profile that rises rapidly to over $1.25 billion per year for FY 1992 through FY 1995.
- Adequate procurement authority will be made available at the SSCL and DOE On-site Project Office to allow the necessary contractual actions to be completed as expeditiously as possible to conserve time and to reduce the paper chain.
- There are no restrictions on conventional construction before the 1992 magnet-string test.
- The R&D program will progress on the required fast-track schedule.
- The E1 complex, including the magnet development laboratory and prototype installation facility, will be available when required.
- The progress of the magnet industrialization program will be rapid, leading to the testing of industrially assembled magnets in the E1 complex in September 1992.
- Industrial bids for magnet production will be well matched to the SSCL estimate.

- Agreements with the consortia selected to develop the initial complement of detectors will reflect deadlines necessary for meeting cost and schedule goals.
- Underground conditions actually encountered will match predictions developed from the boring programs to date, and adequate tunnel boring machines will be available when needed for the very aggressive underground construction schedule.
- Facilities located outside the SSCL boundaries, planned to be provided by others, will be completed as required.

7.2.2. Schedule/Funding Overview

The SCDR master schedule developed by the SSCL, presented in Fig. 7.1, was developed to indicate an overall logic for integration of R&D, design, construction and commissioning activities leading to completion of the project in late 1998. Funding profiles were also developed by SSCL for a baseline case (Fig. 7.2) and for an alternate case (Fig. 7.3), which takes into account delays in the construction of the tunnel until after the ability to produce collider dipole magnets is proven. The SCDR schedule has been manpower loaded to reflect the overall manpower plan for the SSCL (Fig. 7.4). The baseline schedule and resulting funding profile assume that an aggressive ramp-up of resources and an obligational authority of between $1.25 billion and $1.39 billion will be provided between FY 1992 and FY 1995. The schedule also assumes that the very aggressive pace of project activities can be planned for and maintained throughout this period.

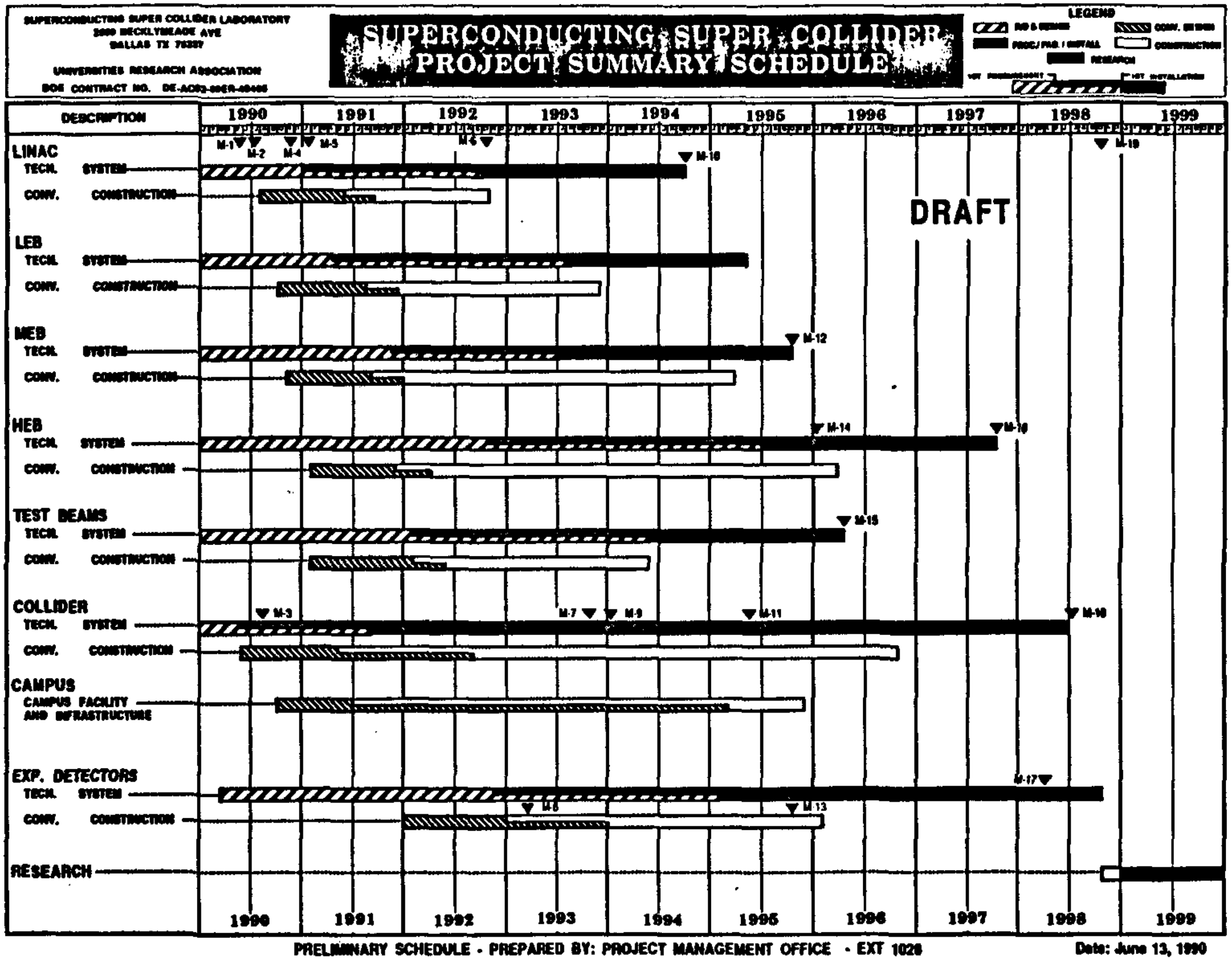


Figure 7.1. SSC Project Summary Schedule: the master schedule developed by the SSCL.

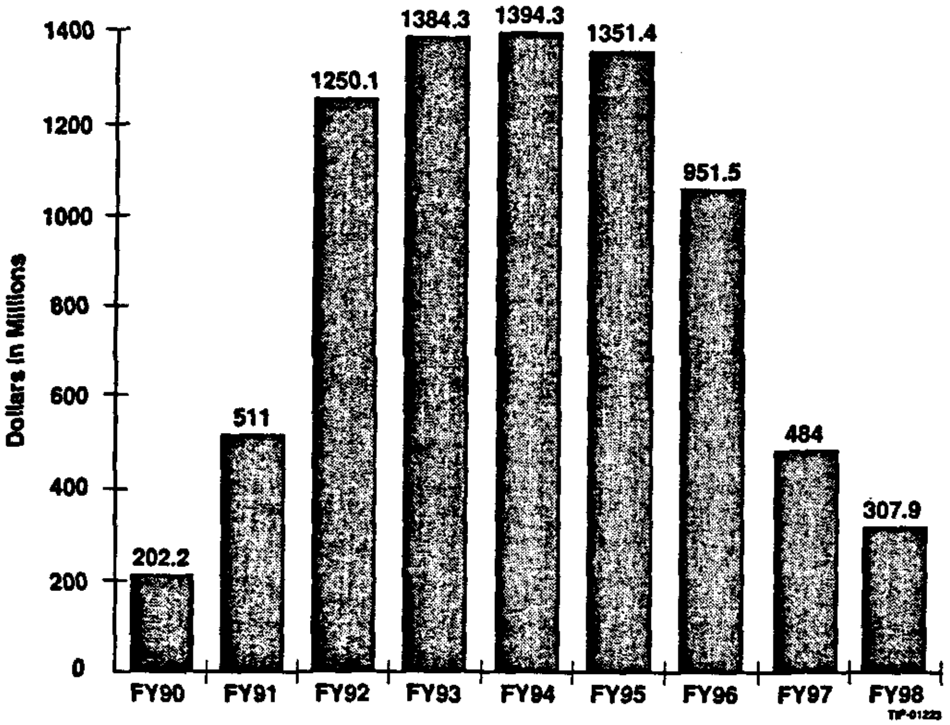


Figure 7.2. Baseline funding profile developed by the SSCL.

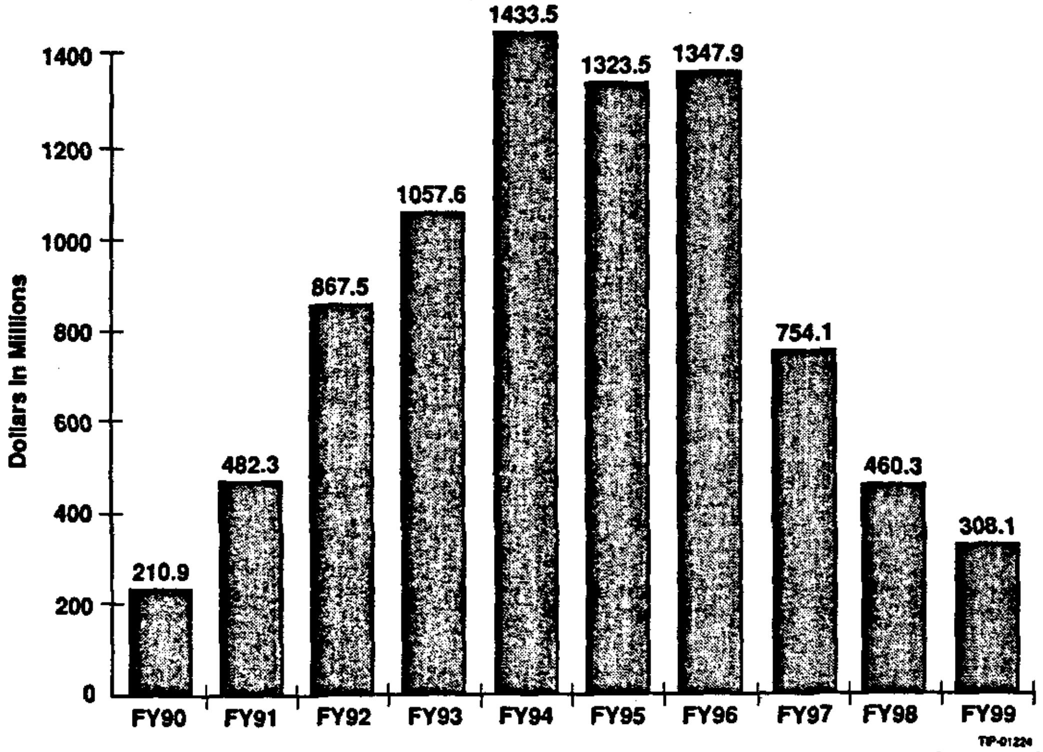


Figure 7.3. Alternate funding profile, also developed by the SSCL, for the case of postponing tunnel construction until after the ability to produce collider dipole magnets has been demonstrated.

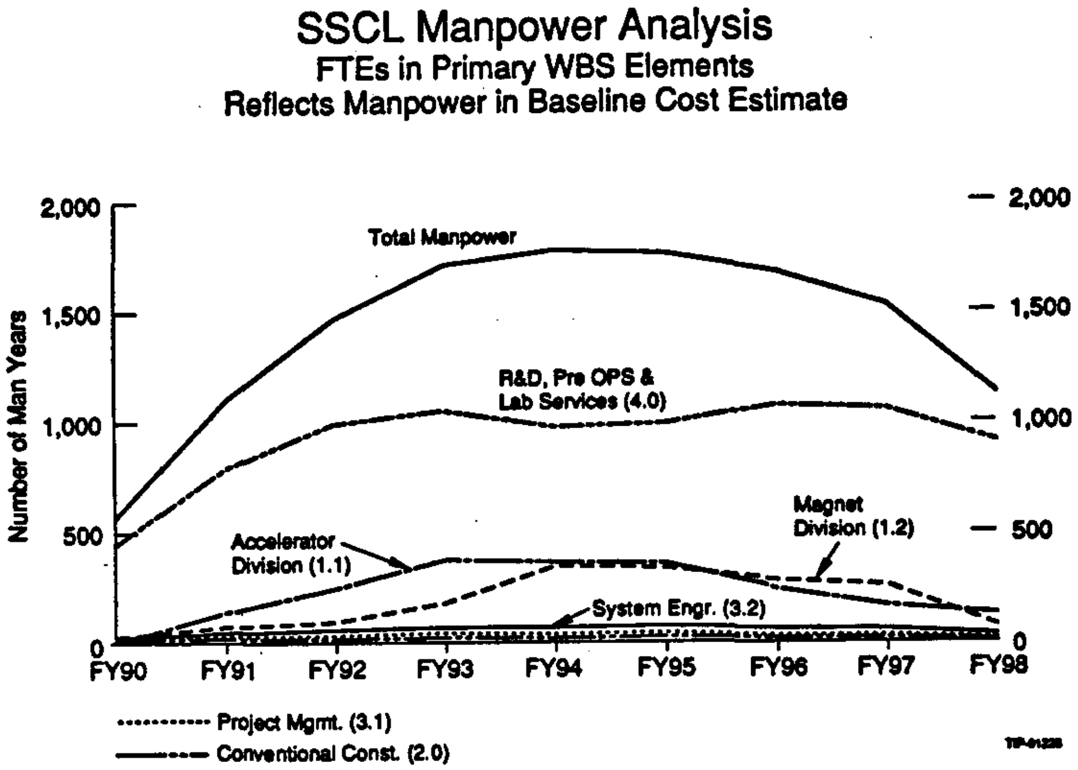


Figure 7.4. SSCL manpower analysis showing FTEs in primary WBS elements. This profile reflects the manpower in the baseline cost estimate.

7.2.3 Key Milestones

Draft level 1 milestones for the project proposed by SSCL are presented in Table 7.5 and are contained in the draft Project Management Plan. These are pending approval and are subject to modification. The ability of the project to meet the early milestones presents the most risk to maintaining the overall project schedule. The pending collider dipole magnet contract award is a critical milestone which sets in motion an intensive series of activities leading to a collider dipole magnet string test in September 1992. This testing of industrially assembled superconducting magnets at the E1 complex represents a critical milestone which should be carefully monitored in order to gauge the project's early progress. Similarly, a Record of Decision is a necessary and critical milestone for start of conventional construction at the Ellis County site. The committee notes with concern that there are no milestones for the 20-month period from January 1991 through September 1992.

Table 7.5
Draft Major Project Milestones
Superconducting Super Collider*

		DATE
M1-1	A/E Award	May 90
M1-2	Baseline Validation Complete	Jul 90
M1-3	Collider Dipole Magnet (CDM) Contract Award	Aug 90
M1-4	SEIS Record of Decision	Nov 90
M1-5	Start SSC Civil Construction	Jan 91
M1-6	Collider String Test Complete Industry Prototypes	Sept 92
M1-7	Start First Sector CDM Delivery	Oct 93
M1-8	Begin Excavation of Experimental Halls	Mar 93
M1-9	First Collider Sector—Start Installation of Major Components	Jan 94
M1-10	Linac—Start Commissioning	Oct 94
M1-11	First Sector—Start Cool Down	May 95
M1-12	MEB—Start Commissioning	Oct 95
M1-13	Beneficial Occupancy of Large Experimental Halls	Oct 95
M1-14	HEB—Start Installation	Jan 96
M1-15	MEB—Test Beams Available	Apr 96
M1-16	HEB—Start Commissioning	Oct 97
M1-17	Detectors—Start Commissioning	Mar 98
M1-18	SSC—Start Commissioning (Beam)	Jul 98
M1-19	SSC—Complete Commissioning—Beams to Experiments	Oct 98

* Taken from SSCL draft Project Management Plan.

7.2.4 Schedule and Funding Profile Evaluation

The schedule and funding profile are inextricably linked in any project. For this project, their sensitivity to each other could result in the potential for large cost impacts due to schedule slippage. Very large projected project expenditures in FY 1992 through 1995 are required for meeting the very aggressive schedule. In addition, many major activities are critically dependent on one another so that delays in one aspect of the project can have a significant schedule (and cost) impact on others. For example, should the project follow the option permitting tunneling only after the production capability for superconducting dipole magnets is proven, approximately $0.5 billion of tunneling contracts is at risk of slipping into succeeding fiscal years with resultant delay and additional cost. Similar examples of critical linkage are the relationship between tunneling progress and the schedule for installation of collider components, including the superconducting magnets, and the need to commission the injector complex before the collider can be commissioned.

Significant delays in this lengthy project will result in large cost impacts due to escalation and to staffing stretchout.

The proposed construction project schedule leading to completion in late 1998 is considered by the committee to be possible, although it is very aggressive and, therefore, carries considerable risk. The committee points out that this schedule is the basis for the funding profile developed by the SSCL which rises rapidly to over $1.25 billion per year for FY 1992 through FY 1995. This schedule implicitly assumes that the required level and quality of technical staff is put in place quickly, that the R&D program proceeds on a success oriented, fast-track schedule, and that the development of the currently undeveloped site of the facility and of the associated support infrastructure proceeds rapidly. Should the actual funding profile be less favorable, or should the supporting assumptions prove overly optimistic, there would be a delay in the project completion and a consequent increase in the total project cost.

7.3 Management Evaluation

Fig. 7.5 depicts the SSC organizational relationships and Fig. 7.6 depicts the SSCL organization. Both tables were extracted from revision 6 of the SSCL Project Management Plan (PMP) and from presentations to the ERC.

The management approach for the project adopted by the DOE and the SSCL (as described during the review) is that of a team approach with close working relationships between the two organizations with the goal of processing most administrative decisions at the local, on-site level. Achievement of this goal will require that considerable responsibility and authority be delegated to DOE and SSCL at the local level. In addition, this approach relies on time limitations for review and approval decisions in order to assure steady schedule progress and a high degree of administrative efficiency.

The DOE and SSCL organizational arrangements in the PMP will provide a framework for the necessary management relationships and interactions. They will be successful only if both organizations are fully staffed with experienced people of the best quality who work closely as a team. Top management attention and support for requiring only essential administrative actions will also be required for success. The relationship between the Project Manager and the Magnet Systems Division is considered vital to the successful production and installation of the magnets.

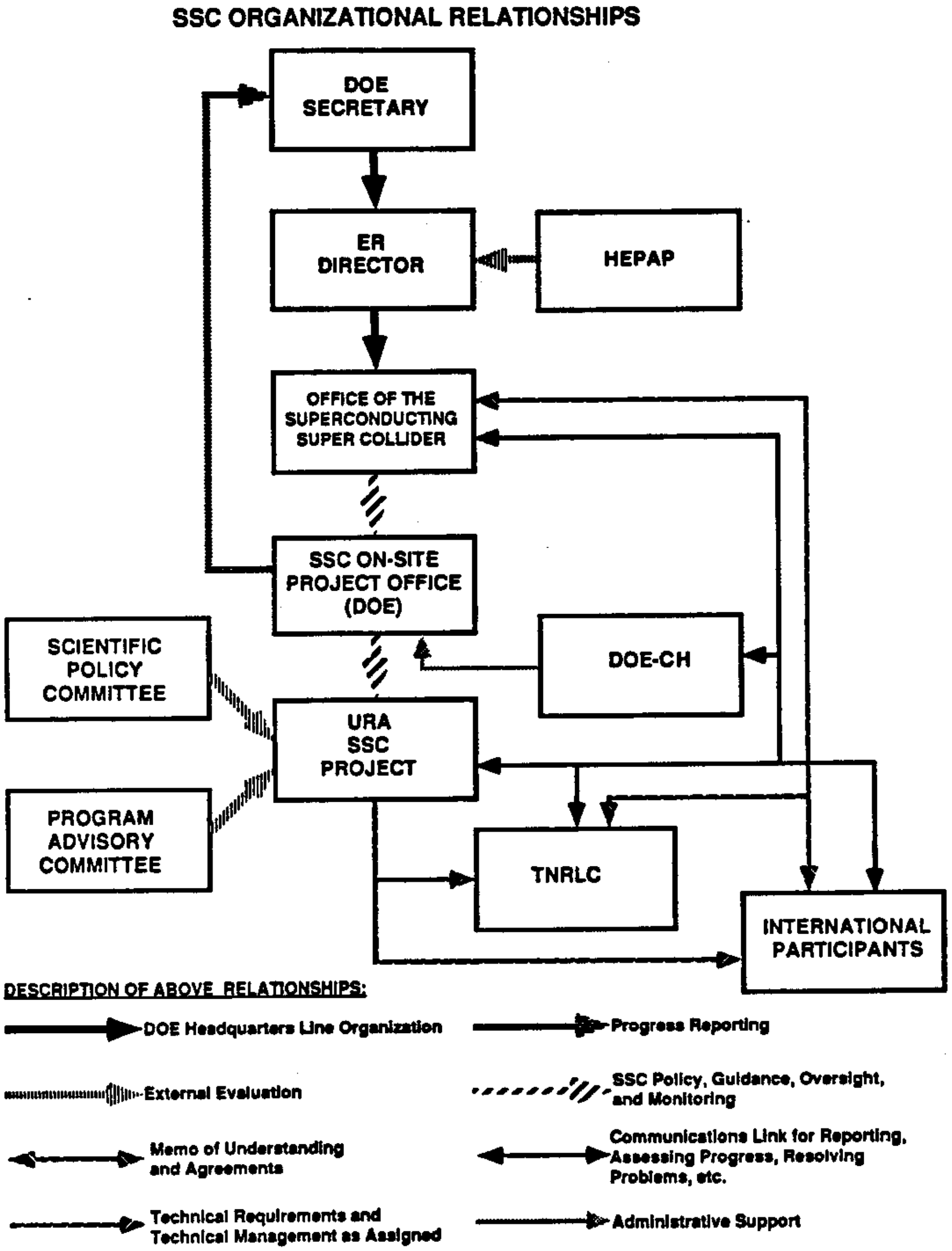
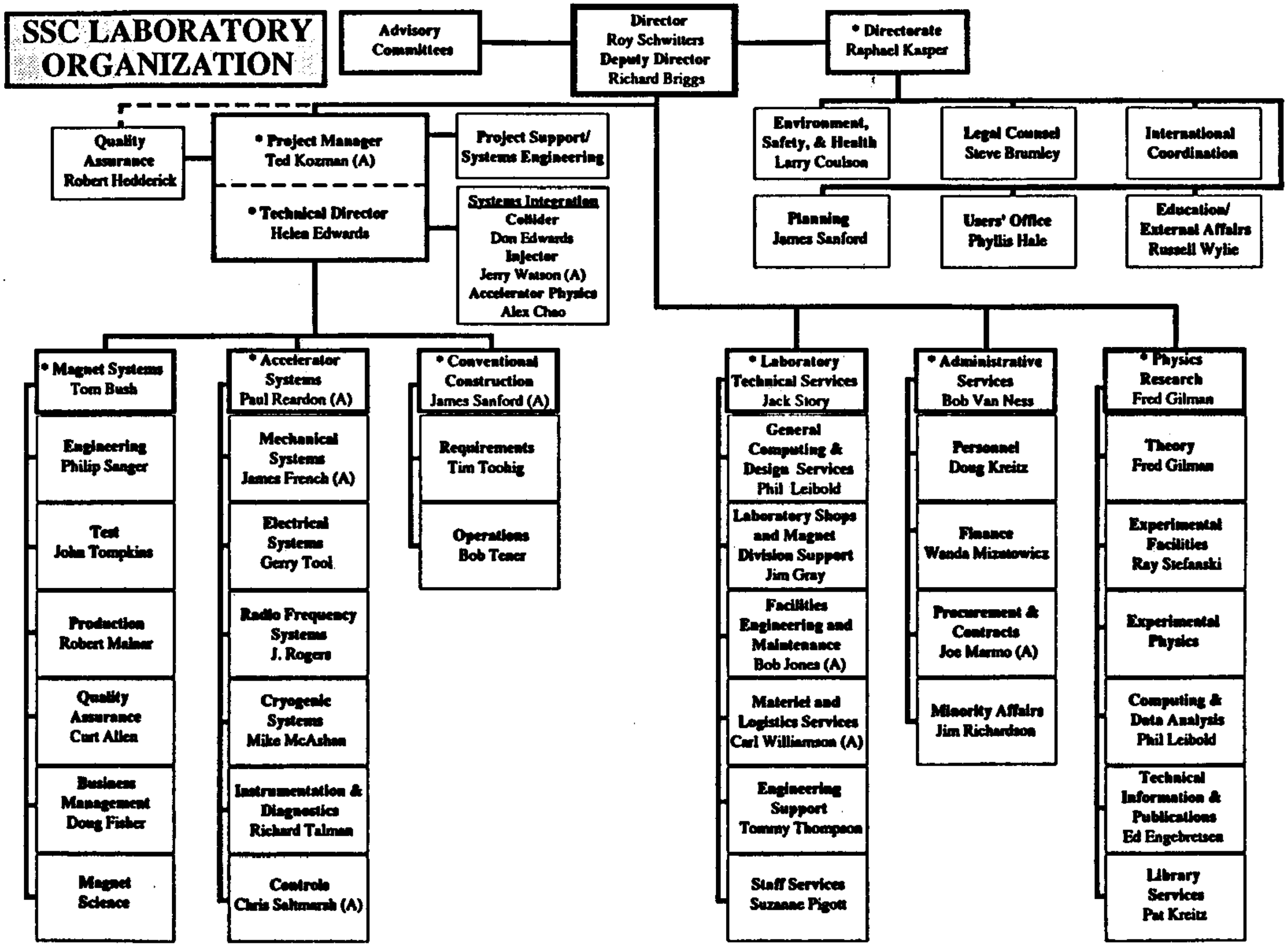


Figure 7.5. SSC organizational relationships.



** Laboratory Associate Director*
(A) = Acting

June 21, 1990
SSCL · TB-00774a

Fig. 7.6

In regards to the management philosophy and organization for the SSCL to accomplish the necessary R&D, design, construction, commissioning, and operations, the committee judges them to be appropriate for a project of this magnitude. The SSCL management has also properly considered the organizational changes that will be required to ensure a smooth transition from construction to operation of the SSC.

Strong, effective, and appropriate management is absolutely necessary for successful project completion. Currently, the SSCL is understaffed, and three of five key senior management positions are filled on an acting basis. The Laboratory Director has stated his intention to fill these positions on a permanent basis before the end of 1990. Earlier action on these positions would be beneficial. The position of DOE Project Director for the On-site Project Office has recently been filled, and his office must also be staffed. The DOE Office of the Superconducting Super Collider also requires a permanent head and additional qualified staff. The SSC contractor must assure that the most capable management team possible is put in place within the SSCL. The Department of Energy must also assure that its management and oversight personnel for the SSC project are of the highest quality and are given the necessary authority, particularly at the site office level, to shorten the time required for necessary administrative decisions and for a reduction in administrative paper requirements in order to assure that the SSC project can proceed as planned. These are judged by the ERC to be necessary conditions for the SSC project to succeed.

8. CONCLUSIONS AND RECOMMENDATIONS

From June 25 to 30, 1990, an Office of Energy Research Review Committee (ERC) evaluated the technical feasibility, estimated cost, and proposed construction schedule for the Superconducting Super Collider (SSC) as set forth in the Site-Specific Conceptual Design Report (SCDR) and related documentation and presentations provided by the Superconducting Super Collider Laboratory (SSCL). The ERC was impressed with the work accomplished since the CDR review of 1986 and with the documentation developed by the SSCL. Major changes since the 1986 CDR reflected in the SCDR are the site-specific nature of the design and the increased attention that has been given to ease of commissioning and operation as well as to reliability. The ERC believes that the design presented by the SSCL is a reasonable basis on which to build the SSC project. To a significant extent, the present design is also a reasonable basis for developing an appropriate baseline for the SSCL. This accomplishment serves as a tribute to the skill and dedication of the SSCL team.

The ERC concludes that the design presented by the SSCL is technically feasible and scoped to meet the requirements of the U.S. high energy physics program well into the next century. The design provided by the SSCL reflects advanced design activities that address many accelerator physics issues not considered in the design of previous colliders and holds the promise of performance levels beyond the basic luminosity goal of the SSC. Hence, there is little doubt that a collider based on the present design would provide the scientific community with a facility of unique capabilities promising major discoveries at the forefront of knowledge. The current design is judged by the review committee to be based on reasonable conservatism and has taken into account both reliability and maintainability.

An essential ingredient, needed for this ambitious project to succeed in meeting its technical goals, is the commitment of a world-class scientific and technical staff whose skill, experience, and dedication are matched to the challenge of the SSC. The present level of technical staffing (physicists and engineers), of both accelerator-experienced personnel and others in key areas, places severe limits on the amount and depth of work that can be accomplished in the near term.

8.1 Cost and Schedule

The SSCL has documented an estimated total project cost (TPC) for constructing and commissioning an SSC facility of $6.57 billion in FY 1990 dollars, which includes $0.75 billion in contingency. Included in this estimate is $0.98 billion for component R&D and for the preoperational commissioning of the facility, and $0.75 billion for fabrication of an initial complement of detectors for the SSC research program. Escalating the costs using the schedule and the associated funding profile developed by the SSCL and escalation rates provided by the DOE and OMB resulted in a TPC of $7.84 billion in as-spent dollars.

The ERC finds, with the exception of certain items, that the SCDR base cost estimate (i.e., without contingency) in FY 1990 dollars is credible and generally consistent with the scope of the project. The allowance provided in this estimate for experimental apparatus, together with the anticipated significant level of non-Federal contributions for detectors, will provide a balanced initial program of research with the SSC. However, the procurement strategy developed by the SSCL and DOE for the collider dipole magnets represents a significant cost risk.

The committee has identified a few items in the base estimate presented by the SSCL which it believes are underestimated and a few which are overestimated. The committee also notes that the level of contingency associated at this early stage with certain areas of the project is less than would be desirable in order to assure successful completion of this project within the planned level of funding. The committee also notes that the budget for support and operation of certain SSCL facilities and services required during the commissioning phase of the project (estimated by SSCL as about $0.35 billion, as-spent) is not included in the TPC.

The proposed construction project schedule leading to completion in late 1998 is considered by the committee to be possible, although it is aggressive and, therefore, carries considerable schedule risk. The committee points out that this schedule results in the funding profile developed by the SSCL, which rises rapidly to over $1.25 billion per year for FY 1992 through FY 1995. This schedule implicitly assumes that the required level and quality of technical staff is put in place quickly, that the R&D program proceeds on a success-oriented, fast-track schedule, and that the development of the currently undeveloped SSC site and of the associated support infrastructure proceeds rapidly. Should the actual funding profile be less favorable, or should the supporting assumptions prove overly optimistic, there would be a delay in the project completion and a consequent increase in the total project cost. The testing of industrially assembled superconducting magnets in the E1 complex in September 1992 represents a critical milestone which should be carefully monitored in order to gauge the project's early progress.

8.2 Recommendations

Major recommendations of the ERC are given below. More detailed discussion and additional recommendations can be found in Section 10.

Management

1. Strong, effective, and appropriate management is absolutely necessary for the successful completion of this project. URA should assure that the most capable management team possible is put in place within the SSCL. Key senior management positions should be filled on a permanent basis as soon as possible. A permanent manager for the injector and a lead person for each accelerator in the injector chain should be appointed.

2. The DOE should ensure that its management and oversight personnel for the SSC project are of the highest quality and are given the necessary authority within the Department to ensure that the SSC project can proceed as planned. To limit administrative delays, the management system should include a time limit for approvals by all involved parties. DOE should ensure that a single entity with appropriate authority to act on behalf of the Department is identified

for providing Environment, Safety, and Health guidance and oversight.

3. SSCL should make every effort to increase severalfold the present level of technical staffing (physicists and engineers) of both accelerator-experienced personnel and others in key areas such as controls programming as soon as possible. The URA and SSCL should make every effort to remove any administrative impediments to the recruiting of quality staff and should strive to make the Laboratory environment as attractive as possible for its technical staff. Assistance and special action by the DOE may be required to accomplish this essential goal.

4. The interfaces among the three divisions of the SSC project, between the project and the rest of the SSCL, and between the SSC program and the other national laboratories are crucial and need more attention from upper-level Laboratory management. Particular attention should be given to the relations between the Magnet Systems Division and the rest of the SSCL. The Systems Integration Group should lead the effort to form agreements and devise schedules for resolving issues.

5. Establishment by SSCL and official validation by DOE of the SSCL procurement system and procedures must be pursued expeditiously.

6. The SCDR should be updated and revised for internal consistency as well as for consistency with its executive summary and the design presented to the Committee. The SCDR should describe the baseline design and any future options for which accommodating provisions influence the baseline design. Descriptions of design alternatives that preceded the baseline design should be eliminated. The work breakdown structure (WBS), which forms the basis for project interfacing and cost estimating, should be reworked and optimized to ensure a consistent approach.

7. Adoption by the SSCL of a more structured method of setting systems requirements is strongly recommended. Requirements on common technology have generally been set by looking at the most pressing current issue, for instance, the 15-m collider dipole magnet, rather than at the most stringent service condition across all similar devices. Once the most stringent requirement is located, a conscious decision can be made as to the life cycle cost effectiveness of maintaining or rejecting commonality.

Cost

8. The base cost estimate identified by the ERC for the total project is increased by $57 million (FY 1990), a 1 percent increase compared to the estimate presented by the SSCL. The contingency allowance is increased by the ERC by $395 million (FY 1990), a 53 percent increase when compared to the comparable SSCL figure. The resulting TPC determined by the ERC is $7.02 billion (FY 1990), an increase of 7 percent over the SSCL TPC. Escalating to as-spent dollars using the funding profile developed by the SSCL and the escalation rates provided by the DOE and OMB results in a TPC calculated by the ERC of $8.4 billion (as-spent). This TPC does not include the budget for support and operation of certain SSCL facilities and services required during the commissioning phase of the project (estimated by SSCL to be approximately $0.35 billion, as-spent). In view of these findings, the ERC recommends that SSCL consider possible scope changes and design optimizations and reconsider their contingency allocation and their TPC estimate.

9. The SSCL and the DOE should develop a plan for providing the level of operational spare components needed for the SSC project.

Schedule

10. The schedule for this project, which is a source of considerable risk, should be refined as soon as the baseline is approved. Further refinement should include clear identification of the critical path and of those activities that could become the critical path if milestones slip. Milestones should be reassessed to ensure that they reflect cost and schedule criticality as well as appropriate control level and frequency.

Superconducting Magnets

11. An alternative strategy for procurement of the superconducting magnets should be considered that enhances SSCL/industry technical interaction and also relieves the manufacturer of uncontrolled risks, thereby reducing the procurement cost risk to the project.

12. The superconducting magnet development program is the critical path element for the SSC project. Magnet R&D at the national laboratories should continue with high priority in the near term until full superconducting magnet R&D capability is in place at the SSCL. The magnet development laboratory (MDL) is an important part of this capability.

13. The proposed E1 complex should proceed as scheduled to ensure timely testing of the industrially assembled magnets by September 1992. The MDL and prototype installation facility are an especially important and time critical portion of this complex. SSCL should focus all necessary effort on this activity, and DOE should provide assistance and take action as necessary to support this effort. A comprehensive plan for tracking critical path items pertaining to magnet fabrication and civil construction in the E1 complex should be developed as soon as possible. The need to obtain additional geotechnical data on the Eagle Ford shale at E1 and elsewhere where it

could affect detector and experimental hall design should be incorporated into this effort.

14. The bore diameters of the HEB dipole, HEB quadrupole, and collider quadrupole should be fixed as soon as possible. Cost, schedule, heat transfer, fine filament conductor availability, slow extraction of test beams, and future upgrade potential appear to be key constraints on the decisions.

15. There is an absolute requirement to minimize, and preferably eliminate, design changes during the high rate production of superconducting magnets, power supplies, vacuum components, and other custom items to be procured in large quantity. SSCL staff must be trained about the costs and schedule delays associated with manufacturing change notices to ensure that this understanding will be universal in three to four years when production rates begin to increase.

16. Several key technical issues in the collider magnet designs deserve attention. The possibility of hanging the upper collider ring should be seriously considered as this would allow beam separation to be reduced. It would probably reduce the cryostat cost as well. The adequacy of the 0.6-K temperature margin specified by the SSCL for the collider dipoles should be reviewed by an independent panel. Energy input from scattered beam particles at full field and at injection should be included explicitly in this review, as should the recent change in the copper to superconductor ratio in the collider dipole inner conductor.

Other Technical Systems

17. An integrated and optimized conceptual design of the injector accelerator complex should be carried out with all deliberate speed in order to increase the probability of rapidly achieving the primary

technical goals for this system and to provide upgrade potential for the future. All sources of beam emittance growth throughout the collider and injector chain, including power supply noise and transfer errors, should be addressed. In developing this conceptual design, the design team should be charged with developing an optimized approach for the whole complex unfettered by previous constraints.

18. Cold testing of all cryogenic components before moving them into the SSC tunnel should be considered.

19. Further tracking studies should be done with low-β insertions in place and tuned at both 2 TeV and 20 TeV energy. These studies should include more realistic errors and more realistic correction schemes. The implications of the 0.5-m low-β insertions for the ring dynamic aperture, beam current, and lifetime should all be addressed.

20. The goal of 80 percent beam availability for physics experiments requires very high availability per component. The availability required of each subsystem needs to be determined to allow the responsible managers to integrate their subsystems to meet the overall SSC availability goal. Managers should be made responsible for meeting their availability allocation as each will enormously impact the overall SSC operating cost per unit of physics.

21. The magnetic field properties of all the conventional accelerator magnets should be measured as part of acceptance testing. These measurements will permit sorting of magnet locations to suppress major resonance strengths in the rings, as well as provide a control on manufacturers' adherence to shuffling standards; this is only a small cost item.

22. The management of the controls group is providing the necessary strength of vision to this project, but manpower shortages and the slow start are of concern. The control group's position, particularly in negotiating interfaces with other groups, should be strengthened by

the assignment of a permanent person in the role of control group leader.

23. The instrumentation and controls experience gained from the early implementation of the E1 complex and the linac offers significant opportunities for use of an iterative process to develop the optimum systems. For this type of prototyping solution to be well exploited, a senior management decision on whether to proceed in this manner should be made soon, and detailed scheduling and implementation work begun.

24. Two cryogenics-related issues need further consideration by SSCL: removal of the liquid nitrogen plants and main storage tanks from the project, and the integration of magnet and cryogenics personnel.

25. The SSC footprint does not include land in fee simple for the 44 penetration pipes needed for tunnel alignment. The Laboratory should resolve this issue.

26. The following items may have significant cost, maintenance, performance, or safety impacts to the project. Therefore, these items should be carefully reexamined.

    - Determine whether or not an additional grounding system for the accelerator is required prior to freezing the civil construction design.

    - Assess the impact on component temperatures and reliability of the decision that the HEB and collider not have distributed cooling water systems.

    - Work out detailed procedures for changing underground rf system components before freezing the associated civil construction design.

- Decide whether or not the rf power supplies, with their associated insulating oil, will be installed underground.

Detectors and Conventional Facilities

27. The SSCL and its advisory subcommittees should focus and prioritize the R&D effort so those areas critical for initial detector operation can be adequately supported.

28. Decisions on the scope of the initial detectors are needed as early as possible to meet the scheduled SSC start-up date. SSCL management should obtain adequate engineering support as soon as possible in order to keep to the presented schedule. All of the experimental halls should be ready by mid-1995 in order to allow sufficient time for detector assembly and installation.

29. Consideration should be given to optimizing the location of the four detectors at the different interaction regions in an attempt to mitigate the effects of long-term foundation movement in the Eagle Ford shale (see Recommendation 13).

30. The SSCL should consider construction of the diamond bypass tunnel at both the east and west IR clusters, if cost experience permits.

9. ENVIRONMENT, SAFETY, AND HEALTH

The Environment, Safety, and Health (ES&H) Subcommittee reviewed the relevant portions of the Site-Specific Conceptual Design Report (SCDR), the pre-decisional draft of the Supplemental Environmental Impact Statement (SEIS), and other pertinent documents. From these reviews and discussions with personnel from the SSC Laboratory (SSCL) and DOE, the subcommittee concludes that the SSC can be constructed and operated with acceptable environmental impacts and without undue risk to the health and safety of workers or the public. In fact, there are some environmental improvements expected from the project (e.g., preservation of existing habitat, wetlands creation, and socioeconomic benefits).

The ES&H organization, staffing plans, and plans for documentation (e.g., policies, procedures, ES&H manual, etc.) were reviewed by the subcommittee. The ES&H organization will be given top management support (the head of the ES&H organization is an Assistant Director, reporting to the SSCL Director). It is clear that a great deal of thoughtful planning is taking place in the SSCL ES&H organization in working toward having an appropriate program in place in anticipation of the initiation of design and construction. This planning represents a unique opportunity at a new national laboratory to develop an ES&H program that complies with today's strict ES&H requirements and that has the benefit of the current DOE emphasis on ES&H performance.

There are no ES&H issues that should have any significant impact on the overall SSC cost and schedule. There are two potential issues that require near-term management attention (both DOE and SSCL) in order to prevent schedule (and thus cost) impacts. These issues are: (1) the need to finalize as many design parameters as possible now so that the SEIS and other ES&H documentation can adequately address potential impacts and mitigations, and (2) the need within DOE to clearly assign responsibilities for providing ES&H guidance and oversight on items such as Safety Analysis Reports (SARs) and the application for a permit to construct as required by the National Emission Standards for Hazardous Air Pollutants (NESHAP). These and other issues are discussed in detail in the subcommittee report (Section 10.10).

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10.1 Accelerator Physics: Collider

10.1.1 Summary and Recommendations

The design of the SSC is based on previous experience with storage rings and synchrotrons. Its most striking feature, its physical size, does not invalidate the basic accelerator principles used for its design. Comparing the SCDR with the CDR of 1986 highlights five substantial changes:

- The injection energy of the SSC has been doubled to 2 TeV;
- The aperture in the dipole magnets has been increased from 40 mm to 50 mm;
- A new lattice with 90-degree betatron phase advance and shorter cell length has been adopted;
- The correction system is now based on lumped elements; and
- The cycle periods of the SSC and HEB have been substantially increased.

Of these, the first three changes are specifically aimed at increasing the effective available aperture for the beam at injection. From an accelerator physics viewpoint, these changes will produce a collider that will be initially faster to commission and ultimately easier to upgrade to higher luminosities. In the subcommittee's opinion the most crucial and cost-effective design change has been the increase of the injection energy from 1 TeV to 2 TeV. This has resulted in a reduction of the magnitude of the multipole errors due to persistent currents at injection and, as a consequence, has greatly reduced the requirements of the corrector system. A new simplified corrector scheme based on lumped spool elements has now been proposed. This scheme has the advantage of simplifying the commissioning, tuning, and operation of the collider.

The increase of the dipole aperture also increases the dynamic aperture; however, with the increased injection energy and reduction in the cell length, it is the opinion of this subcommittee that the 40-mm aperture with an appropriate multipole correction scheme could also provide more than adequate aperture for the design emittance. With the 2 TeV injection energy, the design luminosity of 10^{33} cm^{-2} s^{-1} should not be seriously jeopardized with 40-mm magnets. It would result in some loss of safety margin, but a luminosity of 10^{34} cm^{-2} s^{-1} is not out of the question.

The last change, made to reduce cost, may significantly impact the availability of the SSC for physics. This change nearly doubles the reload time of the SSC, which the subcommittee estimates to be between 140 and 215 minutes now, including allowances for all the necessary operations. The cycle times could be reduced without major design change if experience shows that such a change is appropriate.

The SCDR has a design luminosity of $10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. Although we believe this value will be achieved, many of the implications of the detailed design choices for the new SSC lattice have not yet been fully studied. In the present design of the collider it appears that luminosities higher than the design may eventually be attainable. The subcommittee feels that this option should, if possible, not be excluded by design refinements.

Although analysis has shown that the intensity threshold for the transverse mode coupling instability is significantly above the design current per bunch, we believe that strict impedance monitoring and control should be exercised on all components installed in the collider rings. This impedance policing is necessary in order to ensure stability at the highest intensities.

The present scenario assumes a 40-mm bore quadrupole and a 50-mm bore dipole. For consistency, consideration should be given to increasing the quadrupole aperture to 50 mm in order to get a more efficient use of space and a smooth vacuum chamber.

The SCDR is a *conceptual* design report. The enormous task of producing the detailed *engineering* design, which will be used for component specifications and tolerances, will necessitate a substantial increase beyond the present numbers of accelerator physicists and engineers. Without this increase the project will have continued and substantial delays.

Recommendations

1. Give high priority to increasing substantially the present numbers of accelerator physicists and engineers.

2. The option for high luminosity should, if possible, not be excluded by design refinements.

3. Perform a thorough study of all sources of emittance dilution throughout the collider and injector chain, including power supply noise and transfer errors.

4. Do further tracking studies with low-β insertions in place and appropriately tuned at both 2 TeV and 20 TeV energy. These studies should include more realistic errors and more realistic correction schemes. Investigate the implications of the 0.5-m low-β for the ring dynamic aperture, beam current and lifetime.

5. Initiate studies to determine how much beam current loss would produce a magnet quench and how to prevent such losses at each step necessary for commissioning and operation. Do further studies to ensure that the background due to particle loss at the low beta quadrupoles is not excessive. Additionally, study the problem of background and its control by collimators and scrapers.

6. Investigation of correction strategies should continue with high priority and include the effects of higher-order multipole errors and lattice function distortion. The effects of the multipole errors and tolerances in the high-β quadrupoles in the interaction regions should also be investigated. Carefully analyze the problem of closed orbit correction in the presence of sextupole fields due to persistent currents; demonstrate that solutions can be obtained without jeopardizing the commissioning and tuning of the collider.

7. Further study the operational implications of each step of commissioning using an operations simulator. Provide adequate computing power for the simulator.

8. The effects of the beam-beam interaction together with power supply ripple and modulation produced by the collision assurance feedback scheme should be investigated further.

9. Create an "impedance policing procedure" so that the impact of proposed changes can be evaluated prior to implementation.

10. Do a careful study of the rf system in order to attempt to eliminate coupled-bunch instabilities. Consider the suitability of the present rf system from the standpoint of rf noise.

11. Decide whether the quadrupole aperture should be increased to 50 mm.

10.1.2 Lattice and Interaction Regions

The SSC lattice consists mainly of two parts, the FODO cells and the insertion regions for the detectors and other specific applications. The design of the FODO cells has been changed from the CDR to the SCDR. The main change is an increase of the phase shift per cell from 60 to 90 degrees; together with a change of half-cell length from 96 to 90 m, this reduces the dispersion by about a factor of two. These changes have the positive effect of making the correction of non-linear terms easier, and at the same time, they help to produce a larger dynamic aperture. This configuration uses quadrupoles with an aperture of 40 mm; if one desires to have the same aperture throughout the ring, the design of these elements will also need modifications.

Much work has been done to define the magnetic field tolerances, multipole field corrections, and to study procedures for implementing these corrections, in particular for chromaticity and for the horizontal-vertical coupling. Work is in progress to define the strategy for closed-orbit and beta function correction. New simulation tools have been developed, and much progress has been achieved in these areas.

For the interaction region lattice there is a basic design providing different values of β^*, down to a minimum of 0.5 meters, needed for the maximum luminosity of 10^{33} cm^{-2} s^{-1}. The low-beta value of 0.5 m requires a large β_{max} of about 8000 m and a strong gradient of 230 T/m in the IR quadrupoles. The large beta value makes these quadrupoles the main aperture limitation during the low-beta colliding-beam operation, and also a major contributor to the machine chromaticity and non-linearities. The implications of the 0.5 m low-beta for the ring dynamic aperture, beam current and lifetime need further investigation.

10.1.3 Dynamic Aperture and Tracking Results

The subcommittee was given a series of presentations on computer particle tracking aimed at determining the dynamic aperture of the SSC collider under a variety of assumed conditions. While an increased magnet bore improves the dynamic aperture, it also increases the size and cost of the magnet. The requirements and strength of the correction system are also influenced by the choice of magnet aperture.

In response to the concerns voiced in the Report of the DOE Review on the Conceptual Design of the SSC of May 1986, the SSCL staff in the collider group have performed simulation studies with a new computer code to determine the dynamic aperture in the presence of realistic magnet imperfections (multipole errors), misalignment errors of the magnets, and synchrotron oscillations. The code (SSCTRK) has been developed for the SSC and is optimized to run simultaneously (in parallel) up to 4 x 16 particles with 4 different initial conditions (amplitudes) in 16 different machines defined by random error generations. The speed of the code has been increased to allow tracking of up to several million revolutions in the SSC. Though members of the subcommittee have never used such a code, they are of the opinion that, as implemented, it gives a physical representation of the particle motion very close to reality. Moreover, the code is now available to other users who will determine the reliability in more detail. The code employs the "kick" method where all elements, linear and non-linear, are lumped in thin-lens approximation. To simulate synchrotron oscillations, rf cavities are located in zero-dispersion regions and the corresponding "kicks" satisfy the symplectic conditions.

The major task of the simulations effort was to determine the effects on the dynamic aperture at long time. The behavior of the particle motion over one million revolutions (which corresponds to about 5 minutes of real time) gives more confidence than previously available in beam stability during injection. The subcommittee recognizes this to be a very important and significant achievement for the SSC and for the accelerator physics community at large.

Concerning the requirements for the dynamic aperture, it was the goal of the SSC designers to obtain an aperture radius at least 10 times the nominal rms beam size. Considering the size and cost of the project, the subcommittee believes this to be a safe approach. To achieve this, three major modifications were implemented, the consequences of which were investigated with the computer simulations. The modifications are a shorter 90-degree FODO cell in the arcs, an increase of the injection energy from 1 to 2 TeV, and an increase of the dipole magnet aperture from 40 mm to 50 mm. Of these modifications, the second is the most important and crucial. It reduces, at injection energy, the (time-varying) persistent current sextupole component to a value that can be easily handled by the correction system without restricting the dynamic aperture. The subcommittee fully recognizes the importance of and supports the decision of raising the injection energy into the collider. It takes about 70 minutes for filling both rings, corresponding to more than 10 million turns, and we believe that the demonstration of stability up to a few million revolutions greatly increases the confidence for long-term stability.

To date, the tracking simulations have concentrated on the dynamic aperture at injection. For this purpose, a simplified lattice has been assumed where the insertions have been treated as regular FODO cells. In particular, low-β insertions with injection optics were not included. The results of this early stage are extremely useful, and the subcommittee assumes that tracking with the same conditions will be repeated with low-β insertions in place and appropriately tuned at both low (2 TeV) and full (20 TeV) energy. Given the dominant contributions of persistent current effects to the sextupole component, we do not expect major changes in the results at low energy. The top energy case needs to be examined closely.

Though the SSCTRK code can actually simulate any mode of multipole "kick," a simple model was used to approximate the magnet errors in each cell. This method is based on the Simpson rule of integration where three kicks are applied: next to QF, next to QD, and in the middle of each half cell. This method is in a sense the equivalent, but in the opposite direction, of the Neuffer method of error correction.

Systematic and random errors are included in the tracking and each multipole is derived from a scaling law that depends on the magnet aperture. Correction systems are not considered except that the chromaticity is adjusted to +5 units and the systematic decapole error is corrected to 25 percent of the persistent current value (all this with the Simpson method). When all the improvements mentioned above are simulated together, an increase of the radius of the dynamic aperture from ~4 to ~6 mm is predicted when the dipole magnet aperture is increased from 40 mm to 50 mm. In the first case, the ratio of the available aperture to the rms beam size is ~8 and in the latter ~12, allowing the design requirements of the SSC staff to be met.

If tracking were done with a full correction scheme "a la Neuffer," this would directly cancel the multipole errors which were input to the same model. One can expect that the results of tracking in this mode of operation would produce an improved dynamic aperture provided that there is enough strength in the correction spools. As a consequence, it seems quite reasonable to infer that a 40-mm bore dipole could yield the required dynamic aperture when provided with an adequately strong corrector system.

There is indication that systematic errors are mainly responsible for the size of the dynamic aperture. Synchrotron oscillations are said to have little effect. We have been shown results of tracking for the case where tune modulation was added; this resulted in a dramatic loss of aperture, unless the tune modulation is limited to an amplitude of 0.001 up to a few kHz.

The subcommittee congratulates the SSCL staff for the progress made and the methods used. We recommend that they continue to explore other cases with more realistic lattice configurations, more realistic types of errors, and more realistic correction schemes. This type of tracking should also be used to determine the importance of the multipole errors in the quadrupoles in the IR insertions.

10.1.3.1 Correction System

There is a fundamental change in the SCDR concerning the strategy adopted to correct for the magnet imperfections and misalignment errors. The correction system is now made entirely of lumped elements, the so-called spool elements. These are located next to each regular quadrupole in the arcs (QF and QD) and next to many of the quadrupoles in the insertions. There is also space for lumped correctors near the middle of the half cells; initially only 20 percent of these locations will actually be occupied by correctors. Beam tube correctors running the length of the dipole magnets as they appeared in the previous CDR are no longer considered.

Non-linear correctors are provided only in the regular cells where each location next to the QF and QD quadrupole is made up of a steering element (horizontal or vertical, according to location), a regular quadrupole, a sextupole, an octupole, and decapole. The mid-cell correctors are made of octupoles and decapoles. There are 40 mid-cell locations where skew quadrupoles are also included. Each of the QF elements are in series, as are those next to QD or in the middle of the half cells. The skew quadrupoles are independently powered.

At the moment, correctors at the insertions are made only of steering magnets. Beam position monitors are located next to essentially every quadrupole, in either horizontal or vertical configuration according to the location.

The adoption of lumped correctors in the arcs is based on the Simpson-Neuffer method of correction. Because of the increase of the injection energy to 2 TeV, multipole errors are greatly reduced in magnitude and can thus be corrected with reduced strength correctors. This situation allows use of the *superposition principle* to reduce the number of mid-cell correctors, provided their strength is increased correspondingly, without altering the effectiveness of the Neuffer correction method. In the case of the 40-mm dipole aperture, with a 2 TeV injection, the multipole errors would be greater and would require more correctors.

First-turn injection and closed orbit correction are done with the local bump method, which is very effective, easy to model, and useful in commissioning and operation. The method is sound, and reasonably safe estimates of installation errors have been used. Nevertheless, the subcommittee notes that the closed orbit corrections are made complicated by the presence of sextupole fields due to persistent currents. This requires a careful analysis and a demonstration that solutions can be obtained without jeopardizing the commissioning and tuning of the collider.

Skew quadrupoles are powered in several subsets to provide local coupling correction in locations where the eigenangle is desired to be zero. The correctors also provide a global coupling cancellation acting on the Q_H-$Q_V = 1$ resonance. Splitting the betatron tunes by one unit greatly simplifies the corrector system. This method has been proven very effective by tracking.

Chromaticity correction strategies are being investigated. No major problems are foreseen here, including correction of the sextupole field at injection caused by persistent currents. Due to the increase of injection energy to 2 TeV, the sextupole effects are reduced by a large factor and can be easily handled with the lumped corrector system. The same applies to octupole and decapole errors. The subcommittee recommends that this work continue with high priority and include the effects of higher-order multipole errors and lattice function distortion in order to study their influence on beam performance. The effects of the multipole errors and tolerances in the high-beta quadrupoles in the interaction regions should also be investigated.

10.1.4 Performance and Limitations

10.1.4.1 Beam Current Limitations

The electromagnetic fields generated by a beam in the vacuum environment act back on the beam and thus set limits on the beam currents that can be stored. These phenomena are analyzed by first studying the electromagnetic properties of the structures that comprise the beam environment and second, by analyzing the dynamic consequences of these additional electromagnetic fields. These are quantified by thresholds or upper bounds on single-bunch intensities or by growth rates of multibunch instabilities.

These beam current limitations were explored extensively in the CDR. The modifications in the SCDR have had a relatively minor impact on the beam-current limitations for the SSC. The most important single-bunch effect is transverse mode coupling. The threshold for this instability is a factor of four higher than the design intensity in the SCDR. This factor is in addition to a factor-of-two safety margin in the impedance of the vacuum chamber. This margin would also be sufficient for a significant luminosity upgrade provided that a low impedance is actually realized in the machine. To achieve this low impedance it is important to have an "impedance policing procedure" so that the impact of proposed changes can be evaluated prior to implementation. The beginnings of such a procedure seem to be in place.

The situation with coupled bunch instabilities is somewhat different. The SSC as described in the SCDR operates with about 17,000 bunches per ring. Coupled bunch instabilities are primarily driven by the higher-order modes in the rf system. The fastest growth time (0.8 seconds) occurs in the longitudinal direction. The transverse growth time is somewhat longer (4.6 seconds). Although these seem like slow instabilities, when measured in numbers of revolutions they are comparable to those seen in existing storage rings.

Although these instabilities can be handled by a feedback system, it would enhance operational simplicity significantly if they could be eliminated by reducing the strength of the impedance which is driving the instabilities. This is the first line of defense. We recommend that a careful study of the rf system be performed in order to attempt to eliminate coupled-bunch instabilities. This study would also address the suitability of the present rf system from the standpoint of rf noise.

10.1.4.2 Emittance Preservation

The emittance required by the SCDR is about a factor of 3 or 4 smaller than that normally achieved at Fermilab or CERN. The SSC injector chain design can in principle deliver this emittance to the collider. However, thus far many effects which might dilute the emittance both in the injector chain and in the collider have not been studied in detail.

These effects include power supply noise and transfer errors and these have direct impact on the detailed design and cost estimates. We recommend a thorough study of all sources of emittance dilution throughout the collider and injector chain.

10.1.4.3 Beam-Beam Effects

From a beam-beam interaction viewpoint, each interaction region in the SSC consists of the wanted collision at the center of the detector and many unwanted long-range interactions where the bunches in the two-beams pass near one another. In general, most of the experience gained in proton-proton collisions has been associated with the situation where there is a single central collision point in each IR. The normal parameter identifying the magnitude of the beam-beam strength is the linear tune shift ξ. Relevant measurements in the Tevatron collider at Fermilab and the $\mathrm{Sp\bar{p}S}$ at CERN have shown that a beam-beam limit arises when the total incoherent tune spread due to beam-beam effects approaches 0.02.

For the SSC the beam-beam effect may be divided into three categories.

1. The incoherent effect. This is inherent to the central collision. It is the most important for the SSC, but is still quite small for the design parameters. At injection and during acceleration this effect is not present because the beams are purposely separated at the interaction points.

2. The coherent (or coupled beam) effect. This has been shown to be not critical for the SSC. One of the consequences of this effect is to exclude operation at tune values too close to the integer or the half integer. The SSC design tune values are far from these points.

3. The long range effect. This effect results from the need to have a small bunch spacing and is mainly a linear effect. The design of the SSC interaction region and beam parameters results in small total values of the linear tune shift and of the tune spread due to the unwanted collisions. Therefore, the long-range effect

seems to be under control. At lower energies it may eventually be the limiting factor on the ultimate luminosity achievable. The effect can be reduced by increasing the crossing angle of the beams until other limitations are reached.

The incoherent beam-beam effect has recently been the subject of much experimentation and analytical work. The resulting understanding indicates that the beam-beam lifetime for hadron-hadron collisions is significantly reduced when the ratio between the linear incoherent tune shift and the frequency of any modulation (for example caused by the synchrotron motion) on the tune exceeds a maximum value. The SSC design value is less than the maximum value already reached in the Sp$\bar{p}$S. It is, therefore, likely that the beam-beam effect combined with synchrotron modulation will not be a problem for the SSC. However, it is also clear that other modulation effects, especially at low frequencies, should be investigated. In particular, the effects of power supply ripple and the modulation produced by the collision assurance feedback scheme should be investigated further.

In the initial stages of an SSC run, the emittance shrinks due to the synchrotron radiation damping. During this time, if other parameters remain constant, the beam-beam tune shift (and the luminosity) increases. The calculated maximum value is reached after about 20 hours and is still acceptable based on previous experience. However, if there is significant diffusion due to power supply ripple or noise, then the emittance may grow rather than damp. This growth would limit the luminosity lifetime, and it is therefore important to set tolerances on power supplies which take this into account.

10.1.5 Commissioning and Operations

The commissioning and later operation of the SSC will involve several clearly defined steps; a single turn trajectory, stored beam, energy ramping, low β squeeze, pre-collision adjustments, and finally collisions for physics followed by cleanly dumping the beam remaining at the end of the fill. Each of these steps must be done without appreciable beam loss and without significant increase of the transverse emittance if the design luminosity is to be attained. The operational implications of these requirements has not been fully addressed and therefore requires further detailed study. This study is under way in the form of an operations simulator. The goal of this simulator is to provide the SSC accelerator physicists with a tool similar to a flight simulator, so that operational experience can be gained without too many real "crash landings." This technique has not been developed for previous colliders and will certainly be an invaluable asset for fast, efficient commissioning of the SSC. Fortunately, the necessary high-speed computing power for this important activity is now available on the market at reasonable cost. Due to the enormous amount of work yet to be done in order to make the simulator totally operational, it is unlikely that certain important design decisions can profit from this technique. It is therefore imperative that existing techniques also be used to study and illuminate strategies to meet the above requirements. In particular, it is important to know how much beam current loss would produce a magnet quench and if this intensity (or lower) can provide an accurate single-turn trajectory measurement from the beam orbit measurement system.

SSC accelerator physicists have shown the important result that with the 50-mm aperture dipoles and the higher energy injection, it is unlikely that high order multipole correctors are necessary to provide sufficient dynamic aperture. This may be of great importance for the speed and ease of commissioning and for operations.

The low β^* of 0.5 m at the interaction point produces a β max of ~ 8 km at the high gradient low-β quadrupoles. In this situation, the physical aperture is limited at these quadrupoles. Further studies are needed to ensure that the background due to particle loss at these points is not excessive. In general, the problem of background and its control by collimators and scrapers is of great importance and should be studied further.

The design of the beam abort system is at an advanced stage. Under normal operating conditions this system will dump the beam in a safe and clean manner. In order to safeguard the SSC magnets against severe damage, this system must be guaranteed to abort the beam in *all* dangerous situations, yet never abort unnecessarily. Consequently, due to these severe constraints this system requires great care in its design. In addition many component systems must be interlocked to the beam abort in order to protect the collider against excessive beam loss.

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10.2 Accelerator Physics: Injectors

10.2.1 Accelerator Physics of the Injector Complex—Summary and Recommendations

The SCDR point design of the injector complex provides, as intended, a reasonable basis for developing a credible cost estimate. Furthermore, if it were built according to that design, there is a reasonable probability that it would achieve the stated point-design goals for the injector, namely, to provide the specified bright beams at 2 TeV to the collider rings and the intense test beams at 200 GeV to the calibration areas.

The point design is not an optimized design. Optimization should continue with all deliberate speed, focusing on the goal of providing significantly higher beam brightness to the collider as well as mitigating, ameliorating, circumventing, and/or arriving at the best compromise regarding the issues to be enumerated below. An aggressive approach to the design optimization can still allow the early schedule milestones to be met. A design that holds out the reasonable hope of significantly higher brightness would serve two purposes: it would furnish significant safety factor on the point-design goal, which is prudent given the uncertainties involved in trying to predict accelerator performance, and if achieved, it would provide the most reasonable upgrade path to significantly higher luminosities in the collider. Optimization is not expected to have significant cost impact. It is recommended that the designers should not assume *a priori* that the optimization process will merely require fine-tuning of the point design, but should instead start with open minds toward the possibility that an optimal injector might look rather different from the point design.

In reviewing the injector complex, findings, issues, concerns, and recommendations, those that pertain to more than one accelerator will be addressed first, followed by separate discussions of each machine.

10.2.2 Global Issues Concerning the Injector Complex and Recommendations

The number of experienced accelerator physicists on the SSCL staff assigned to the design of the injector complex has been small. The Laboratory management has to a large extent successfully circumvented this limitation so far by enlisting the experienced staff of other organizations such as BNL, LANL, and Fermilab to assist with the design effort. However, this is clearly not ideal in the design stage and would become even less desirable in later stages of the project. A related issue is that, with the exception of the linac, there has been no single individual identified in the organizational structure as responsible for a particular injector accelerator. It is recommended that a "czar" for each injector accelerator be appointed so that responsibility and authority for each subsystem can be identified. It appears that similar issues affect other parts of the Laboratory; as such they will be addressed in greater detail in other sections of this report.

The SCDR scenario for filling the collider would work but is slow and complicated. Most of the collider fill time results from the cycle time of the HEB, which is 515 seconds for one full bipolar cycle. This number was increased relatively recently to save money on rf, refrigeration, and power supplies for the HEB. At issue is whether the projected money saved would be well spent to increase the physics output of the facility and to speed up the commissioning and tuning processes.

The complexity of the filling scheme follows from the fact that the ratio between the total beam lengths in successive machines is not an integer. As a result, to achieve a total occupancy factor of about 92 percent of the available buckets, different numbers of bunches must be transmitted from one machine to the next on different cycles. It is recommended that, in subsequent design efforts, the possibility of adjusting the circumferences of the machines be examined toward the goal of simplifying the filling scenario by achieving an integral ratio of beam lengths in successive machines. Of course, any gaps required for kicker rise and/or fall times must be taken into account in this adjustment, and any machine that might be used to create a regular pattern of missing bunches (LEB and MEB?) ought to have a lot of prime factors in its harmonic number. The problem may be over-constrained and hence may not allow a solution, but it is worth taking another look.

In addition to the optimization of the circumferences of the injector synchrotrons, the transfer energies and corresponding energy ranges should be reexamined. With modern lattice designs, the transition energy can be used as a variable to simplify rf requirements and/or to avoid beam dynamics problems, especially where compromises between adjacent machines are necessary. Since each booster in the injection chain has its own accelerator physics requirements, the optimization must be iterative, and tradeoff studies must be performed among all subsystems. Indeed, the present SCDR injector design represents the work of largely independent groups that have not had the opportunity to interact and develop a truly holistic solution to the injector design.

For several very understandable reasons, the injectors have not enjoyed the amount of attention paid to the collider rings. The injector rings need further detailed work in the areas of dynamic aperture studies and analysis of susceptibility to instabilities. The transfer lines need studies of the effect of errors on lattice functions and injection trajectories, particularly since emittance preservation is an important issue. Since optimization may lead to significant changes in the complex, such detailed studies should wait until the iterations involved in the optimization process begin to converge.

Recommendations

Global Issues:

1. Optimize the injector complex. This pursuit should reconsider the final linac energy, the number of boosters, their transfer energies and energy ranges; attempts should be made to adjust the circumferences of the synchrotrons so that they are integrally related.

2. The injector rings need further studies on dynamic aperture and on machine coupling impedances.

3. Perform sensitivity studies on the beam transfer lines.

4. Identify a responsible design leader for each injector accelerator.

5. Reassess the EDIA needs as soon as the injector designs are frozen and accelerator systems management assignments are made.

Specific Issues of the Point Design:

1. LEB
    a. Resolve the lattice issue, especially in regard to the beam dynamics with extraction close to transition.
    b. Do multiparticle tracking studies, especially in transverse phase space.
    c. Identify actions to be undertaken in the event of a luminosity upgrade.
    d. Maintain an impedance budget.
    e. Develop a means to reduce radiation losses at the extraction septum.

2. MEB
    a. Reconsider the choice of placing the injection energy just below the transition energy.
    b. Perform studies of the dynamics at transition in order to ensure that any transverse emittance growth is minimal.
    c. Identify means to obtain clean, efficient slow extraction at 200 GeV/c.

3. HEB
    a. Do overall cost optimization of the cycle times.
    b. Do tests of bipolar magnet cycles.
    c. Revisit the issue of the dipole aperture.

10.2.3 Linear Accelerator (Linac)

The linac point design will provide acceptable beam to the LEB and is adequate as the basis for costing and schedule planning.

The linac design and components are well understood, primarily due to the presence of an experienced linac chief who has utilized an existing team of seasoned linac designers at Los Alamos.

The linac design strategy emphasized four goals: 1) Cost minimization, 2) flexibility, 3) reliability, and 4) upgradability. It must be realized that 1) and 3) constrain two legs of the cost-time-quality triad, meaning that time could suffer. It is fortunate that the linac is to be one of the first systems procured.

The design-strategy goal of minimizing cost is reasonable only where it does not compromise the other strategy goals. It is a reasonable design technique to use cost minimization to optimize parameters and for hardware selection. It would not be reasonable to jeopardize operability and reliability for the sake of cost; adequate funding must be reserved to achieve these goals.

The ability to achieve the design-strategy goal of obtaining a reliability greater than 98 percent was reasonably defended by referring to linac operating histories from other institutions. Those linacs have been in operation (and have undergone debugging) for 20 years. This experience must be utilized by the SSC, either through obtaining the services of those people or through SSC linac staff doing adequate work at those facilities in order to acquire the necessary knowledge.

The SSC linac beam requirements are rather relaxed for modern linac capabilities. That is, there is no question that a satisfactory linac can be constructed and there are a variety of proven design concepts. However, it was good to see that new ideas are being pursued that should enhance reliability. A volume ion source with its advantages of quick stability and no cesium, in place of the time-honored magnetron, would simplify turn-on and should reduce ion source maintenance caused by the need to replenish the cesium and to clean up cesium that has migrated. Also, the traditional Einzel-lens-based low-energy beam transport from the ion source to the RFQ requires fairly high voltages. A new concept using coil-spring-shaped electrodes, called the helical electrostatic quadrupole or HESQ, is being developed that will allow the use of lower voltages (implying safer and simpler hardware)while providing superior transmission with minimum aberrations.

Upgrade potential is provided by additional linac tunnel. The beam is transported through this extra tunnel with a straightforward transfer line, which would be replaced with additional linac sections should it be desired to increase the beam energy delivered by the linac. Raising the linac beam energy to 1 GeV requires another 400 MeV of linac, which, if procured during the same time frame as the original linac, would cost approximately $10 million. If procured later, the price would probably double. It is quite practical to increase the linac energy to 2 GeV or even higher if desired in order to reduce space charge problems in the low energy booster; however, the linac energy is limited to about 1 GeV in the present design by the space available downstream of the linac and the space available in the LEB injection straight section.

The success to date of the linac design is due to the presence of a key responsible individual who has access to experienced linac support at another institution. That support must continue to be available throughout the design, manufacturing, and commissioning phases of the linac project. On-site personnel must be hired who can learn from the off-site team and carry that knowledge throughout the linac acquisition process and commissioning, and into operations.

10.2.4 Low Energy Booster (LEB)

The LEB accelerates 600-MeV protons from the linac to a momentum of 12 GeV/c at a repetition rate of 10 Hz. The LEB is 540 m in circumference and includes eight radio frequency cavities that deliver a peak rf voltage of 700 kV. The scope of the LEB includes the extraction system and 250-m beam transport system necessary to transfer protons from the LEB to the medium energy booster (MEB).

Injection into the LEB is via H^- --> H^+ stripping in a thin carbon foil. For collider fill operation, the beam delivered to the MEB is made up of 10^6 bunches, each containing 10^{10} protons, with an rms transverse normalized emittance of 0.6 π mm-mrad. For test beam or upgrade operation, the bunch population could be increased to 5×10^{10} protons with correspondingly higher transverse emittances.

While the scope is generally deemed to be adequate, the LEB design is viewed as the highest-risk injector, especially in regard to beam brightness capability and ease of beam manipulation prior to transfer to the following machine. The two major concerns are a large transverse space-charge tune shift shortly after injection ($\Delta\upsilon_y = -0.34$) and the location of transition ($\gamma_t = 14.5$) slightly above the extraction energy ($\gamma = 12.8$).

With regard to the relatively large space-charge tune spread, significant increases in bunch population to emittance ratio N/ε may not be feasible using the present design with 600-MeV injection. However, eventual achievement of the point-design goal can be assigned a high probability based on analysis of experience at other laboratories.

The closeness of extraction energy to the transition energy leads to the following concerns:

1. Beam is sensitive to guide field errors.
2. Transfer synchronization to the MEB is difficult.
3. The rf voltage needed for matching to the MEB is only 4 kV at extraction.
4. Diluting the longitudinal emittance is difficult.
5. Thresholds for collective instabilities are reduced.

The rf program is deemed to be adequate (except for the above concerns); this has been borne out by longitudinal simulations of the rf capture and acceleration. The instability analysis appears to be sound. Information on the higher-order modes of the accelerating cavities should be incorporated in order to assess the situation in regard to longitudinal coupled-bunch instabilities.

Fast extraction leads to the loss of at least two bunches of protons at the extraction septum due to the finite rise time of the extraction kickers. Under test beam operation (5×10^{10} protons per bunch), this represents 10^{12} protons lost per second at 12 GeV/c. No easy way to avoid these losses and induced radioactivity on the extraction septum has emerged from analyses to date.

The critical issue for the short term is to resolve the LEB lattice issue, especially in regard to the beam dynamics with extraction close to transition. Possible solutions or ameliorations may involve 1) a different rf cycle, 2) lower extraction energy, and/or 3) a redesigned machine.

Once the machine design has been provisionally identified, then a number of multiparticle simulations should be done to confirm the design choices . The H^- injection should be simulated including a collapsing orbit bump in order to see the effects of the stripping foil. Likewise, tracking with space charge and magnet errors included should be carried out in order to assess the realism of the assumed final normalized rms emittance of $0.6\ \pi$ mm-mrad.

The actions to be taken in the event of a luminosity upgrade should be identified; examples might include a linac energy upgrade to reduce the space-charge tune spread at injection into the LEB and compensation for betatron resonances crossed by the beam.

The impedance budget should be maintained for the LEB; special attention should be paid to impedances of rf cavity higher-order modes and injection/extraction hardware.

10.2.5 Medium Energy Booster (MEB)

Partly as a consequence of the collider injection energy change, the parameters of the MEB have changed from the CDR to the point design SCDR. The following table shows some of the design changes.

Table 10.2-1.
Some of the MEB Design Changes

	CDR (86)	SCDR (90)
P min (GeV/c)	8.0	12.0
P max (GeV/c)	100.0	200.0
C (m)	1900.0	3960.0
υx	8.41	16.60
υy	8.41	16.58
γ_t	7.2	15.9
D max (m)	14.2	3.8
Superperiods	6	4

The MEB is designed not only to be a part of the injection chain but also to provide slow spill for test beams.

The MEB accepts 7 LEB pulses during 0.6 seconds at the MEB magnet flat-bottom. The number of particles in the MEB is 7.4×10^{12} protons in 742 bunches in the collider mode; the cycle time of the MEB is 4.5 seconds for the collider mode.

Early in the acceleration cycle, the protons pass through transition ($\gamma_t = 15.9$, $\gamma_{inj} = 12.8$).

In order to facilitate bipolar operation of the HEB, the MEB must have two fast extraction systems and two transfer lines to the HEB. Slow extraction from the MEB is also planned for the test beams.

The subcommittee reviewed the materials provided by Laboratory. The materials include assessments of states of design and future plan for optimization by the project personnel. The point design as presented contains required information sufficient to estimate costs for the MEB and its associated beam transfer lines.

Technical issues identified by the SSC Laboratory and discussed with the subcommittee include the following:

γ_t: The present value of 15.9 is too close to injection. The lattice that produces that value has a phase advance of 60 degrees per cell. The transition energy can be raised if the phase advance is changed to 90 degrees per cell; such a lattice has been looked at and appears to be feasible. Raising γ_t will alleviate the space charge tune shift at transition in order to enhance future upgrade potential.

γ_t Jump: Since the accelerator cycle must pass through transition , a transition jump may be needed in order to control the beam emittances. The SCDR does not include such hardware. The final lattice design must be examined in order to ensure the feasibility of such a system.

Dipole Field Quality at 200 GeV for Slow Extraction

Studies done to date for 200 GeV resonant extraction show that the slow spill at 200 GeV for test beams would be difficult without sextupole correction due to the fact that the dipole field in the saturation regime (1.7 T) contains too much sextupole component. On the other hand, efficient extraction can be achieved around 160 GeV (an energy below the level of significant magnet saturation). As pointed out by the SSC Laboratory, there are several ways to deal with this issue.

10.2.6 High Energy Booster (HEB)

The HEB design represents a modern version of the Tevatron or the HERA superconducting proton rings. The HEB accepts three batches of beam at 200 GeV from the MEB and accelerates them to 2 TeV for injection into the collider rings in both directions. The HEB performance and costs can be reliably inferred from these earlier superconducting synchrotrons. The present design described in the SCDR seems appropriate for the SSC injector.

The SSC Lab plans to use the same *50-mm coil inner diameter* as that of the main collider in the expectation that economies may result for the HEB; this design deserves closer scrutiny. In the first case, tracking studies for the HEB at injection energy

(200 GeV), using field errors appropriate for that coil diameter, imply that the dynamic aperture is marginal. In the second case, other requirements may preclude using significant aspects of the main collider magnets in the HEB magnet construction. For example, ramp rate requirements demand both different cable with smaller filament diameter and improved helium flow to offset AC heat losses. If further studies establish that the dynamic aperture is too small, then retreating to the 70-mm coil aperture design or providing correctors in the middle of the half-cell are two possible solutions. (A reexamination of the entire accelerator chain might lead to a different choice of MEB to HEB transfer energy in that one part of the optimization would be the HEB dynamic aperture, which improves with energy.)

The *HEB cycle time* may be a significant component of the collider fill time. An overall cost evaluation should be done in order to reconsider the components that limit the HEB cycle time, namely 1) the number of main power supplies, 2) the heat transfer design of the magnets, 3) the available refrigeration, and 4) the number of rf cavities. Balanced against these costs are the loss of time that would otherwise be available for collider physics, the possible emittance growth caused by noise while the beam is being loaded into the collider, the extra time lost during commissioning when more frequent fills are needed, and a reduction in the duty factor for the HEB itself when used as a source of test beams, a future option. Since the magnet design may be an important aspect of the cycle time limitation and since a more rapid cycle will aid machine commissioning, designing and funding the machine for initial operation at higher cycle rates should be reconsidered rather than waiting for upgrades.

The bipolar operation of the HEB allows a reduction of the length and complexity of the transfer lines to the collider rings, and the present siting plan and collider lattice were developed assuming that bipolar operation is possible. There was some concern in the community that the bipolar operation would create some additional difficulties since this is a new mode for superconducting accelerators. In fact, the Tevatron experience indicates that reproducibility is the most important aspect of the ramp and that very complex multipole time and energy dependences can be controlled with the magnetic correction elements that are already a part of the HEB design. It is likely that cyclic bipolar operation actually makes the HEB operation easier. Nevertheless, the planned tests of bipolar magnet cycles should be carried out in order to determine the values and reproducibility of the important multipoles to verify this mode of operation as well as determine the reliability of the magnets.

10.2.7 Evaluation of Injector Preoperations, R&D, EDIA, and Contingency

In the area of accelerator preoperations, the SSC Laboratory presented a rudimentary outline of their intended turn-on scenario of the machine complex. At this early date of the project, combined with the uncertainties due to funding, etc., we believe their plans and estimates are reasonable. The preoperations schedule is properly matched to the proposed construction schedule.

In the area of research and development, we believe the assumption of the point design being near the optimum design naturally leads one to an optimistic assessment of the R&D needs. We believe there will be modifications in the injector system configuration and component specifications that will then reflect themselves in the R&D needs. The R&D schedule is presently properly matched to the construction schedule, assuming an aggressive staffing program to execute the proposed program.

In the area of EDIA, the subcommittee believes as the design evolves into the optimum version and matures, the EDIA needs will have to be reassessed. We note that the yearly allotted EDIA manpower for each injector accelerator is the same. We believe a rigorous reassessment will have to be made of the EDIA needs as soon as the injector designs are frozen and accelerator systems management assignments are made.

In the area of contingency, the subcommittee finds the contingency estimate of the injector systems to be inadequate. The relative percentage of contingency assigned to the high technology items is inconsistent with those assigned to the conventional construction items. We believe a reassessment of the contingency will have to be made when the injector system conceptual design is frozen.

10.3 Superconducting Magnets

10.3.1 Summary, Conclusions, and Recommendations

The SSC consists of over 11,000 superconducting magnets distributed among the collider dipole magnets (CDM), collider quadrupole magnets, and high energy booster (HEB) accelerator magnets. All of these magnets are state of the art components that have been the subject of an intense development program for many years. The most critical of these magnets are the 7956 collider dipoles, each of which produces a 6.6-tesla field over a 15-m length, and the 504 similar dipoles of a 13-m length. In addition there are quadrupole magnets for focusing of the beam in the collider and the HEB accelerator magnets.

While initial dipole developmental magnets did not meet the desired performance and trained excessively, more recent 40-mm-bore size magnets at Brookhaven and Fermilab have been quite successful when tested. However, the dipole bore size was recently enlarged to 50 mm, requiring further work to verify the new design. There is now an intensifying development effort to further improve the magnet performance, coupled with a somewhat more conservative design of the 50-mm dipole. Thus, there is confidence that the necessary magnets for the SSC are technically credible and will improve with further engineering development. The good performance of the most recent quadrupole model is heartening.

The magnet costs have been competently estimated from detailed parts lists and laboratory experience. However, the resultant estimated base costs are probably a lower bound. The margin to obtain a lower cost is nearly zero, while the potential for a significant cost increase is high. Accordingly, the industrial transfer process and the procurement method are extremely important. It is the opinion of the majority of this subcommittee that the present leader-follower method limits competition and the opportunity for alternate fabrication methods. The projected costs do not adequately allow for the risks and profits expected in a fixed-price contract. Under the current strategy, the majority of the subcommittee must recommend either a dramatic increase in the magnet procurement contingency or conversion to another type of contract for the bulk of the dipole manufacturing. A more flexible type of contracting would enhance the likelihood of achieving the projected magnet base costs. It would also improve technical communication between the SSC Laboratory and industry to correct any technical difficulties or accommodate design changes. Even with enhanced communication and improved procurement methods, the subcommittee recommends increasing the overall magnet contingency from the present 19 percent to 34 percent to reflect the uncertainty and optimism in the cost estimates.

The subcommittee asserts that there is an absolute requirement to minimize, and preferably eliminate, design changes during magnet production if these contracts and the SSC program are to be completed within the cost and schedule envelope. This will require that, in the absence of major flaws that must be fixed, improvements after start of production will not be tolerated. Adequate attention must be paid by the Magnet Systems Division (MSD) and Laboratory management to see that this policy is strictly adhered to.

The magnet schedule is very tight and certainly on the project critical path. In particular, the development schedule to produce the initial 12 prototype 50-mm-bore, 15-m collider dipole magnets with industrial participation at Fermilab is very short and dominated by the time required to make tooling. There is no float apparent in the schedules provided to the subcommittee, so careful attention and full resources must be applied to this SSC program critical path activity. The testing of these industrially assembled superconducting magnets in the E1 complex in September 1992 represents a critical milestone that should be carefully monitored in order to gauge the project's early progress.

A key element of the management of the critical path is the identification of the product managers who will be responsible for integrating the efforts at Fermilab, BNL, and LBL, as well as the MSD matrix from completion of the magnet design through industry production. It is essential that these positions be filled as quickly as possible. Although a matrix management arrangement is being used within the MSD, the magnet production managers should be permitted to have small, direct staffs to assist them in managing schedule, cost, and technical performance. The subcommittee was pleasantly surprised at the current size and quality of the MSD staff. The first line supervisors are a highly qualified group.

Design criteria for the CDMs are under development and partly specified in the Prime Item Development Specification (PIDS) sent to industry. Several of the items marked TBD (to be determined) should be filled in and marked as tentative numbers as soon as possible. Despite the considerable progress in the design, fabrication, and test analyses to reduce magnet training, a great deal of further work will be needed, particularly in the areas of stress and thermal analysis.

Materials tests now underway will be essential to a proper understanding of the coil behavior. These tests should be in all three principal directions rather than simply azimuthal as at present. The test program should be expanded to include cyclic lifetime tests for all critical components. The required number of excursions beyond the nominal operating point were not presented to the subcommittee. These must be defined early because of the strong impact on fatigue lifetime and structural design criteria. The latter have a direct impact on structural weight and cost.

The HEB magnet schedule and cryogenic design are extremely aggressive, with concomitant risk. There is a significant schedule risk due to the need to develop fine filament (2.5-micron), high-current-density superconductor. These risks suggest that the cost contingency should be doubled in this area to about 40 percent. The subcommittee is encouraged that the HEB magnet product manager is in place, and that key problems of adapting the collider dipole magnet design to the HEB have been identified and seem manageable.

The baseline cryostat design is suitable for the CDM with opportunities for component and subsystem optimization during the industrial development phase. Support of the upper magnet from above would allow for a reduced vertical magnet centerline-to-centerline distance. Longer, straight (not reentrant) support posts could then be used. Both features could result in cost savings.

With the 10 to 12 magnet test stations planned, only 10 percent of the magnets can be cold tested in a routine manner during high rate production. This could produce a serious risk of delaying and complicating the SSC initial operation. The HERA system experienced about 1 percent defects, which extrapolates to approximately 100 magnet failures in the SSC. Complete cold testing of all magnets seems justified on a cost and reliability basis. The SSC should, therefore, consider ensuring full cold testing capacity for full rate production.

The additional margin associated with changing to the 50-mm diameter CDM is an obvious benefit. The change to a different Cu/SC ratio appears to be reasonable, but requires more time and effort to assess than available in this type of review. As a result, an independent, more detailed assessment by another group is recommended. It should also take into account the expected spread in cable performance based on critical property information taken to date. This should be done as soon as possible.

Finally, it is imperative that the MSD immediately start implementation of the Cost Schedule Control System (CS/CS) to aid them in managing their expanding effort. Performance, cost, and schedule responsibility should be delegated to the lowest possible level. Annual performance appraisals should address this responsibility to ensure that it is kept in mind by everyone participating in the design process.

Recommendations

Cost Recommendations:

1. The subcommittee recommends increasing contingency from 19 percent to 34 percent overall on the superconducting magnet budget, an increase of $290 million.

2. The SSCL should do detailed cost-benefit analyses under various magnet failure rate scenarios and then consider ensuring full cold testing capacity for full-rate production. A back-of-the-envelope calculation using the HERA failure rate of 1 percent puts the ratio of cold test cost to increased installation cost from magnet failures close to breakeven.

3. The responsibilities of the magnet subcontractors and the SSCL with respect to design need to be reexamined, taking into consideration the actual status of the performance requirements and of the design of each magnet type. A change in this area could reduce the prices offered on the superconducting magnets.

4. The majority of the subcommittee recommends conversion from firm fixed price to another, more flexible type of contract for the bulk of the dipole manufacturing.

5. The subcommittee strongly endorses full industrial participation in the design and manufacture of SSC magnets.

Technical Recommendations:

6. The bore diameters of the HEB dipole, HEB quadrupole, and collider quadrupole should be fixed as soon as possible. The MSD should work closely with the SSCL Technical Director and the Systems Integration group in coming to closure in these areas. Cost, schedule, heat transfer, fine-filament conductor availability, slow extraction of test beams, and future upgrade potential appear to be key constraints on the decisions.

7. Availability allocations should be made at the subsystem level as soon as possible to allow the responsible managers to start seriously thinking of what they must do to meet overall SSC availability goals. Managers should be made responsible for these allocations, which could enormously impact the overall SSC operating cost per unit of physics.

8. The information associated with the reliability and availability experience at the Tevatron, HERA, and UNK should be obtained, organized, and made available to the SSCL and the high energy physics community by the MSD.

9. There are many TBDs in the Prime Item Development Specification contained in the collider dipole magnet RFP. As many as possible of these should be filled in before the RFP is issued, if only with tentative numbers; the latter should be marked. It is noted that values for many of the TBDs were presented to the subcommittee. In particular, early resolution of acceptance test peak field (above nominal) is urged as it will strongly affect design and cost.

10. The HEB magnet requirements documents should be issued as soon as possible, preferably by year-end rather than the first quarter of 1991. Tests of AC losses during fast ramping should be initiated as soon as possible, perhaps on existing short magnets. Investigation of the time dependent magnetic field quality of dipole magnets operated in the bipolar mode must also begin as soon as possible.

11. Optimization of the cryostat design should be vigorously pursued. In particular, the possibility of hanging the upper collider ring should be seriously reviewed as this change would allow cryostat changes to reduce cost. Beam separation could also be reduced.

12. An independent, more detailed analysis of the implications of the change in copper-to-superconductor ratio should be commissioned by the SSCL. This should include at least minimum propagating zone, quench velocity, and peak coil temperature considerations. Heat transfer properties of single phase (supercritical) helium must be used in the analysis. The experimental program in this area at BNL should be vigorously pursued.

13. The sufficiency of the 0.6-K margin defined by the MSD should be independently reviewed. Energy input from scattered beam particles should be included in the examination. This review might be combined with that recommended on copper-to-superconductor ratio, as the two are intimately related.

14. Planning of the collider magnet life test should start now to define lead time and critical path items and to designate specific magnets for the test so they may be properly instrumented.

15. The SSCL should develop and maintain well-equipped laboratory facilities for material, structural, thermal, and electromagnetic measurements.

16. Mechanical properties of the key composites, the cold-mass and the cryostat support posts, should be measured at room temperature and at cryogenic temperatures (e.g., 77 K) in all three primary directions. Finite element models should use orthotropic solids with experimentally verified properties in all critical areas.

17. Mechanical testing should be expanded to include cyclic loading and fatigue properties. It appears that the cryostat support system design has not taken fatigue into consideration, yet each magnet will take a truck trip of perhaps forty hours with energy input at frequencies of a few hertz — close to a million cycles near the resonant frequencies of the support system.

Management Recommendations:

18. The subcommittee asserts that there is an absolute requirement to minimize, and preferably eliminate, design changes during magnet production. MSD and Laboratory management must begin training SSCL staff to ensure that this realization will be universal in 1994 when production begins.

19. The testing of the laboratory-designed, industrially-assembled magnets in the E1 complex in September 1992 represents a critical milestone which should be carefully monitored.

20. Performance, cost, and schedule responsibility should be delegated to the lowest possible level within the SSCL.

21. The interfaces between the magnet development program, the rest of the SSCL, and the other national laboratories are crucial and must be addressed with a communications vehicle less unwieldy than the wall-sized bubble chart now used within MSD to control magnet development.

    a. Adoption by the MSD of a more structured method of experimental design, one which provides for the extraction of maximum information from the minimum number of experiments with known confidence, is strongly recommended. This would allow more useful information to be extracted from each prototype magnet fabricated in the future than has been the case in the past.

b. Adoption by the MSD of a more structured method of setting systems requirements is strongly recommended. Requirements on common technology have generally been set by looking at the collider dipole magnet rather than at the most stringent service condition across all magnets. Once the most stringent requirement is located, a conscious decision can be made as to the cost effectiveness of maintaining or rejecting commonality. It was not apparent to the subcommittee that any such evaluations had been undertaken by the MSD.

22. The establishment of the three magnet product management offices and the hiring of Dr. Palmer as deputy director for technology provide the MSD with the opportunity to reorganize to provide clearer lines of responsibility and authority. Matrix management arrangements such as those now in place in the MSD are most effective in a mature organization where responsibility is clearly identified and acknowledged by support staff; under other circumstances, lines of responsibility are too often blurred and accountability obscured.

a. The MSD director should delegate full authority for product development to each of the product managers. The director has a larger job coordinating the efforts of the total division with those of the rest of the SSCL and the other national laboratories.

b. It is essential that the positions of CDM product manager and collider quadrupole magnet (CQM) product manager be filled on a permanent basis as soon as possible with very strong individuals.

c. The three magnet product managers should be provided with small, direct staffs to assist them in managing cost, schedule, and technical performance.

d. The staff of the business management group should be assigned to the three magnet product managers and to the MSD director, rather than remain as a line organization.

e. The Magnet Science Group should report directly to the new deputy director for technology. The subcommittee strongly recommends that the positions in the Magnet Science Group not be filled on a permanent basis, but rather that a revolving complement of the best available people be brought in on a nominal one-year basis.

23. The MSD should immediately start implementation of the CS/CS system to aid them in managing their expanding effort.

    a. The subcommittee recommends that MSD expeditiously develop a set of key milestones, distribute these throughout the Division, and track actual progress against the milestones. It notes, for instance, that only about 8 of the 16 40-mm-diameter, 17-m-long magnets planned for FY 1990 completion in July 1989, will in fact, be completed in FY 1990.

    b. The MSD should move promptly to integrate the divisional cost, schedule, and critical path database it is developing with that of the rest of the SSC project.

    c. Concern was expressed about the ability of the MSD to manage the six large contracts for superconductors to be placed within the next few months. In particular, the HEB product manager should be prepared to take action to ensure proper oversight of HEB-related conductor contracts.

24. The MSD should develop summer intern and fellowship programs for undergraduate, graduate, and post-doctoral students to create a pool of talent for the division and the Laboratory. Affirmative action efforts of the division should be strengthened.

10.3.2 Scope

The magnet subcommittee examined documentation on all of the superconducting magnets for the SSC project to assess whether the design is consistent with the performance objectives and is technically sound, the cost estimate is rational, and the schedule for performance is credible. In this subcommittee report, we review the costs (Section 10.3.3), the development and manufacturing schedule (Section 10.3.4), the management (Section 10.3.5), and the procurement plan (Section 10.3.6). The technical basis in Section 10.3.7 was expanded to cover development activities at the national laboratories and SSC (Section 10.3.8). We note the differences in the HEB magnets (Section 10.3.9), review the cryostat design (Section 10.3.10), and suggest additional testing (Section 10.3.11).

10.3.3 Costs

In general, the MSD presented a very thorough and comprehensive assessment of the detailed cost elements that are included within the Magnet Systems WBS categories. The WBS framework structure for each general magnet type separates the work elements for SSCL efforts from each of the currently planned subcontract work element packages. Further breakdown within each of these SSCL and subcontract packages shows individual product development, tooling, and production categories, as appropriate, depending on the SSCL's current plan for product manufacture. All costs are shown in FY 1990 dollars and are contained in the SSCL Cost Estimate Report of June 11, 1990. Total cost is $1904 billion. Because the magnet Request for Proposals is about to be released, the SSCL's cost estimate details are not included in this report.

10.3.3.1 Collider Ring Dipole Magnet Costs

By far the largest cost element is the production of collider ring 15-m and 13-m dipole magnets and most of the detailed presentation material was developed for these magnets. In general, most of the data for the other magnets was scaled, extended, and derived from the collider dipole magnet data base, so it is appropriate to focus most of our analysis and comments on these magnets.

The production cost breakdown for the long (15-m) magnets follows a sequence of 12 Fermilab industrial demonstration units, 10 industrial prototypes, and 65 pre-production units followed by 7956 full-rate production units. This progression shows the anticipated steps leading to full production and indicates a reasonable expectation of cost trends as production rate and learning increases. Most of the cost analysis and discussion below is based on the thousand unit price for the production magnets. For these magnets, the material and component cost is 83 percent of the total cost, and the labor cost is 17 percent of the total.

Superconductor

The largest single cost element for each magnet is the superconducting cable. A very thorough analysis of the basis for the cost projections was given. The unit projected cost of $16.70 per meter ($5.06/ft) for 30-strand, 6-micron inner cable and $13.33 per meter ($4.04/ft) for 36-strand, 6-micron outer cable was considered by the subcommittee to have a very sound basis and was consistent with a rough scaling from other large superconductor purchases (e.g., Tevatron, HERA, recent R&D billets, etc.). The NbTi material cost is projected at $96.80/kg ($44.00/lb) and dominates the overall material cost. For these unit prices, the resulting total superconducting cable cost of $42.4 thousand per magnet ($20.3 thousand inner and $22.1 thousand outer) represents 30.4 percent of the total magnet cost. The assumption of 90 percent yield at second extrusion is aggressive.

Bore Tube

The bore tube fabrication is considered to be a relatively straightforward fabrication and is estimated to cost approximately $4.8 thousand. A significant fraction of this cost ($1.6 thousand) is estimated for internal copper coating; hopefully minor development in processing or an imaginative vendor can supply a more cost-effective product.

Coil

The coil fabrication relies heavily on the successful utilization (and labor savings efficiency envisioned) of the coil winding, curing, and collaring tooling systems.

The estimated collared coil cost represents nearly 50 percent of the overall finished magnet cost. The estimate assumes the availability of Nitronic 40 or equivalent laminations at low cost and requires the successful demonstration of a reliable and durable coil insulation scheme. The coil end fillers and spacer elements that are now made from very complex five-axis milled surfaces are assumed to be manufactured as rather inexpensive molded components.

Yoke Cold Mass Assembly

The magnet yoke/cold-mass assembly represents an additional cost for materials and labor. The iron laminations are estimated at approximately $0.25/lb overall and the subcommittee considers this unit price to be unrealistically low for this type of material. The entire yoke assembly is contained within a welded stainless steel shell helium containment enclosure.

Cryostat

The balance of the hardware items comprise the cryostat and support system. The costs presented appeared to be reasonable projections of the present design being employed in the 40-mm long magnet development program. Considerable development and/or optimization is planned for these subsystems and the subcommittee considers this to be an area in which some additional cost savings might be realized.

Other Costs

An overall warm magnetic measurement allowance of 10 hours is included with each magnet. This seems a very minimal amount for testing to the subcommittee. Considerable sentiment exists within the subcommittee, in fact, that 100 percent cold testing of all magnets should be accomplished. This would be a considerable scope increase to the project not only in direct labor required, but also in refrigeration equipment and overall test facilities. The subcommittee strongly recommend that 100 percent cold testing be seriously considered.

In addition to the direct costs explicit in the details of the bottoms-up analysis for each dipole, there are several indirect costs that are also included in the estimate to be apportioned to each of the magnets. An indirect cost is estimated for an overall materials factor of a 10 percent surcharge applied on all materials costs. This 10 percent overall factor is assumed to cover 2 percent for material utilization, 2 percent for materials procurement processing, 1 percent for rejected materials, and 5 percent for magnet vendor's fee for handling materials. There is an additional 3 percent indirect labor factor applied for rework and/or repair labor. These factors are considered to be quite minimal to the subcommittee; perhaps twice those amounts could, in fact, be envisioned as more appropriate and should be considered in the contingency analysis.

A second indirect cost is a labor factor applied as a 40 percent overall addition to the direct labor total to cover manufacturing support labor. This 40 percent factor is distributed to cover supervision, engineering liaison, manufacturing engineering, industrial engineering, quality assurance, production control, and materials handling, program management, and CS/CS reporting.

Another allowance factor of approximately $2.0 thousand per magnet was added for truck transportation from a vendor's site to the SSCL site.

General Dipole Discussion

A very large factor in the accuracy and correctness of the overall dipole magnet cost estimate is the specific acquisition contracting scenario and the methods of procurement being planned. The SSCL plan utilizes a leader and follower pair of vendors (at CPFF) for the design/product-development, tooling design, and production of combined pre-production (35 each) and low-rate initial production (LRIP) (251 each) magnets, followed preferentially by the selection of a single vendor (at a firm fixed price) to continue with the nearly 8500 remaining collider ring (CR) dipole magnet production. Considerable discussion ensued regarding the subcommittee's concerns of relying on a single supplier for development, and its concern for possible cost uncertainties or consequences if price competition and aggressive and innovative manufacturing were not ensured. The unknown risk cost that will be included by an offeror in developing a quote also adds a large uncertainty factor to our confidence in the overall cost. This concern has been expressed in more detail in the previous paragraphs. The subcommittee felt that its concern in this area should be reflected in a higher overall contingency being applied to the production cost elements, and this is indicated in the contingency discussion that follows.

The SSCL's individual dipole cost for each of the 7956 long production magnets is comprised of materials and components labor. Overall, the subcommittee found no significant omissions in individual element details, but, in general, felt an uneasiness that perhaps each of the bottoms-up details was based too heavily on ideally considered rationales (e.g., quantity discount, learning curves, etc.) that might lead to an idealistically low overall composite price. For example, it was not clear whether prudent inefficiency factors had been considered for each labor element estimated, and whether the lowest projected bid from material and component suppliers represents the basis being used in most cases. Again, this concern is reflected in the contingency analysis.

Other Dipole Related Costs

The costs for the projected product development costs (both by the vendors and the SSCL) were presented and discussed. Cost estimates for the projected tooling system were also presented and reviewed. A thorough review of all the tooling assumption costs was not carried out, but a spot check of several of the large cost drivers (e.g., coil winding, collaring, skinning presses, lamination die-sets, etc.) were shown to be derived from recent vendor quotes or estimates and are considered by the subcommittee to provide a reasonable basis for the estimate.

Other Collider Ring Dipoles

The vertical CR dipoles are costed as separate WBS categories, but are planned to be manufactured in the same procurement package as the 15-m and 13-m dipoles. No additional subcommittee cost concerns were raised in this area.

10.3.3.2 Collider Ring Quadrupole Costs

The several families of CR quadrupoles are each itemized in the WBS, and the individual costs for product development, tooling, and production were presented and reviewed. The present quadrupole cost is based on the current 40-mm design and most of the cost data has been scaled from the detailed database developed for the CR dipoles. The subcommittee reviewed these plans and costs and finds them in good agreement and consistent with the overall dipole projections. The subcommittee also notes, however, that many detail elements in the specific quadrupole R&D have not yet been demonstrated, but there appears to be little risk that a satisfactory design will not become available. There is some concern, however, that the quadrupole aperture will, in time, be increased somewhat (e.g., perhaps to 50 mm as in the dipole); this would have a subsequent effect on cost and schedule. The decision deadlines on such a parameter change should be identified as soon as possible.

Most of the quadrupole production magnets (approximately 1848 units; CQM, DSQ, and M1Q) are planned to be produced by an industrial magnet vendor in a combined procurement package. Many other of the smaller quantity quadrupole families are planned to be made by the SSCL Magnet System Division.

10.3.3.3 HEB Magnet Costs

The HEB dipole and quadrupole magnets were also reviewed by the subcommittee; approximately 710 production units representing three different designs are planned to be procured from another industrial magnet vendor.

Whereas there are overall similarities in the proposed HEB dipole and the CR 15-m dipole (e.g., same length, bore, similar field levels, etc.), there are substantial differences in the details of the technical requirements. It is currently projected that a 50-mm coil diameter magnet will be utilized, but there seems to be a strong likelihood that it will need to be increased (to 60- or 65-mm) due to cooling uncertainties; the subcommittee strongly recommends that this requirement be studied and resolved as soon as possible. Another major overall uncertainty in the dipole concept concerns the successful development and availability of fine strand (2.5-micron filament) NbTi superconductor wire. Although initial projections and plans appear to be promising, the technology in this area has not been demonstrated.

The cost projections presented for the HEB magnets are basically scaled from the CR dipole cost estimate database. The overall scaling factors and adjustments to the unit pricing were presented to the subcommittee and appear to be uniformly applied and adequately examined. Most of the overall general concerns the subcommittee has expressed for the CR dipole production procurement also exist for the HEB magnets. In addition, larger cost uncertainties exist because of superconductor availability, uncertainties in cryogenic and cooling complexities, potential aperture increases, etc.

Each dipole magnet includes an allowance of $54.0 thousand for the superconducting cable (based on scaling from the CR dipole and adding a 20 percent factor for providing 2.5-micron filament). The SSCL is presently planning to operate the HEB ring in a bipolar mode on each machine cycle. The subcommittee considers this to be desirable, but is concerned that magnet properties and behavior have not yet been studied and verified, and is, therefore, concerned that additional technical and cost uncertainties will raise the overall system cost from that presented. The subcommittee considers overall increases in contingency to be reasonable to cover these overall technical risks and production uncertainties.

10.3.3.4 Other Magnet Systems Division Costs

In addition to the overall magnet manufacturing costs discussed above, WBS elements for both product development and tooling occur for each magnet type and within either (or both) the SSCL effort and subcontract sections. Again, most of the detail cost database development occurred for the CR dipole system and was scaled to cover similar activities in each of the other subsystems. Although the subcommittee was not able to thoroughly study the large volume of data presented and made available for review, area spot checking indicated that all areas were addressed and estimated on a uniform and consistent basis. It is noted that EDI costs for the CDM (leader), CQM, and HEB dipole are the same even though there should be substantial use of CDM technology in the other magnets.

An overall summary of all of the Magnet Systems Division costs for the 1.2xx WBS categories is listed below:

Table 10.3-1
Summary of Magnet Systems Division Costs for 1.2xx WBS

		($K)
1.2	Magnet Systems Total	1,904,207
	1.2.1 System Management	26,944
	1.2.2 HEB Magnet Production	171,052
	1.2.3 CR Magnet Production	1,667,590
	1.2.4 SSCL MDL & MTL Equipment	38,621

10.3.3.5 Contingency

The magnet system base costs presented to the subcommittee have been discussed in the sections above. The contingency analysis that the SSCL has performed resulted in an overall composite factor of 19.3 percent, or a total of $368,171 thousand applied to the base costs of $1,904,209 thousand.

The SSCL contingency has been applied down to WBS level 6 for each of the major magnet categories. The SSCL contingency is applied by assessing technical, cost, and schedule risk factors that range from 0-20 percent, 0-10 percent, and 0-6 percent, respectively. These factors are added to form an overall composite contingency percentage to be applied to each category. These standard factors would allow a maximum of 36 percent to be applied in some areas; the contingency factors actually projected in the SSCL contingency tables for the magnet systems range from a minimum of 15 percent (for 15-m dipole product development) to a maximum of 21.8 percent (for 15-m dipole tooling).

The subcommittee considers this overall SSCL direct assessment of contingency factors to be necessary to cover the cost increase areas that normally arise, but is concerned that there are additional uncertainties in the magnet program and that additional lump sum contingency values should be addressed:

1. *Cold Magnet Testing*: There is ongoing discussion regarding the necessity of 100 percent cold testing. A cost of adding this scope to the program may result in an overall cost increase of up to $100 million to cover test and measurement labor and equipment, cryogenic facilities, and space.

2. *Contracting Uncertainties:*: All of the unknown factors inherent in the proposed vendor selection and contracting method proposed have significant cost uncertainties. An additional lump-sum contingency of $150 million is suggested to cover this unknown project risk. For a total production of approximately 11,000 magnets, this implies an average of $14 thousand per magnet additional lump-sum contingency. There are many individual factors that might give rise to this additional $14 thousand figure: If the overall labor quantities increase, if the procurements cost for materials doubles (e.g., from 2 percent to 4 percent), if the rework labor increases by a factor of five (3 percent to 15 percent), if the contractor's labor rates (or G&A, or fees, or labor, etc.) are 20 percent higher than estimated, and overall, if the vendor's perception of his risk is higher or unknown, his product cost will also be higher. Potential schedule delays, design modifications, contract change orders, etc., all further affect this uncertainty.

3. *CR Quadrupoles:*: The uncertain but likely increase in CR quadrupole bore diameter will affect the overall cost. An increase in quadrupole cost caused by diameter increases would add approximately $15 million.

4. *HEB Magnets:* The uncertain but not unlikely increase in HEB bore diameter (as well as other significant design requirement changes) will also affect the cost. Also, uncertainties in 2.5-micron filament production may add further costs. An appropriate overall increase in HEB magnet production cost would add approximately $25 million.

Total: These total contingency lump-sum suggestions would add approximately $290 million overall. When added to the SSCL base contingency of $366 million, the total overall contingency would be $656 million. If compared to the magnet systems overall estimated cost of $1904 million, this $656 million contingency would represent 34 percent of the base cost. This overall contingency factor is suggested by the subcommittee to allow reasonable assurance, at this time, that the overall technical, cost, and schedule risk to the magnet systems total cost can be contained within this total.

10.3.4 SCHEDULE

The overall schedule for activities in the Magnet Systems Division can be characterized by three words — interrelated, dynamic, and ambitious. Great skill and attention is required by management to complete the projects as currently scheduled.

10.3.4.1 Schedule Complexity

The Magnet Systems Division is comprised of a number of projects that have been in progress over many years, sited individually or jointly at several national laboratories, and complemented now by recently active SSCL-sited projects. As never before, all these projects have become interrelated with definite input and output influences that are time-sensitive. What was once a program of three or four research projects with separate timelines has suddenly become 20 or so intertwined aspects of a large magnet program that additionally has major technical, cost, and schedule implications for the overall SSC program. With this interrelated quality comes a dynamic aspect to the Magnet System Division schedule beyond any previous condition. Now that specific actions and timelines are set, changes in internal division projects due to design improvements or vendor complications and revised aspects of interfacing external projects necessitate retiming or restructuring Magnet Systems Division schedules on an as-needed and possibly frequent basis.

The schedule for conducting a string test of 50-mm aperture CDMs by September 1992, for occupying the Magnet Development Laboratory by March 1991, and for delivering the first production CDM by January 1994, are indeed ambitious. These are success-oriented schedules with a myriad of possible adverse influences that might affect meeting the schedule, even with efforts to mitigate the effects.

The review subcommittee notes the ambitious nature of the schedules, but supports them as possibly achievable with constant attention to critical path items and aggressive reaction to discovered problems. It will also take considerable effort to maintain momentum in the various laboratories.

10.3.4.2 Critical Path Management and Decision Points

There are concerns that the system in place for these critical path components, the superconducting magnets, and the analyses performed in some areas, may not give the Laboratory sufficient insight into the design and manufacturing efforts.

For example, only one critical path diagram was shown in material from the early part of the review — the 50-mm collider dipole magnet program. It has inputs shown but no float is shown, and there is no indication of any real critical path lead-in items.

All the Magnet Systems Division leaders who described programs, schedules, and costing had Gantt chart schedules. No schedules showed much sophistication (float, influence routes, input interfaces, output information to other projects). All leaders knew the most time-sensitive steps, though no such steps were specifically marked for obvious use by others.

The Magnet Systems Division Business Manager has in place a section of people, and the hardware and software, to gather, input, manage, select, and output cost and schedule information, including critical path charts. This system is in the process of being implemented, but is effective at this date only for the 50-mm CDM string test project. A limited but growing coverage of the CDM procurement is now also available.

Open Plan is the software program being used for scheduling. It has recently been designated as the Laboratory-wide system, although other software programs are also currently in use in the Laboratory.

The Laboratory Project Office is instituting a Laboratory-wide top-level scheduling function that will be capable of showing critical path relationships. Integration of the Magnet Systems, Accelerator Systems, and Conventional Construction Divisions has not yet been implemented.

The Magnet Systems Division has set an internal target date of October 1, 1990, to have a complete, once-iterated cost, schedule, and critical path database in place. The database as it stands is valuable, however, and should be periodically distributed to key personnel beginning as soon as possible. Once the magnet project database is in place, it should be integrated with the project database for the rest of the SSC.

10.3.4.3 Milestones

No overall list of official milestones for the Magnet Systems Division was presented to the subcommittee during the review. The subcommittee recommends that the MSD expeditiously develop a set of key milestones for the Division, distribute the milestone set throughout the Division and track actual progress against the established milestones. The following dates and events were extracted from the provided material, but the dates are known to be likely to change.

Table 10.3-2

Key MSD Dates and Events Extracted from SSCL Provided Material

Date	Event
October 1990	Vendor selection for CDM (contract award is SSCL milestone M1-3)
December 1990	Fabricate and test 8 short 40-mm CDMs at BNL
January 1991	Beneficial occupancy of Magnet Development Laboratory
January 1991	Test first 5-m long 40-mm CQM at LBL
February 1991	Vendor selection for CQM
March 1991	Fabricate 8 and test 3 long 40-mm CDMs at BNL
June 1991	Start assembly of first industry demonstration CDM
July 1991	Complete fabrication of 6 short 50-mm CDMs at Fermilab
July 1991	Fabricate and test first long 50-mm CDM at Fermilab
September 1991	Beneficial occupancy of Magnet Test Laboratory
September 1991	Complete conceptual design of dipole and quadrupole HEB magnets
January 1992	Test first long CDM in MDL
April 1992	Finish assembly of 12th industry demonstration CDM
May 1992	Test 2 LBL/Industry CQMs at BNL
July 1992	Start test of first industry prototype magnet in MTL
September 1992	Complete half-cell string test underground at SSCL (SSCL milestone (M1-6)
January 1994	Accept first production CDM
May 1994	Deliver first special utility quadrupole magnet
June 1994	Start production of CQMs
April 1995	Deliver first low-beta quadrupole magnet
July 1995	Start production of HEB dipole magnets
July 1995	Start production of HEB quadrupole magnets
September 1995	Deliver first dispersion suppression quadrupole magnet
December 1995	Deliver first vertical dipole inboard magnet
April 1996	Deliver first M-1 quadrupole magnet
May 1996	Deliver first vertical dipole outboard magnet
May 1996	Deliver first medium-beta quadrupole magnet
March 1998	Last CDM installed

10.3.4.4 Schedule for High Energy Booster (HEB) Magnets

The HEB magnet program is now in the same situation that the collider dipole magnet program has been in with respect to superconductor cable, i.e., dependent on a conductor research program for the material to wind magnets. The situation has repeatedly delayed collider dipole magnet prototypes during the last 2 years and is likely to delay the

HEB magnet program. Projected delivery dates for two of the four 2.5-micron R&D billets have slipped by 4 months since the contract was awarded a year ago. The program the SSCL is putting in place is the best available to minimize the risk in this area, but there is still significant risk in this area that must be carefully managed. The Magnet Systems Division may lack the resources necessary to manage the six large contracts for superconductor cable that are planned for issue during the next 6 months. If this proves to be the case, the HEB product manager must take action to ensure proper oversight of the HEB-related conductor contracts, thereby minimizing the schedule risk to this program.

The design, analysis, and fabrication schedule for the HEB magnets is extremely aggressive. The 50-mm bore and AC service impose coupled design constraints that will require a number of conceptual and experimental design iterations before convergence to a useful magnet is achieved. It will be very difficult to remove the ramping energy losses with the liquid helium flow annulus available.

10.3.4.5 Schedule for Half-Cell String Test

The half-cell string test is a SSCL first level milestone (M1-6) scheduled for September 1992. This is a critical path activity for the Laboratory in the program to achieve official approval to initiate subsequent activities. The half-cell collider string test uses five 15-m 50-mm aperture CDMs built by industry and one CQM in the test facility to be built at the E1 service area.

10.3.4.6 Schedule for Collider Dipole Magnets (CDM)

More than 8600 CDMs will be produced under a development and production program now being established. The SSCL has issued a draft request for proposal (RFP) to interested industrial companies, has received comments and suggestions on the draft RFP, and will issue an RFP within a month or two. The award of contracts to two industrial companies to begin the CDM work is a first-level SSCL milestone (M1-3). The schedule for this milestone is still officially listed as August 1990, but the procurement action must be revised in schedule, perhaps to November 1990, for vendor authorization to proceed and to March 1991, for final contract award.

The present plan calls for the delivery of a total of 15 prototype, 70 pre-production, and 502 initial low-rate production CDMs from two vendors within 44 months after contract award. In a subsequent phase of the program, one or more contractors will deliver approximately 8200 CDMs over a several-year period at a rate of 10 magnets per day. Final installation of the last CDM in scheduled for March 1998.

The subcommittee notes that the early phase of this program is already behind schedule, that an effort is underway to issue the RFP as soon as practical, and that the date for the intensive rate of production has not yet been affected but will require continual attention by SSCL and subcontractor management.

10.3.4.7 Schedule for Magnet Support Facilities

The magnet support facilities consist of the magnet development laboratory (MDL), the magnet test laboratory (MTL), and the magnet acceptance and storage (MAAS) facility.

The MDL and prototype installation facility (PIF) are parts of the proposed E1 complex that will be used for testing the industrially assembled 15-m long 50-mm aperture CDMs. This test is a first-level SSCL milestone (M1-6). The use of the MDL and the MTL are on the critical path schedule to meeting that milestone.

The planned start date for work by the AE/CM company on MDL and MTL has already passed, with no work yet accomplished. When the contract with the AE/CM company is signed, or when actual AE/CM work begins, an early and strong effort must be devoted to these facilities to minimize schedule slippage. Magnet development activities were planned to start in the MDL in January 1991. The SSCL-milestone test of the 1/2 string of 15-m long 50-mm CDMs and CQM is presently planned for September 1992.

The MAAS will be needed by 1994 for receiving and final acceptance of warm test pre-production and production magnets and for temperature-controlled storage of up to 300 magnets prior to magnet installation in the tunnel.

10.3.5 Magnet Systems Organization

The Magnet Systems Division has described its primary responsibilities as: (1) magnet industrialization (technology transfer), (2) magnet R&D, and (3) magnet repair/production. To accomplish these goals, the Division has established a matrix-type organization consisting of the Director, deputies for programs and technology, five line branches (engineering, quality assurance, production, test, and business management), three staff product managers (for collider dipole, collider quadrupole, and HEB magnets), a contracts group, and a magnet science group. Staffing levels of these organizations range from 117 in the production branch to 44 in the management area in peak year 1994.

A matrixed organization can lead to a blurring of the lines of responsibility and authority and, in fact, the subcommittee had difficulties in determining where the responsibility for meeting the magnet critical path milestones rested. The collider dipole magnet has been described as the critical path item for the project. The ability to proceed with the accelerator tunneling is dependent upon having successful, industry-assembled magnets string tested as planned in September 1992. The importance of using critical path management techniques in a program of this magnitude cannot be overemphasized. A key element of critical path management is the identification of the product managers who will be responsible for beginning to focus the efforts of groups at Fermilab, BNL, and LBL; the matrix Magnet Systems Division staff; and for successfully bringing the magnets on line. Currently the HEB effort is headed by a permanent staff member, whereas the collider dipole and quadrupole efforts are headed by acting SSCL staff with other significant responsibilities in the Laboratory. It is essential that these two positions be filled as quickly as possible with permanent staff. In this regard, the Division Director has advised that qualified candidates have been identified and that negotiations are ongoing.

Examination of the present and near-term workload indicates that there is a heavy emphasis on magnet fabrication and tests. Management should be sensitive to the likely possibility that the above activity will generate a multitude of problems that analysis and design people will be called upon to solve, thus overloading their limited capability. Their ability to stay ahead and influence design will be impaired.

The Magnet Systems Division is to be complimented on hiring Dr. Robert Palmer as the Deputy for Technology. Dr. Palmer's agreement to join the SSCL in September will help provide the Magnet Systems Division with the expertise in and direction of magnet design that has been diffused throughout the national laboratory structure to date. His appointment also provides the Laboratory with the opportunity to reorganize to provide clearer lines of responsibility and authority. This new organization should be compatible with and supportive of meeting the Division's stated goals, i.e., R&D, magnet industrialization, and magnet repair/production. A matrix management arrangement is most effective in a mature organization where responsibility is clearly identified and acknowledged by support staff; under other circumstances, lines of responsibility are too often blurred and accountability obscured.

The subcommittee was pleased to see the organizational line of a Magnet Science Group, intended to be a small complement of technically excellent people for use on important technical problems. This group will not be burdened by administrative responsibilities. The budgeted staffing level of this group is 2.2 in FY 1990, 2.8 in FY 1991 and 5.0 in FY 1992-1998. The subcommittee strongly recommends that these positions not be filled on a permanent basis, but rather that a revolving complement of the best available people be brought in on a nominal one-year basis for intense interaction with the permanent staff and the ongoing technical studies. The subcommittee suggests that the type of person recruited for this position include distinguished university professors (possibly on sabbatical leave), industrial experts (probably on leave of absence) and international scholars and technologists from other countries such as the Federal Republic of Germany, Japan, USSR, etc.

The Magnet Science Group should report directly to Dr. Palmer, who should be responsible for assigning the research tasks to be undertaken by this group and for assigning Laboratory resources as necessary to support their tasks.

It is imperative that the Magnet Systems Division immediately start implementation of the CS/CS system to aid them in managing their expanding effort.

The magnet product managers should be permitted to have small, direct staffs to assist them in managing schedule, cost, and technical performance. The product managers alone cannot adequately call upon the combined talents of the five line divisions. The subcommittee views a staff consisting of an engineering coordinator, site representatives at the contractor's plants, a subcontract administrator, and a business manager as a minimum staffing profile for each of the three product managers. This staffing level will provide the product managers with adequate control while preserving the matrix management which the MSD Director feels is important to assure uniform or compatible magnet parameters. Increased attention should be given to identifying women and minorities for jobs, intern programs, and fellowships within the MSD.

The Magnet Systems Division Director must appoint extremely strong individuals for the two remaining positions and should be prepared to delegate full authority for product development to each of the product managers. The Director has the larger job of coordinating the efforts of the total division.

The essential function of the business management group is to provide the Director with divisional cost and schedule tracking, roll-up budget development, and administrative coverage. These activities are generally organized as staff rather than line functions. The staff of the business management group should be assigned to the three magnet product managers.

10.3.5.1 Staffing

The MSD currently employs 130 scientists, engineers, business managers, technicians, and clerical staff. The number is expected to reach a peak of approximately 380 in FY 1994 and to drop to an operational level of about 190 FTEs in FY 1998. The MSD will reach a staffing profile of about 40 percent URA employees and 60 percent EG&G employees in FY 1994. As staffing reductions occur in the magnet area, the EG&G staff will either be relocated within the SSC Laboratory or move to other EG&G projects. The staff levels are carefully planned to ensure that URA staff fill the long-term positions at the Laboratory.

Many on the subcommittee were pleasantly surprised at the current size and quality of the MSD staff. The MSD has recently made significant advances in hiring. Dr. Robert Palmer will join the staff as deputy for technology in September on a half-time basis. Dr. Jayakumar's work was most impressive. Appointments of the collider dipole and collider quadrupole product managers will be made in the next 4 months.

The impression remains that skilled personnel at other DOE national laboratories will not relocate to the MSD. Yet the industry as a whole is undermanned in the majority of the skills needed by the MSD and, in general, the MSD has attracted its share of the skills pool. There is every expectation that a few more qualified staff members of BNL, LBL, and Fermilab will join the MSD, but the long-term employment needs of the MSD must be met through internal training. MSD currently has no specific programs for bringing on undergraduates, graduate students, and postdocs to enhance its hiring opportunities. The bulk of the future personnel needs of the MSD can only be met by the MSD's growing its own talent.

The first-line supervisors within the organization are a highly qualified group. Activities underway in the Laboratory, as described during the presentations, cover all areas of magnet design, development, and planned production. The subcommittee did not discover any omissions of major technical areas in the presentations of the MSD staff. In particular, the engineering group manager, Dr. Phil Sanger, has assembled a staff that is technically strong and broad across technical disciplines. In addition, careful attention to hiring and career path opportunities for their employees was evidenced by several of the group leaders. Some notable examples included Dr. John Tompkins, who has his recruits interviewed by the Director of Physics Research so that when testing activities diminish these staff members have career opportunities with the experimental group, and Dr. Jon Zbasnik, who, unable to find experienced personnel in specific areas, hires consultants to train his staff and new hires in these fields. The latter example illustrates a concern of the subcommittee, namely, that the average experience of the staff is somewhat less than what might be desired. In this regard, however, it should be noted that CEBAF was designed and is being built by staff with similar years of experience.

As the MSD recruits employees and develops intern, fellowship, and training programs, it is essential that consideration be given to identifying women and minorities for positions in the MSD. As it is the Secretary's plan to have the SSCL serve as a key educational center for the Department of Energy, it is imperative that minority and female future scientists and engineers find role models at the Laboratory.

The Magnet Systems Division should develop summer intern and fellowship program for undergraduates, graduate students and postdocs to create a pool of talent for the Division and/or the Laboratory.

10.3.6 Magnet Acquisition Plan

The Laboratory currently plans to procure its collider dipoles under a two-phase procurement. Engineering design, tooling design, prototyping, preproduction and low-rate production will be performed in the first phase using cost-plus-fixed-fee contracts. Two contracts will be awarded to industrial firms under a leader-follower arrangement. During the first phase, the leader will locate at Fermilab to assemble 12 prototype units for the 1992 string tests. Near the completion of the first phase, a competition between the leader and follower is expected to result in the award of a contract for the production units (less any foreign contributions) to a single company on a firm fixed-price basis. The RFP does not preclude the possibility of continuing two firms in production and recompeting at a later time. It is the SSCL's position that a single supplier is acceptable for the production units because 1) the cost of keeping one firm in production is less, 2) the award will be made to a qualified firm based upon an evaluation of the firm's cost and capability, 3) it is likely that a foreign contributor of collider dipoles will also be in production, and 4) the HEB and collider quadrupole magnet suppliers will also have been involved in the early design effort and will have developed similar techniques. While there would be a manufacturing schedule slippage in moving the tooling to the HEB supplier, the quadrupole supplier, or even the loser of the production competition, the SSCL feels that back-up suppliers are adequate. Nevertheless, there was general consensus in the subcommittee that it is not likely that the CDM acquisition strategy will meet the cost and schedule estimate presented.

The responsibilities of contractor and SSCL with regard to the collider dipole design need to be reexamined, taking into consideration the actual status of the design and performance requirements. The Laboratory should assume responsibility for the design features that affect critical performance characteristics, such as field quality, quench properties, etc. It is unrealistic to hold a contractor responsible for producing acceptable magnets in a string when the critical performance specifications are outside of his control. On the other hand, the responsibility for other features of design, such as general features of the cold mass and cryostat, reliability, manufacturability, etc., along with the responsibility for manufacturing, should stay with the vendor. This shared responsibility can be expected to result in more-reasonable costs. There are far too many TBDs in the PIDS for an offerer to assess on a sound basis the potential development difficulties and to estimate the effort required to clean these up. Indeed, the varying interpretations of the remaining TBD by proposing firms may not lead to a level playing field for offerers and will complicate the evaluation of the proposals. Again, every effort should be made to eliminate as many TBDs as possible, even if only on a best-estimate basis.

There is no clear information in the RFP on SSC-furnished items such as:

- Analysis
- Drawings
- Studies
- Equipment
- Test Results

Uncertainties in these areas will add to the cost and schedule uncertainties. Because of these uncertainties, the subcommittee feels that the RFP gives the impression that the SSCL attaches low importance to cost in the vendor evaluation process. Some subcommittee members also believe that not asking for a definitive detailed cost estimate for production of 8000 magnets is another indication of lack of emphasis on cost. While some believe that this data will be very valuable in comparing vendors and allowing SSCL identification of cost drivers and will also provide an insight into the offerer's understanding of the production process, others believe that the data will have little validity due to their being provided so early in the engineering design process.

It is recommended that the decision as to method of contracting production of 8150 CDM units should be postponed. Options to execute a contract that may be either FP or CP plus incentives should not be decided upon until progress on the first phase of the contract is evaluated, particularly the remaining risk in meeting cost and schedule objectives from the contractor's viewpoint.

The comments above notwithstanding, the subcommittee strongly endorses full industrial participation in the design and manufacturing of SSC magnets.

10.3.7 Magnet Technical Basis

10.3.7.1 Summary

The technical basis for the SSC magnets has matured considerably since the last review. The new database developed through testing has led to a better understanding of the magnets' behavior in general and of the 40-mm-bore collider dipole magnet (CDM) in particular. However, the data developed has led to the project decision to increase the technical margins of the project by scaling the CDM up to a bore of 50 mm. This new design was presented to the subcommittee.

The system requirements documents should be completed as soon as possible even if the yet-to-be-determined parameters are specified with a best-judgment number for the interim so that feasibility studies can be made.

It is felt that availability allocations should be made at the subsystem level as soon as possible so that the responsible managers start seriously thinking of what they must do to meet the overall SSC availability. With a projected SSC operating cost of a million dollars a day, availability is an important cost driver. The subcommittee suggests that a data base and a methodology for this allocation should be developed.

The subcommittee strongly supports the recent strengthening of the analysis area at SSCL. There is a feeling that this group is still not up to a reasonable strength and therefore must pay close attention to how it expends its resources. Areas that can easily be covered by the associated national laboratories like field quality calculations, etc., should be temporarily shed in favor of analyses that are crucial to developing the maturity of the 50-mm design such as structural, thermal, stability, and quench analyses.

The work of the task force in developing recommendations for tests has been very useful in increasing the understanding of the CDM design. It should continue its work with increased analytical support as that MSD group comes up to speed. There has been progress in developing design criteria for the magnets but it is suggested that an attempt be made to develop criteria in a numerical form which can be related, for example, to reduced training in future management designs.

The analysis group will need better material-property data to simulate the behavior of the CDM. This will have to come from a testing program sponsored by the SSCL since the literature in this area either does not exist or is of poor quality.

Overall the subcommittee feels that a substantial amount of high quality technical work has been accomplished by the SSCL on the magnet designs. Though there is still much work remaining to complete the new design the subcommittee feels that the change from the 40-mm to the 50-mm-bore design for the CDM has significantly increased the technical margin for this crucial element of the SSC. The cost effectiveness of the change is discussed in Section 10.1.

10.3.7.2 Design and Analysis

System Requirements

System requirements should be targeted to:

1. Convey definitive critical performance parameters to initiate design.
2. Identify environmental and interface conditions.
3. Provide general guidance concerning parameters that have significant uncertainty and indicate limits on the uncertainty.
4. Indicate parameters that are yet to be defined as TBD. This category should be as small as possible.

Several items were marked TBD in the requirements lists. These should be filled in with temporary ballpark values as soon as possible for evaluation of feasibility.

The number of required excursions beyond the nominal operating point during tests or postulated operations scenario must be defined early because of the strong impact on fatigue lifetime, reliability and structural design criteria. The latter have a direct impact on structural weight and cost and have not been considered.

Consideration should be given to freezing magnet requirements at the time each magnet contract is issued. This will minimize magnet design iterations and allow concentration on optimization of features and tooling for production efficiency.

Design Criteria

Design criteria are now under development and are partly specified in the PIDS (e.g., for the collars and yoke materials) for the CDMs. Consideration should be given to a review of these items from the standpoint of fatigue lifetime and crack growth, for consistency with the expected operational conditions. Specifications must be developed for all material including filler blocks and insulation.

There has been substantial progress in the design, fabrication, test, analysis, and understanding of the conditions that reduce training. In order to aid the CDM-magnet scale-up and to complete the design process for other magnets, structural design criteria for the winding and support components require immediate best-guess definition, followed by iteration as more analytical and empirical information becomes available. Although a necessary and sufficient set of conditions cannot yet be defined, it is essential that quantification of criteria be started and implemented. Since quenches in recent magnets seem to initiate in the ends and splice regions, the implication is that the ends require attention; however, more-refined 2D analyses should also be done on the straight sections of successful magnets. These analyses may lead to tentative criteria in the form of limits on deflections, strains, stresses, shear stresses, or another parameter that can be used for straight-section design of other types of magnets and then evaluated further.

The ends, splices, and terminations are necessarily complex, 3D in nature, and difficult to analyze. Criteria development in this area will no doubt take longer to define and verify, but the attempt must also be started. The discipline associated with the documentation of tentative criteria will aid in progress toward their ultimate generation.

Design criteria associated with the tolerances for acceptable field quality also require definition for use in the magnet and tooling design areas. This effort has been started and should aim for a unified approach among participating laboratories.

Specifications

Several specifications in the PIDS were indicated as being TBD. These should be filled in as soon as possible even if the values used are best-guess. This will allow a preliminary evaluation and response by potential bidders and designers. The SSCL is in the position to make the best guess and assume the responsibility rather than risk a totally unrealistic assumption by a magnet subcontractor.

Reliability/Availability

The issue of reliability should receive more attention. To begin, the information associated with the experience on magnet performance at Fermilab and at HERA should be organized and made available. Such information would allow some insight to be gained into rates for rejection and failure, as well as into the likely points of nonconformance and sources of component failure.

A high operational availability of the machine must be one of the priority design goals. Operational cost in terms of lost experimental time amounts to ~ $1 million per day. If lost time has to be made up at 50 percent availability it will cost ~$100 million per year. This is a substantial incentive to achieve a high degree of availability.

The SSC is comparable in complexity to recently constructed and operated particle accelerators even though it is an order of magnitude larger in size. Only a moderate extrapolation of existing data is required to predict the availability for most SSC subsystems, except for the magnet system, which requires greater extrapolation.

Table 10.3-1 below shows the percentage of unscheduled down-time relative to scheduled up-time of the major systems of various machines for recent extended running periods. In compiling these data, all unscheduled down-time is taken into account in each of the entries. Thus, for example, although CESR does not report its power supply failures separately, they are included in the other systems, such as magnets. We note here that the entries are not exactly compatible from machine to machine, so comparisons are sometimes difficult, but trends are clear. The more-involved injector systems of the Tevatron are a greater cause of downtime than the less-complex systems of CESR and PETRA, but it should be noted that the failure rates of many of these systems do not scale with size. Thus the CESR vacuum system has the same failure rate as the Fermilab system.

Some of the entries are anomalous. The large percentage down-time of the PEP injector is unusual, as the SLAC linac has operated reliably for many years. This downtime probably contains a large contribution from the modifications that were being made in preparation for operation of the Stanford Linear Collider (SLC). A thorough analysis of the collected down-time data could be done to form an valuable data-base for detailed engineering of SSC systems.

Table 10.3-1

System Down-Times as a Percentage of Scheduled Up-Time

System*	CESR	PEP	PETRA	Tevatron 800 GeV	CERN Fixed Target
Power Supplies	.0	3.0	4.2	4.1	1.0
Cryogenics	.0	.0	.0	4.2	.0
Vacuum	0.4	0.6	1.7	0.4	0.2
Control/Instr	1.1	1.6	0.6	0.7	0.8
RF	12.2	0.9	4.2	0.6	1.4
Injector/Abort	.0	.0	.0	0.7	.0
Utilities	0.9	1.8	1.0	3.0	3.4
Interlocks	0.4	0.8	1.0	3.0	3.4
Magnets	3.3	.0	.0	6.2	1.8
Miscellaneous	1.7	6.0	4.0	1.1	3.0
System Avail.	77.7%	60.3%	77.2%	64.4%	82.4%

* Data extracted from recent annual reports of the indicated institutions and from supplemental operation logs supplied by D. Rice, CESR; J. Paterson, PEP; H. Kumpfert, PETRA; R. Mau, Tevatron; G. Brianti, CERN.

In addition, Table 10.3-1 shows the total availability for each accelerator. These data imply that a realistic level of performance for an accelerator is 60 to 80 percent. It seems appropriate, therefore, to aim for an availability of 80 percent for the SSC.

Where data and procedures exist, modeling should be performed to estimate availability; where no detailed data exist, scaling by size and complexity from the data of Table 10.3-1 could be done initially. Iterations are then necessary where required redundancy or other design changes are needed to increase availability. Use of Bayesian statistics (use of prior distribution) is a necessity because specific statistical data will not be available within any reasonable cost-time envelope.

Consider the following example in which the total SSC availability goal of 80 percent can be allocated to each of the SSC systems. This will require a somewhat higher level of subsystem availability than in existing accelerators. It will necessitate taking advantage of progress in technology and improved designs and analysis. The result for the required availability of each system is shown below:

Magnet System (including interconnect)	~0.96
Power Supplies	0.96
Cryogenics	0.98
Vacuum	0.995
Control and Instruments	0.98
RF	0.98
Injector Complex	0.95
Injector/Abort	0.985
Utilities	0.99
Safety Interlocks	0.99
Overall	~ 0.80

An early allocation of availability goals for each system should be done and will provide guidance for the responsible technical system managers. They, in turn, should reallocate availability for their subsystem to determine critical areas. The task is non-trivial and requires a disciplined approach, but has proven to be useful in other complex system designs. This example indicates the high availability required in the magnets to support a sample requirement for the SSC. The subcommittee was pleased to note that reliability analyses of this type have started for the collider dipole. The Collider Dipole Reliability Plan was discussed with the subcommittee and it represents a good framework for further effort in this area.

Electromagnetics

The analytical tools for adequate field quality calculation of straight section and end field harmonics are available and being upgraded at SSCL. Recent design calculations and experience with warm and cold measurements on SSC 40-mm magnets as well as with the HERA magnet series production indicate that the required harmonic coefficient limitations for the 50-mm system are achievable, except perhaps for the a_1 term, which reflects the up/down symmetry of the half coils.

The analytical tools for optimized turn placement, field distributions, and error fields are also available at SSC and other laboratories. Some additional coordination may be desirable to avoid duplication of activities to allow the central design team to concentrate on the most critical issues for achieving reliable performance. At this stage, items in this category involve structural, thermal, stability, and quench effects.

Stability and Quench

The 5 percent additional margin associated with changing to the 50-mm diameter CDM is an obvious benefit. The change to a different Cu/SC ratio appears to be reasonable, but requires more time and effort to assess than available in this type of review. As a result an independent, more detailed assessment by another group is recommended. It should also take into account the expected spread in cable performance based on critical property information taken to date. This should be done as soon as possible.

One of the issues to be considered in assessing the margin is the impact on the temperature margin at the operating point. Quench and training data from magnets that have been built indicate that a margin of about 0.6 K is the minimum desirable. The value for the 50-mm design was indicated to be slightly more than 0.6 K. However, there have been significant changes in conductor processing and it would be desirable to have this measured directly.

Calculations also need to be done concerning the heat load and temperature rise in the winding due to scattered-particle energy deposition, both at the full operating field and at injection.

Quench analysis codes are available at SSC and are probably adequate for near term purposes, particularly in view of empirical data being generated in the testing program. However, more advanced codes may exist in other areas (e.g., fusion). This should be investigated in parallel with present activities. The potentially damaging thermal stresses associated with quench have not been analyzed, nor have thermal stresses from cooldown transients, but these analyses will be required as the design develops.

Structural Analysis

Considerable progress has been made in developing and acquiring tools to aid in the design of the magnet systems. This effort should be commended and expanded in the near term to allow timely turnaround of design characteristics.

Several 2D and 3D finite-element structural codes are currently available to the SSCL. In most cases, they require a considerable amount of experience to run and obtain results with confidence. They are often incompatible with each other and with other codes that may be used to generate data for loads of electromagnetic origin. To conserve available manpower and to turn around cases more quickly, it may be desirable to concentrate activities on one or, at most, two of these finite-element codes as soon as possible.

Since the staffing level is still in a growth phase, it may also be desirable to set priorities in a manner that is most consistent with critical issues. This may require temporary neglect of the most sophisticated codes and more-complex models in favor of concentration on gaining insight from more-approximate models and on comparisons with experimental performance.

Tooling Requirements

It may be advisable to initiate a standard format for presenting and interpreting measured multipole coefficient information. This would aid in comparing information from the supporting laboratories and in the consistent calculation and translation of the information into a form desirable for tooling design requirements and tolerance adjustment for existing tooling.

10.3.7.3 Supporting Tests to Date

The organization of a task force to provide coordination among the laboratories in the magnet design and test activities allows a rapid response to critical issues and is to be commended. There has been an obvious improvement in the understanding of some of the features that aid in suppression of training. A continuing effort using a more-intensive experimental/analytical effort to iteratively approach numerical design criteria would benefit the design activities for all magnets of this type.

Material Properties

Test programs are now underway to measure mechanical properties of winding components and of the winding composite. This is essential to a proper understanding of the behavior of the winding and development of more accurate analytical models to aid in formulation of design criteria. Measurements should be made for all three primary directions.

Thermal contraction characteristics of selected materials is also of importance because of the dependence of magnet training on "local stick-slip." Published material data in this instance is often unreliable, hence consideration should be given to a test program in this area.

Electrical and mechanical tests of insulation are underway. These tests should use conductor in a simulated winding pack for an adequate representation of the operating environment. Testing should be expanded to include cyclic loading to consider creep and flow effects and fatigue lifetime. Testing under temperatures representative of manufacture and operation are necessary.

The glass component of the baseline insulating scheme is about half as thick as the glass in the Tevatron magnets. Although similar systems have been used with success in recent magnets (i.e., HERA), it should be noted that it requires precise application and quality control. It is unlikely that any commercial product would be made with an insulation scheme that is this thin. The reasons are its lack of tolerance to the handling and application procedures in a factory environment and its sensitivity to local mechanical disturbances (e.g., burrs, chips, or local applications of other materials to start or stop new lengths of insulating material). It is likely to be the weakest point in the magnets from the reliability standpoint. However, changing insulation schemes is a very- high-risk item in magnets of this type. The testing and selection program must be thorough and rigorous, and must occur as soon as possible. After the system design is frozen, substitutes of materials or application procedures should be avoided.

LBL Activity: Quadrupoles

LBL has made exemplary progress in the design, installation, and operation of the high speed cabling machines required for the conductor.

Recent tests on quadrupoles have been promising. It is important that a timely decision on bore diameter be made by the project. This will reduce the number of iterations required to achieve a final design and allow tooling characteristics to be developed at the proper dimensions without iteration. An issue of particular importance is to measure the possible shift in magnetic center due to thermal cycling.

BNL and Fermilab Activity: Dipoles

Recent experience in the dipole magnet program indicates that, at 4.35 K, magnets reach the conductor limit after one to two quenches if pre-conditioned. There is no retraining after thermal cycling in the 1.8-m dipoles. Recent 17-m magnets have retrained after thermal cycling, however. There is now a good understanding of the location of quench initiation. The isolation of the quench initiation sites should be emphasized, together with the corresponding structural and thermal analyses, to iteratively define numerical goals for design to suppress quench initiation.

The application of data from the 40-mm to the 50-mm program is non-trivial and not straightforward because of the lack of the numerical design guidelines for quench suppression. The electromagnetic loads on the end turns of the 50-mm magnet increase as a function of the radius squared and the loads on the straight section increase as a function of the radius. As a result, it is desirable to transfer to the 50-mm program as soon as possible.

The CDMs for the string test and life test will be produced at Fermilab. Timely delivery and adequate performance of these units is crucial for the SSC program. To meet the schedule and performance requirements, the Division should implement configuration management, QA/QC practices, and CS/CS suitable for the task at hand.

10.3.8 Magnet Development Activities

10.3.8.1 Summary and Conclusions

The summary Magnet Development Plan supplied to the subcommittee can provide the basis for a focused magnet development effort at the DOE laboratories that will produce the technology base required for industrial engineering development of the SSC's superconducting magnets in a timely fashion. It should be expanded substantially if it is to be used as a control document and information tool within the SSCL. The proper level of detail is approached in the draft Magnet Development Plan of February 22, 1990, sent by the SSCL to the DOE on that date. (This draft document was supplied by the DOE to the subcommittee to supplement the SSCL's summary document.)

Control of the magnet development effort is effective, however. The medium used is a bubble chart that mixes tasks, questions, and milestones in the style of a CPM drawing. This chart is available on the Magnet Division's CAD system for easy reference by its personnel, but is not easily used in communicating with those outside the division. The interface with the rest of the SSCL and the other national laboratories is crucial and must be addressed by another instrument.

Adoption by the Magnet Division of a more structured method of experimental design, especially one that seeks to extract maximum information from minimum experiments like the Taguchi method, would allow more useful information to be extracted from each prototype magnet fabricated than has been the case in the past.

The collider dipole magnet design is closest to completion. It is expected that the last piece-part drawings for the demonstration magnets will be available by the end of July 1990. The draft specification for the magnet was placed under change control late in March, albeit with many TBDs. The collider dipole draft requirements document is to be placed under change control on August 1, and the HEB magnet draft requirements document are due early in 1991. Earlier issuance of the HEB document is recommended. Full and complete requirement specifications will be written by the SSCL's industrial subcontractors in cooperation with the SSCL once the subcontractors have been chosen.

The other Department of Energy laboratories that have been participating in the SSC program have been assigned roles that capitalize on their strengths. LBL has been assigned the collider quadrupoles and will continue to assist the SSCL in superconductor development. Fermilab has had the lead role in the design of the collider dipole cryostat and will soon acquire the capability of making cold masses as well. Since its tooling is an improved version of that originally designed at BNL, and since the SSCL facilities will not be available in time, Fermilab has been chosen as the site for the baseline 50-mm magnet fabrication, including the industrial demonstration. BNL will pursue a backup 50-mm program and continue its efforts in superconductor measurement.

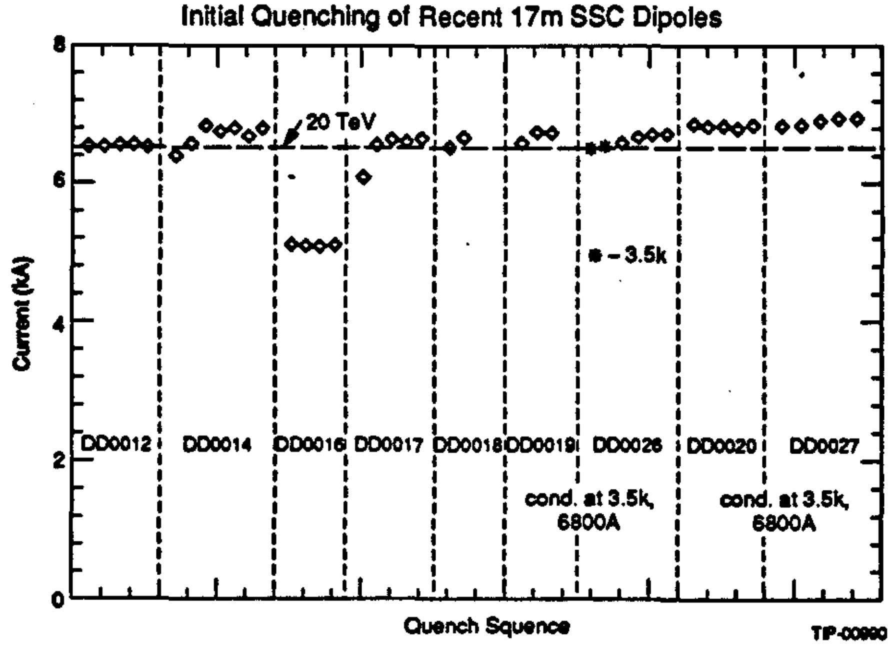
As in the rest of the SSC, reliability is an overriding concern for the superconducting magnets. The required mean time to failure for each magnet is roughly 3 million days for 98-percent availability of the magnets (failures in the interconnect region are not included in this calculation). The Laboratory has therefore adopted the integrity approach to design. Lockheed, the SSCL systems integrator subcontractor, is working closely with the Magnet Division to ensure the proper application of this somewhat unfamiliar approach. The Magnet Division has drafted a reliability plan and will work with its industrial subcontractors to improve and implement the plan.

Improvements in this area are still possible, however, it is clear that the immense effort the SSCL has been putting into the collider dipoles has limited the breadth of its vision in the area of reliability requirements. For example, the MSD is designing a common support post for the 15-m and 13-m dipoles using the structural requirements of the 15-m dipole even though the post sees more severe service requirements in the 13-m dipole. Similarly, common electrical insulation requirements are being set by the collider dipole requirements even though service in the HEB dipoles is an order of magnitude more severe. It is expected that the SSCL will mature in its ability to apply design-for-reliability methods systematically over time.

The subcommittee was unable to assess the Magnet Division's preparation for technology transfer from the national laboratories to industrial subcontractors from the material provided. The material provided in the draft RFP is clearly inadequate. On the other hand, the computer design tools available at the SSCL for transfer to their subcontractors are very good. Since Fermilab has begun purchasing piece parts for their 50-mm magnets and expects to complete all piece-part drawings by the end of July 1990, it is assumed that a complete drawing package of the 50-mm demonstration magnet design will be available for transfer to the collider dipole industrial partner upon selection. If the RFP issue is delayed until August 1, 1990, it is recommended that the entire package be attached. The professionalism demonstrated by the magnet production group leads the subcommittee to conclude that the SSCL manufacturing documentation will also be in good shape at the time of vendor selection.

10.3.8.2 Background

During the four years since the conceptual design review, much progress has been made in the design and fabrication of full-length superconducting accelerator magnets. From 1986 through 1988, there was debate on conductor restraint. Two significant changes were implemented in early 1988 and were successfully tested in magnets 12 and 14 to determine the effectiveness of improved axial and radial restraint. Other options were tested in magnets 11 and 15 with limited success. A baseline design that incorporated the concepts of magnets 12 and 14 was defined and seven such magnets have been fabricated and tested since early 1989: magnets 16, 17, 18, 19, 20, 26, and 27. Quench performance of the baseline design magnets is shown in Fig. 10.3-1. The performance of the two most recent magnets, 20 and 27, is especially noteworthy. The magnetic field margin of 5 percent demonstrated is the maximum available to the 40-mm magnet at 4.35 K without pushing the 1990 state of the art in superconductor production. Superconductor improvements corresponding to a margin increase to 8 percent were thought probable before production of the 40-mm SSC magnets began, but further increases in margin could be obtained in this design only through temperature reduction; there just isn't enough room for additional superconductor. (Note: Magnet serial numbers were assigned in blocks to BNL and Fermilab at the start of the CDG magnet program. As the program has been modified in response to earlier results, magnets of certain configurations were not fabricated. Their assigned serial numbers were not reused to avoid confusion.)



DD0012 and DD0014 are considered baseline design pre-cursors

axial constraint is obtained by shims between collared coil and yoke

Variation in plateau current reflects variation in I_c of conductor

DD0016 lower inner cable had leader still attached which put 23 cold welds within 1m on pole turn

Figure 10.3-1. Initial quench performance of collider dipole models baseline design magnets.

In March 1989, responding to concern in the high energy physics community, the Director of the SSCL formed the Collider Dipole Review Panel to advise him on the status of and prospects for the collider dipoles. The principal recommendation of this panel was to set margin goals for the magnets of 10 percent above the requirement for the proper function of the collider. At the time the panel met, magnet 16 was the one most recently tested.

Early in 1990, the SSCL decided, as a result of recent computational results, to increase the collider dipole aperture from 40 mm to 50 mm. This change was reviewed and approved by the Laboratory's Machine Advisory Panel. A brief discussion of this issue may be found in Section 10.1, Accelerator Physics: Collider.

The increase in diameter to 50-mm allowed for significant improvements to the conceptual design of the magnets, including the increase of the design magnetic field margin to 10 percent as recommended by the Dipole Review Panel. The need to minimize the schedule delay resulting from the change in magnet aperture requires a more focused development effort than had been in place prior to 1990. Early design of lifetime and string test instrumentation is required.

10.3.8.3 Technical Detail

The SSCL has carefully thought through the many open questions that remain in the art of accelerator magnet design and has devised a plan, known as the bubble chart, to address those which are most pertinent to the design of a functional, reliable, and manufacturable superconducting accelerator magnet. The areas to be addressed are discussed below.

Superconductor

The SSCL recently formed the Superconductor Advisory Panel consisting of six members from universities, other national laboratories, and the Department of Energy. Discussions with this group have resulted in a coherent plan to address the remaining technical questions that might impede full scale production of superconductor for the SSC magnets: barrier thickness and extrusion parameters. This program should result in qualified vendors, manufacturing processes, and long-lead-time material in ample time for magnet production, keeping superconductor well off the critical path for the project.

The review subcommittee is concerned, however, about the elimination of 1.3:1 copper to superconductor ratio conductor from the development program before the issue of the optimum conductor for magnet fabrication is decided by experiment and by analysis.

Cold Mass

Magnetic Field Margin

The design presented has a magnetic field margin of 10 percent in the inner coil and 13 percent in the outer coil, as Dr. Palmer has concluded that, for quench stability, it is more important to increase the copper in the inner coil than to increase the amount of superconductor. The subcommittee believes that this decision has been made with inadequate analytical and experimental documentation, and urges that further rigorous analytical and experimental work in this area be pursued. The subcommittee recognizes that a series of short magnets with different copper-to-superconductor ratios are being fabricated at BNL to investigate this very point. It urges that a similar level of resources be directed at analytic modeling of quench initiation with transient cooling by single-phase helium as a function of copper-to-superconductor ratio. The subcommittee also views with concern the changes in the superconductor development program that may preclude the use of 1.3:1 superconductor in production even if the BNL experimental work and the further analytical work suggested demonstrate the superiority of the 1.3:1 conductor.

Magnetic Field Quality

At least one iteration of the 50-mm dipole magnet cross section will be required to adjust field quality as it is known that the b_8 component will be too large. This should not require any tooling changes. Alternate designs with fewer wedges and/or better field quality are being considered numerically.

Yoke-Collar Interactions

The importance of the interface between the yoke and collar was made clear in the four magnets tested in 1988, which examined this area in particular. Since that time detailed finite element analysis has provided greater insight into the interactions. The yoke in the 40-mm magnets is split in the horizontal plane. A complicated series of interactions between the yoke, collar, and cold mass skin occur as the magnet is assembled, welded, cooled, and energized. Detailed calculations during the last 6 months show that a vertical split in the yoke will reduce the cyclic elastic deflection of the coil during these operations, probably leading to increased reliability via reduced wear. This approach, although untried, has therefore been designated as the baseline for the 50-mm magnet, and it is being pursued at Fermilab. BNL is continuing to pursue the more proven horizontally split yoke it originated as a backup to the new approach.

Coil End Configuration

The R&D 40-mm cold masses fabricated at BNL (all of those tested to date) have used a very labor-intensive coil end configuration not suitable for manufacture. Fermilab has taken the lead in researching alternate end configurations that are more suitable for manufacturing and has begun testing such configurations in short magnets. LBL is calculating the three dimensional magnetic fields of the proposed end configurations. It is expected that the SSCL's industrial subcontractor will contribute significantly in this area.

Cold Mass Cooling

The increase in coil inner diameter to 50 mm allows for direct-flow cooling by liquid helium between the outside of the bore tube and the inside of the coil. The maximum bore tube diameter compatible with 4.35-K deposition of synchrotron radiation after a luminosity upgrade is being investigated.

Insulation

Kapton film is used to provide electrical insulation and a glass-epoxy prepreg used to provide mechanical integrity in the baseline design. The radiation resistance of this system is about 1 million grays, adequate everywhere in the collider except possibly in the interaction regions. Creep is also a concern. Accordingly, alternate systems are being investigated at BNL, including Kapton-epoxy and all-Kapton.

Field Quality Correction

The mechanical and material sources of field quality errors will be investigated, including assembly tolerances, manufacturing methods and persistent current effects. The time dependence of the latter will be investigated, as will the use of passive superconducting correctors to minimize error field amplitude and time dependence. This area of investigation recently increased in importance because of the elimination of 80 percent of the mid-cell correction magnets as a cost-reduction measure.

Quench Protection

It is still not possible to predict the quench velocity in the 40-mm dipole magnets from first principles. Additional physics is being added to the computer models available at the SSCL in an attempt to narrow the gap between the measured and calculated velocities. The increase in copper to superconductor ratio will impact quench velocity, in a manner that is neither obvious to the subcommittee nor contained in the material presented. This must be carefully considered.

Cryostat Mechanics

Piece-Part Testing

Cryostat piece-part testing is being pursued at Fermilab and through a contract with LTV in Dallas. The SSCL is ordering equipment that will allow it to test piece parts at room temperature. This effort should be pursued vigorously, as discussed in Section 10.3.10.

Subsystem Testing

Complete support post assemblies and tie bars are being tested or are planned for testing in similar fashion to that described above.

System Testing

Two dummy 50-mm cold masses, support posts, and vacuum vessels will be fabricated by the SSCL, instrumented, and tested for mechanical response. The mechanical testing will include both shaker table work and actual truck transport. The subcommittee urges the SSCL to expand the requirements to include the vibration spectra encountered in ocean shipping to obtain information necessary for possible foreign in-kind donations. Computer simulation should be started before testing is attempted.

Detailed planning remains to be done in this area. Since the required instrumentation and battery operated multi-channel data recorders have long lead times, the Magnet Division is urged to begin preliminary planning and procurement as soon as possible.

HEB Magnets

Ramping Losses

The Magnet System Division plans to fabricate and test three short dipoles with 6-micron filament to investigate ramping losses. Similar dipoles using 2.5-micron conductor will then be fabricated and the results compared, verifying the design models used. This plan is commended. Earlier tests with existing short dipoles should be considered.

Bipolar Operation

Investigation of the time-dependent magnetic field quality of dipole magnets operated in bipolar mode must begin as soon as possible. The Accelerator Division stated that such testing will begin late this fall at Fermilab. The Magnet Division should immediately begin to work with the Accelerator Division to define a test plan and ensure that all the required instrumentation and equipment is available when needed at the test site.

10.3.9 High Energy Booster Magnets

10.3.9.1 Summary and Conclusions

The high energy booster (HEB) magnet concepts are extremely aggressive technically, with concomitant risk, especially in their heat transfer design. There is significant schedule risk due to the need to research, develop, and bring into commercial production fine-filament (2.5-micron) high current density superconductor. These two risks imply a cost risk that the subcommittee concludes is substantially higher than that estimated by the SSCL. Consequently, contingency in this area has been roughly doubled to 40 percent.

The subcommittee is encouraged by the fact that the HEB magnet effort is headed by a permanent product manager. It also believes that all the key problems in adapting the collider dipole to the HEB have been identified by the HEB magnet team. Involvement of industry in the design and test of the HEB magnets should begin as soon as possible.

10.3.9.2 Scope

The high energy booster magnets consist of two main types, dipoles and quadrupoles. The dipole concept is identical to the collider dipole magnet, save only three modifications: substitution of 2.5-micron filament superconductor for 6-micron superconductor, a non-circular bore tube, and a 24-mm increase in sagitta.

The HEB quadrupoles must have an inner diameter of at least 45 mm to allow for adequate cooling during ramping and for beam location during slow extraction, so significant changes are required to adapt the 40-mm collider quadrupole design for use in the HEB. An aperture of 50 mm has been chosen for the HEB quadrupole. Since high gradients may be achieved at this diameter, the HEB quadrupole is quite short: roughly 1 m long.

10.3.9.3 Technical Discussion

The HEB magnet concept is an extremely aggressive one that pushes the state of the art in three areas: fine-filament superconductor, cryogenic cooling, and bipolar operation. The HEB magnet concept was changed very recently in an attempt to reduce cost, so the conceptual design presented was somewhat deficient in detail. Even more recent was the decision to fill the collider rings with alternative HEB pulses rather than in sequence, increasing hystereisis losses. These have not been calculated yet, but they will clearly impact the magnet design.

While the SSCL has not yet received any fine-filament superconductor that meets the requirements of the HEB magnets, it has a program in place that should deliver R&D material of the required quality by then end of 1990 from each of two to five vendors. A new program is being put in place that should provide at least two qualified vendors of fine-filament conductor in a timely manner. Since fine filament superconductors have been pursued for decades for power system service and since 1987 for the SSC, the technical and schedule risks in this area are regarded as moderate. Cost risk is regarded as high and warrants an increase in contingency.

The heat input to the HEB consists largely of two components: AC losses due to eddy currents in the copper stabilizer and hysteresis losses in the superconductor. This heat must be removed by helium at the inner diameter of the coil in the present design, requiring a non-circular beam tube providing substantial annular space for liquid helium. The amount of space available is marginal for the heat deposition on the cycle presented in the SCDR, which cycle has lower hystereisis losses and higher eddy current losses than the cost estimate cycle. As mentioned above, the cycle used in the cost estimate has not been analyzed thermally yet, but it is probably slightly easier to cool than the SCDR cycle. Upgrade potential for faster collider fill times appears small for the 50-mm HEB dipole.

Bipolar operation of superconducting accelerator magnets remains *terra incognito* four years after the CDR review team recommended that careful evaluation of this area be undertaken. The first tests of collider dipoles in bipolar operation are now planned for late in 1990. Experience in the operation of rotating superconducting machinery gives credence to the statement that the technical risk in the magnets is low, but raises concerns about reliability. Design reliability goals in areas impacted by magnetic cycling, such as insulation, are being set on the basis of the collider even though the HEB design is identical and sees an order of magnitude more magnetic cycles. This defect in systems engineering ensures high risk — no global analysis has been done to determine the most stringent service conditions across all magnets of common technologies before design goals are set.

The technical risk of bipolar operation in the area of accelerator physics is addressed elsewhere in this report.

10.3.9.4 Costs

A more detailed discussion of HEB magnet cost issues may be found in Section 10.3.3. Some conclusions are summarized here for completeness.

The subcommittee views as commendable and prudent the exploratory design efforts undertaken by the SSCL on a lower-risk, higher-cost 65-mm HEB magnet concept. The estimated cost of the magnet can be used to place an upper bound on the contingency for the HEB dipoles of approximately 40 percent. It should be noted that the 65-mm magnet can be fabricated with 6-micron conductor. A similar analysis applies to the HEB quadrupoles.

10.3.9.5 Schedule

The design, analysis, and fabrication schedule for the HEB magnets is extremely aggressive. The 50-mm bore and AC service impose coupled design constraints that will require a number of conceptual and experimental design interactions to converge.

The HEB magnet program is in the same situation as the collider dipole magnet program has been with respect to conductor: it is dependent on a conductor research program for the material to wind magnets. This situation has repeatedly delayed collider dipole magnet prototypes during the last two years and is likely to delay the HEB magnet program. Projected delivery dates for two of the four 2.5-micron R&D billets have slipped by four months since the contract was awarded a year ago. The program the SSCL is putting in place is the best available to minimize the risk in this area, but there is still significant risk in this area that must be carefully managed. The Magnet Division may lack the resources necessary to manage the six large contracts for superconductor that it is planning to issue during the next 6 months. If this proves to be the case, the HEB Product Manager must ensure proper oversight of the HEB-related conductor contracts, thereby minimizing the schedule risk to his program.

10.3.9.6 Management

The HEB magnet program is unique among the three major efforts in having a permanently assigned Project Manager. The individual assigned has an appropriate background and has properly identified and scheduled the RDT&E tasks required to complete the program in a timely manner. As the matrix management system in the Magnet Division is just beginning to gel, it was not possible to assess whether the Project Manager will be able to command the resources required to complete the program as scheduled.

10.3.10 CDM Cryostat

The CDM baseline design cryostat was motivated by the needs of, and has evolved during, the CDM development program. The cryostat must precisely and stably position and support the magnet cold mass while providing the necessary insulation required for the operation of the superconducting magnet coils in a thermally and hydraulically efficient manner. The cryostat must function safely and reliably and be producible at reasonable cost on a mass production basis.

Cryostat development has included component and assembly detailed design and supporting analysis. Component performance measurements made include thermal and structural responses of the cold mass assembly, suspension system, thermal shields and insulation. Cryostat assembly performance measurements include extensive installation, cooldown/warmup and steady state operations evaluations during magnet testing at the Fermilab and BNL magnet test facilities. Shipping and handling responses were measured both with a specially constructed over-the-road transportation evaluation model and during test-magnet assembly shipments between Fermilab and BNL. It is the subcommittee's understanding that MSD is starting to construct a transient 2D thermal model utilizing an existing CAD to guide their design and optimization effort.

The resulting baseline cryostat design is suitable for incorporation into the overall CDM design with opportunities existing for component and assembly optimization during the CDM product development phase. Many areas of the design should be reexamined by a fresh and unbiased eye, however.

A review of the cryostat design requirement that requires that the cold mass be supported from below in both rings should be considered. Support of the upper magnet cold mass from above, i.e., hanging, would allow for a reduced vertical magnet centerline-to-magnet-centerline distance and would allow for a longer support-post length that could permit the use of a straight (i.e., non-reentrant) support post. Both of these features could result in potential cost savings. The review should include considerations of technical feasibility, performance, interfaces with other systems, and cost.

In order to accomplish the above activities in a time frame that can influence the final CDM cryostat design, the SSCL should continue to increase its engineering and technical staff with qualified and experienced personnel. The SSCL should also develop and maintain well-equipped laboratory facilities for materials, structural and thermal evaluations. These capabilities developed during the development phase will continue to be assets to the SSCL throughout the lifetime of the Laboratory. Continued use of the staff and facilities at other national laboratories and with industry should take place as is appropriate.

10.3.11 Magnet Testing

10.3.11.1 Summary

Superconducting accelerator dipoles and quadrupoles like those being used for the SSC have a great complexity and are sensitive to all kinds of perturbations. On the other hand a high reliability is necessary in order to fulfill the requirements of a high energy accelerator. Therefore, extensive testing during fabrication at the vendors and after reception of the magnets at the SSCL is required. Early resolution of acceptance-test peak field (above nominal) is urged as it will affect design and cost.

The SSCL has developed elaborate and sound plans to set up the necessary test procedures and test systems (production inspection at the vendors, Magnet Test Laboratory, string tests, life tests) and to provide the necessary manpower. Cold testing is presently foreseen for 100 percent of all magnets of the initial production phase but only ten percent during the full-rate production. In order to avoid possible drawbacks for the installation and commissioning phase of the collider, the SSCL should consider ensuring full cold-testing capacity throughout the whole production. The proposed staff for performing cold measurements seem to be at the low limit.

10.3.11.2 Production Inspection and Room Temperature Tests

Intensive production inspection will be performed at the vendors by personnel of the vendors and witnessed and audited by SSCL QA personnel. The inspection will include electrical and mechanical tests, warm harmonic measurements and acceptance tests prior to shipment to the SSCL. Final room temperature acceptance tests will be performed at the SSCL comprised of visual inspections for shipping damage, mechanical and electrical checks, alignment verification, and leak tests. The number of people assigned to the tasks seems to be sufficient.

10.3.11.3 Cold Testing of Prototypes and of Magnets of the Initial Production Phase

The development of collider dipole and quadrupole magnets requires extensive cold testing in order to establish the performance and reliability. In the first phase of this program the availability of an adequate cold testing facility is extremely important. The properties to be verified fall into several categories:

- quench properties
  - —critical current level
  - —possible training
  - —reproducibility after life time cycles
- field quality
  - —magnitude and variation of harmonics at full current
  - —magnitude and variation of harmonics at injection
  - —time variation of harmonics
  - —harmonics variation between magnets
  - —field integral
  - —variation of field integral between magnets
  - —field angle
  - —reproducibility of field properties after life time cycles
- vacuum properties
  - —pump down time
  - —possible leaks
- heat loads
- electrical properties
  - —ground insulation of coil
  - —turn-to-turn insulation
  - —quench heater insulation
  - —resistances
  - —inductances
  - —reproducibility of electrical properties after life time cycle

A test facility consisting of ten cryogenic test stands will be constructed at the SSCL site. In addition a two-stand cryogenics test facility will be built at the leaders and will be operated by the leader's personnel. This will allow the leader to do its own investigations at his plant immediately after completion of the magnets. These two test facilities will enable cold-testing of 100 percent of all prototype and initial production magnets. The staff assigned to this task at the SSCL seems to be just sufficient. Full competitiveness of the follower will occur only if the followers has fast access to cold test facilities.

10.3.11.4 Cold Testing of Full Production Magnets

With the facilities mentioned above, only a small fraction of full-rate production (about 10 percent) can be tested cryogenically in a routine fashion. This raised the question concerning the impact on the installation and commissioning phase of the collider if magnets with serious defects are installed in the tunnel. Possible defects might be:

- Low quench-current due to conductor problems.
- Electrical insulation problems.
- Field orientation problems due to support defects.
- Cold leaks.

Defects of this kind will occur during the initial phase much more often than at full rate production, where design faults hopefully will have been eliminated. Nevertheless some of these defects may occur during the production. Experience from HERA indicate that the fraction of magnets with this kind of defects is of the order of 1 percent, which, extrapolated for the SSC, would mean that about 100 magnets may fail in the collider.

Possible drawbacks of such a situation are:

- Perturbation of the magnet installation on adjacent tunnel areas.
- Increase in required manpower for taking defective magnets out of the tunnel.
- The necessity to have spare magnets to replace the defective ones.
- Late repair of defective magnets at the vendor.
- Late detection of possible systematic magnet faults.

There is concern that this situation would lead to unforeseen costs and program delays. The SSC should therefore do a cost-benefit analysis under various failure rate scenarios and then consider ensuring full cold-testing capacity for full-rate production.

10.3.11.5 String Tests

Some magnet system properties cannot be tested on individual magnet test stands. Such properties must, however, be determined before the series production is initiated. The properties to be determined are:

- Cryogenic properties during cooldown and warmup.
- Quench properties in connection with the magnet quench protection system.
- Pressure build up and relief valve properties.
- Quench propagation.
- Magnet interface properties.

Two string-test systems will be installed at the SSCL. There will be one above ground that will be used first for a full test consisting of Fermilab demonstration magnets and then for testing a string of six complete cells of the production. The second string test will be installed in a special tunnel near the E1 region.

10.3.11.6 Life Tests

Near the aboveground six-cell string, another string of three magnets will be installed to perform test over the full life-time quench and cryogenic cycles. This test is extremely important in order to provide data for assessing the reliability of the magnet design.

Defining instrumentation for the life test is a very difficult and time-consuming task. It involves defining performance parameters to be measured, critical components and their failure mode, and type and range of sensors suitable for the parameters being measured. This requirement implies completion of electromagnetic, thermal, structural analysis, and modifying designs to accept sensors. The latter has to be done prior to fabrication and assembly.

Planning of the life test should start now to define lead time and critical part items and designate specific collider magnets for test.

10.4 Conventional Magnets

10.4.1 Summary, Conclusions, and Recommendations

The designs presented for the warm magnets in the SCDR for the LEB, MEB, Test Beams, and their associated transfer lines and abort systems represent a point design from which a detailed cost estimate has been derived. The system, as presented, is not optimized and future changes in these designs will evolve with additional engineering. However, it is felt that the costs presented are sufficient to cover these changes. The subcommittee felt that the engineering done in the preparation of the cost estimate reflects an excellent standard from which the Laboratory can proceed in the future. In spite of this, there is an urgent need, if the schedule is to be maintained, to proceed from this point design to a final engineering package. Since staffing at the SSCL in this area is sparse, (most of the detailed designs and cost estimates presented were made at other laboratories), SSCL management is urged to aggressively seek additional experienced staff.

Recommendations

1. The contingency assigned to various magnetic elements, using the formula provided by SSCL management, does not reflect what the subcommittee felt is true contingency. Management's formula should be modified to reflect more accurately the contingencies utilized on other accelerator projects.

2. No spare magnets are indicated in the cost estimates. For reliable operation, rapid interchange of complete spare units is usually required. In the case of the large number of identical magnets making up the LEB and MEB accelerators, spares represent a small incremental cost. For speciality magnets, the percentage cost increase is larger. The impact of spares will represent a few percent of total cost, or a few million dollars.

3. It is recommended that the magnetic field properties of all the accelerator magnets be measured as part of acceptance testing. These measurements will permit sorting of magnet locations to suppress major resonance strengths in the rings, as well as provide a control on manufacturers' adherence to standards; this is only a small cost item.

4. DOE and SSCL are urged very strongly to expedite the appointment of a lead person for each accelerator in the chain as well as to recruit the needed engineering and technical staff.

10.4.2 Scope

The scope of the SCDR is adequate to provide the necessary warm magnets for the accelerators and beam lines for the SSC. The specific design of the magnets is adequate for purposes of estimating costs of the project. In some cases the design should be reinvestigated to improve performance or reduce costs. Minor omissions from the cost base were found. The level of risk in the components is modest in most components (in the scale of typical projects like this one). Most components are based on designs of magnets recently built or under active development at Fermilab or Brookhaven. There is only one magnet, the 0.6 -T collider abort kicker, that represents a significant increase in the state of the art. This magnet, however, is based on the design of a new Tevatron abort kicker that will be put in service in March 1991.

The subcommittee was pleased with the level of engineering employed to arrive at the cost estimate. The Laboratory is to be complimented on arriving at this level so early in its life with such a small staff.

10.4.3 Cost

We find the cost estimates to be reasonable and derivable from recent experience at Fermilab, SLAC, and BNL. In particular, the BNL booster and the Fermilab main injector are useful recent and current projects with which to compare, while the Fermilab TeV-1 provides detailed labor and material costs which can be escalated to provide data for comparison. SLAC PEP data is older and less detailed but still useful. Our principal problem is to know how to "industrialize" these data, that is, how to relate these data to costs bids from industry. In attempting to do so we

1. reviewed the SSCL labor cost data;
2. made independent estimates of labor hours, steel, copper, and parts costs for the major magnet (MEB dipole);
3. rationalized SSCL costs against specific Fermilab magnets; and
4. compared crude ($/unit) rates for SSC designs against established costs of magnets built elsewhere.

We found the SSCL cost estimates to be well within the expected range of bids for these components by industry.

The labor rates used by SSCL are derivable by escalation of TeV-1 rates and with a typical industrial overhead added. For the MEB dipole, we generally agree with the total labor hours, but would predict a slightly different mix between coils, cores, and assembly. The MEB dipole is a simpler magnet than the Antiproton Source magnets at Fermilab, and the SSC MEB magnets are indeed lower priced than escalated costs of the Fermilab Antiproton Source magnets. Finally, the crude escalated $/unit rates of BNL or Fermilab magnets agree well with the MEB designs, with some consideration given to their simpler construction.

It should be noted , however, that the contingency assigned to the various magnetic elements, using the formula provided by management, does not reflect what the reviewers felt is true contingency. Management's formula should be modified to reflect more accurately the contingencies utilized on other accelerator projects.

The MEB point design dipole is not optimized for slow extraction fixed target operation at 200 MeV, but rather at a lower energy due to iron saturation. Various remedial courses of action can be considered to retain the full, 200-GeV capability:

1. A modified die design can be made for the pole region only that will reduce the saturation aberrations at 200 GeV, but at the expense of increased low-field aberrations. Tracking calculations can easily establish whether lumped corrections will successfully remove the effects of these aberrations.

2. A slightly more expensive modification would be to widen the pole while maintaining the basic coil design.

3. If neither of the above solutions is satisfactory, a redesign of the dipole with coils on the midplane will assure superior high-field performance. The saddle end coils in this solution will be more expensive than the simple bar race-track coils in the point design.

The MEB point-design quadrupoles have small coil cross sections and saddle-type ends. The coil cross section is probably not optimum, resulting in large power consumption. A final design at the moderate pole tip field can result in larger cross-section coils of simple racetrack design, but reduced power. This can probably be accomplished within the present cost.

The LEB point-design magnet performance and cost estimates are quite satisfactory. For a 10-Hz machine, however, magnet costs are intimately intertwined with vacuum chamber costs.

1. The LEB dipole design assumed a thin walled vacuum chamber supported externally with ribs. This chamber is quite expensive, i.e., $7000 per magnet.

2. Comparative designs based on the Fermilab and Argonne boosters and the Cornell electron synchrotron should be made to look for potential LEB cost savings. These accelerators used magnets with external vacuum containment, i.e., no chamber in the aperture.

3. An alternative possibility is to use a self-supporting thicker wall vacuum chamber. The larger eddy current sextupole incurred can be corrected with inductive auto compensation using coils attached to the outside of the vacuum chamber as is being done for the BNL Booster.

No spare magnets are indicated in the cost estimates. For reliable operation, rapid interchange of complete spare units is usually required. In the case of the large number of identical magnets making up the LEB and MEB accelerators, spares represent a small incremental cost. For specialty magnets, the percentage cost increase is larger. The impact of spares will represent a few percent of total cost, or a few million dollars.

The subcommittee was unable to find any provision for shipping magnet components from the manufacturers to the site. A typical cost would be 3- 5 percent of the unit costs.

It is recommended that the magnetic field properties of all the accelerator magnets be measured as part of acceptance testing. These measurements will permit sorting of magnet locations to suppress major resonance strengths in the rings, as well as provide a control on manufacturers' adherence to standards; this is only a small-cost item.

It was pointed out by the SSCL staff that 10 Lambertson magnets are missing from the cost estimates for beam transport from the MEB to the HEB. Correction of this omission will add about $0.5 million to the cost. (Subsequently, SSCL identified these costs to be in the WBS 1.1.4.2.15.)

With more detailed design, the subcommittee feels that some costs may come down modestly. This possible reduction provides some cushion against the vagaries of bidding and changes resulting from further study of the injection process.

10.4.3 Schedule

The schedules as presented are aggressive but achievable if the staffing profiles developed by the accelerator systems division are guaranteed. There is an urgent need to move beyond the point design to an optimum design of the injection chain in order to proceed to actual magnet engineering. This design optimization requires the expeditious appointment of a lead person for each accelerator in the chain. Further, the engineering and technical staff in the Accelerator Division must be augmented at least as rapidly as suggested by the Division head (0 in 1990, to 150 in 1991, to 260 in 1992). Both the DOE and the Laboratory are urged very strongly to do everything possible to expedite the appointment of these personnel. The rapid development of actual in-house experience in magnet construction will facilitate a rapid schedule, accurate cost updating, and efficient technology transfer to industry.

10.5 RF, Power Supplies, and Linac

10.5.1 Summary, Conclusions, and Recommendations

The ERC reviewed rf, power supplies, and the linac. The total cost of these items is 4.7 percent of the TEC (FY 1990 dollars), however the cost risk to the project from potential technical and schedule impacts could be of great significance, so primary concerns are placed on technical and schedule aspects of these subsystems.

The subcommittee finds that the design of the reviewed systems is at a satisfactory conceptual stage, and that some portions of the systems are at significantly more advanced stages than would be necessary for a conceptual design review. In view of the fact that the SSCL has limited manpower, that other systems are on the critical path and are appropriately receiving more emphasis, that proofs of existence of the required systems exist at other laboratories, that there is a reasonable amount of float in the schedule, and that the percentage cost of the reviewed systems is relatively small as compared to magnets or conventional facilities, the subcommittee believes that the status of the designs is at an appropriate stage. Although a few minor technical and cost concerns have emerged, as discussed below, there are no major problems identified.

Recommendations

1. Primary emphasis should be placed on functionality, reliability, and holding any schedule delays within the available float.

2. The planned collider rf system uses four cavities powered by the same klystron. Whether or not sufficiently small rf noise can be achieved by this technique needs to be explored. Similar considerations apply to the rf quadrupole and first drift tube linac section.

3. Individuals responsible for management of each of the accelerators within the matrix organization need to be identified. Interfaces should be well defined and function smoothly.

4. Simulations have shown that a small power supply ripple applied to the beam at a betatron sideband of the revolution frequency causes significant emittance dilution. The extent of this problem and methods of mitigating it merit further exploration.

5. Transmission line modes on the power supply distribution system may be a problem and deserve investigation.

6. More cost effective alternatives should be investigated for design, procurement and production of the linac.

7. The SSCL should track developments in digitally controlled power supplies; should they become sufficiently reliable and cost effective, they could be considered.

8. Although the distribution of reliability allowances should be subject to ongoing optimization as a cost minimization measure, the current goal for the collider power supply reliability translates to an unavailability allowance for each power supply of 0.000017 of the time. Methods of achieving this level of reliability require intensive exploration. The contingency for this item should be increased due to the risk associated with achieving the high reliability required.

9. Off-energy particles caused by beam loading transients, if not addressed, would cause objectionable beam spill in the LEB. The optimum method for mitigating this problem needs to be addressed.

10. Whether or not an additional grounding system for the accelerator is required needs to be determined prior to freezing the civil construction design.

11. The amount of spare cross sectional area in the tunnel cable trays should be adequate to accommodate any plausible addition of cables.

12. The HEB and collider do not have distributed cooling water systems. The effect of this decision on component temperatures and reliability should be assessed.

13. Detailed procedures for changing underground rf system components need to be worked out before freezing the associated civil construction design.

14. Careful consideration as to whether or not the rf power supplies, with their associated insulating oil, would be installed underground.

15. The ERC recommends for these subsystems an increase of 15.3 percent; $25,405 FY 1990 K dollars in base cost and $8,939 FY 1990 K dollars in contingency. Details are discussed within the cost section.

16. Management should consider changing the way EDIA/QA funds are tracked. It is not apparent that the cost account manager, who identified the need for these funds, has control and responsibility for them.

10.5.2 Scope

The scope of the rf systems includes the rf systems necessary to provide the acceleration and bunch retention in the LEB, MEB, HEB, and collider rings. Each of these systems includes rf cavities, rf sources, rf transmission lines, interlocks, low-level rf and other associated controls, high-voltage power supplies and local ac power connections. Vacuum, remote computer controls, and the master oscillator signal are included in other systems. General software for control of the subsystem hardware is provided by the global accelerator controls system group. Specific and specialized applications software, if needed, is handled within the subsystem.

The scope of the power supplies includes the main power supplies, correction power supplies, and pulsed-magnet power supplies. Connections to the magnets and to the local sources of ac power are included. Cable trays and LCW water is included. These items apply to the LEB, MEB, HEB, collider rings, transfer lines, and test beam facility, but not to the linac.

The linac includes most of the local subsystems required for its operation, including the ion source, low-energy beam transport, rf quadrupole, drift-tube linac, coupled-cavity linac, power supplies, focusing and correction magnets, rf system, utilities, and vacuum.

The identified scope is appropriate for the requirements of the accelerator.

The collider rf system is very similar to the PEP system, and operates at 360 MHz. One change since the CDR is that the cavities are made of copper rather than aluminum; this change provides a broader industrial base of manufacturing capability and a higher shunt impedance. There is also a reduction in risk, since the process of applying anti-multipactor coatings does not have to be mastered. One item that merits further analysis is the question of whether the design stability goals of 0.5 percent in amplitude and 0.5 degrees in phase can be achieved with four independent five-cell cavities powered by the same 1-MW klystron; such a procedure requires that the voltages in the four cavities be vector summed with considerable accuracy. Note that electrons (which are used in PEP) are much more forgiving of rf amplitude and phase variations than are protons. If this summation proves to be difficult, use of a separate klystron for each cavity would solve the problem, and would have the further advantage of providing enough reserve voltage to permit the accelerator to continue to be operated even if one cavity were down. If the four-way power splitting can be used in the SSC, it has the advantage relative to the PEP system that the spacing between cavities in a pair can be an odd integral multiple of a quarter wavelength, since particles are accelerated in only one direction; this procedure has the advantage that reflected power can be routed to a load, rather than having it reflected to the klystron.

It was reported by one of the reviewers that a klystron manufactured by one of the two existing manufacturers oscillates if it is operated without its drive saturated; if this information is correct, this klystron would be unacceptable for this application.

The main components of the other rf systems are patterned after ones that have been successfully implemented elsewhere, and should present minimal technical risk.

The HEB rf system operates at 60 MHz and has an output power of 160 kW per transmitter. Seven subsystems are required. The rf power will be transported through approximately 50 ft of coaxial line. This rf power system appears to be well thought out. It follows the work that has been done previously at Fermilab and Los Alamos. The cavity will be of the same design as that which has been used very successfully at Fermilab. The SSCL staff has done a good job of considering the reliability of this rf power system, as it can run with two subsystems down without affecting the operation of the HEB.

The MEB rf system operates at 59.7 to 60 MHz, and has an output power of 160 kW per subsystem. Twelve subsystems are required. The same comments apply to this system as to the HEB system, except that the rf output tube is mounted directly on the cavity. In this way, the cavity forms the anode cavity for the amplifier. This is a standard Fermilab technique and should not present any problems.

The LEB rf system operates at 47.5 to 59.8 MHz and has an output power of 160 kW per transmitter. Eight subsystems are required. The same comments apply to this system as to the MEB system, except that the cavity planned is of a Los Alamos design that has been built and tested. Again, the power tetrode couples directly to the cavity, and the cavity is tuned with a biased ferrite core.

Precise temperature control is not planned for the cavities with ferrite tuners, since frequency shifts due to temperature changes can be compensated with the ferrite.

In general, the power supply and rf system of the SCDR have been adequately conceived, well cost estimated, and well managed. The structure of the power supplies and rf groups is a matrix organization covering all aspects of all of the individual accelerators. This type of organization can work well to produce the lowest cost equipment. With the appropriate technical inputs from upper management, a matrix organization will produce the best performance, and highest reliability for the money and time invested. Individuals responsible for each of the accelerators need to be identified.

The power supply group plans to build supplies that do not involve a large enough multiplicity to merit industrial involvement. There is a shortage of qualified and experienced power conversion engineers, and the SSCL may have difficulty recruiting enough such engineers to ensure production of power supply systems with adequate reliability and availability.

In the magnet quench systems, the importance of redundancy was clearly understood and included.

A problem that has been observed in the Tevatron is that power supply ripple applied to the beam at a betatron sideband of the revolution frequency causes emittance dilution. This ripple could be a more serious problem in the SSC due to the lower revolution frequency and the reduced shielding provided by the beam pipe at this frequency. Tracking simulations show that a very small transmitted power supply ripple at the sideband frequency is objectionable. If the ripple amplitude at this frequency proves to be a problem, it has been suggested that transverse feedback on a time-scale short compared to the Landau damping time would be a simple solution to the problem. Notch filters on the power supplies, or selection of a different betatron tune, would be other solutions.

In the CDR, most power supplies in the collider were planned to have two parallel regulator circuits, arranged so that either could supply the full current if the other ceased functioning. This was done to provide an adequate level of reliability. In the SCDR, single regulators are planned. Since the tentative availability goal for the power supply systems is 0.96, and since there are approximately 2400 power supplies, any given power supply could be unavailable almost 17 millionths of the time. It is suggested that the SSC investigate whether or not power supplies satisfying the SSC's general requirements have been built with this level of reliability and, if not, whether this level can be achieved by careful selection of components, operating components well below their maximum ratings, and operating the supplies prior to accelerator commissioning for a sufficient period to approach the minimum of the failure rate curve. Operating the accelerator in such a way that a minimal number of correctors are powered at any one time would increase the allowable down time of the remaining supplies while still achieving the overall reliability goal. Redistributing the down-time allowance among systems, if the tentative one proves not to be the cost optimum, would be another approach. If these approaches are inadequate, use of the parallel regulators might be the best solution. Unless single power supplies significantly more reliable than those customarily produced can be developed, the availability of the power supply systems will be less than 80 percent. If this turns out to be the case, use of redundancy would increase the availability to greater than 98 percent at a cost of not more than $50 million. It is also suggested that the SSCL track developments in digitally controlled power supplies; should these become sufficiently reliable and cost-effective, they could be considered.

Another potential problem associated with the power supplies is that of transmission line modes, aggravated by the large circumference of the collider rings; the potential problems associated with this phenomenon need to be assessed.

The people working on the linac are to be complimented on the advanced state of their conceptual design. The cost estimate is soundly based on recent experience with rf systems and accelerating structures. The prototyping of the ion source and the transport between the ion source and RFQ (radio frequency quadrupole), which is now starting, is especially commendable. However, it is felt that the planned approach of hiring an industrial design team to produce the necessary detailed design for initiating procurements, followed by a highly integrated system procurement, will increase the cost. We recommend that more cost-effective acquisition options, production techniques, and design alternatives be investigated.

The output of the linac is 25 mA of H^- ions at 600 MeV. The problem of eliminating off-energy particles caused by beam-loading transients in the linac should be explored in more detail to prevent unnecessary beam loss in the LEB.

The H^- ion source baseline design is a magnetron source of the type used at Fermilab. The SSCL staff will adopt a volume source that LBL is currently developing, if this is successful. The output current is 30 mA and the voltage is 35 kV. The technology is straightforward and no problems are anticipated. Plans call for building and installing an on-line spare for reliability purposes, but this is not in the baseline construction cost.

The LEBT is the low energy beam transport line from the ion source to the RFQ. This is straightforward and should not have any technical problems.

The proposed RFQ follows the design developed by Grumman for the BEAR system. The design calls for building the RFQ in two lengths and bolting them together; this has been done and does not appear to have an adverse effect on the operational characteristics. The plan to operate the RFQ at 2.5 MeV makes the drift tube linac (DTL) design more conservative, but the RFQ design less conservative. This choice could be revisited if necessary.

The first section of the DTL will have a tapered gradient to more easily match the output of the RFQ. The rest of the DTL will follow classic design practice. There will be four DTL tanks and the output energy will be 70 MeV. No problem is anticipated in their construction. There are plans to perform R&D to lower the cost of the DTL, which is presently estimated at $171,000 per meter. Altering the construction method could result in an increase in the number of companies capable of manufacturing the units; this should be pursued as planned, but caution should be used to avoid innovations that could adversely affect reliability.

The side-coupled cavity linac (CCL) increases the energy to 600 MeV. The design is straightforward and follows the design criteria developed at Los Alamos. The frequency of this structure is 1284 MHz, which is 3 times the DTL and RFQ frequency. The peak surface field in this structure is one times Kilpatrick, and the accelerating gradient is 8 MV/m, which is very conservative. It is not anticipated that any technical difficulties will be encountered with this structure. The procurement strategy for this structure has not been determined.

The linac rf power system consists of two sections. The first section comprises two klystrons operating at 4-MW peak and at 428 MHz. One tube will drive the RFQ and the tapered gradient DTL, and the other tube will drive the rest of the DTL. The same concern that was discussed relative to the collider rf system concerning field control applies to this system.

There are 11 tubes operating at 1284 MHz with an output power of 15 MW. These tubes operate from a standard PFN at a 50-μs pulse length. Although the voltage on these tubes is high, there is nothing in the design that hasn't been successfully used previously.

The transport line from the linac to the LEB performs several functions in addition to transporting the beam from the linac to the LEB. Collimation, scraping, energy compression, and transverse emittance measurement are performed. There is a beam dump where the beam is deposited during tune-up and between LEB cycles. This is all a straightforward design, and comprises only a small fraction of the total linac system cost.

A general concern is that of grounding: in addition to the ground provided as part of the civil construction, grounding for technical systems should be carefully considered prior to freezing the civil design. Options would include provision of additional grounding systems for the accelerator, or of shielding individual subsystems adequately to limit the transients induced on the building ground to acceptable levels.

Another general consideration is that the amount of spare cross-sectional area in the tunnel cable trays be adequate to accommodate any plausible addition of cables.

It should be verified that air, rather than water, cooling of components around the circumference of the HEB and collider rings is the cost-optimum arrangement, taking account of the impact of component temperature on reliability.

Procedures for changing failed rf components, particularly 5-m high klystrons, should be worked out in detail and incorporated into the associated civil engineering design. If oil is used as an insulator in the tunnel, fire and environmental concerns need to be addressed. Whether or not the rf power supplies, with their associated insulating oil, should be installed underground should be considered carefully.

10.5.3 Cost

The base costs listed below do not include contingency, EDIA, pre-construction R&D, or pre-operations.

The base cost of the collider rf system, as designed, is reasonable at $6,851 thousand (FY 1990 dollars). Its cost has been based primarily on the escalated cost of the PEP system, with appropriate labor adjustments. The contingency of 21 percent is appropriate in view of the fact that the cost is based on a completed and well documented system.

The costs of the LEB, MEB, and HEB rf systems total $19,853 thousand (FY 1990 dollars). These costs have a sound basis, as 70 percent are escalated from previous facility costs, actual vendor quotes, or catalog prices. The average contingency on these items is 20.1 percent. This contingency is deemed adequate.

The costs of the power supplies are $116,024 thousand (FY 1990 dollars). The average contingency on these items is 17.2 percent. The subcommittee believes that this number should be increased to 139,189 thousand (FY 1990 dollars) because additional money is required for industrial engineering, industrial profit, and installation. Due to the risk associated with achieving the high reliability required, the committee believes that the contingency should be increased to 20.0 percent on this item.

The costs of the accelerator utilities included in the scope reviewed are $24,402 thousand (FY 1990 dollars). The average contingency on these items is 11.5 percent. The subcommittee believes that the base amount should be increased to $27,402 thousand (FY 1990 dollars) because the large distances between access shafts entail additional installation labor. It is also recommended that the contingency be increased to 14.6 percent because additional installation labor may be required in other parts of the facility.

The costs of the linac are $26,268 thousand (FY 1990 dollars). The average contingency on the linac is 11.4 percent. It is noted that 15 power supplies for charging the pulse-forming networks are proposed, and the committee believes that this function can be accomplished with one supply, and that this supply can have less than 0.1 percent regulation, since de-Q-ing circuits on the charging chokes are used. This would reduce the associated cost by $1,079 thousand (FY 1990 dollars). It is also recommended that the cost of the ion source and matching section be increased from $350 thousand to $550 thousand (FY 1990 dollars), based on recent Los Alamos experience. It is also recommended that the contingency on this item be reduced from 20.0 percent to 15.0 percent in view of the fact that the experience is recent. It is also recommended that the contingency on the rf quadrupole be increased from 7.0 percent to 10.0 percent, since the output energy is higher by 25 percent than that customarily used. This leads to a revised base-cost for the linac of $25,508 thousand (FY 1990 dollars), and the average contingency remains 11.4 percent.

It is noted that spares are not included in the TPC.

In summary, the total SSCL base cost for these systems is $193,398 thousand plus $31,234 thousand contingency, for a total of $224,632 thousand (FY 1990 dollars). The proposed changes lead to a base cost of $218,803 thousand, plus $40,173 thousand contingency, for a total of $258,976 thousand (FY 1990 dollars). This is an increase of $34,344 thousand (FY 1990 dollars), or 15.3 percent.

10.5.4 Schedule

Procedures for changing rf power source components need to be worked out in detail before the civil construction design for their enclosures, particularly the configuration of access shafts, is frozen.

The integrated project schedule, including pre-construction R&D, construction, and pre-operations, identifies 4 months of float for commissioning the HEB (in order not to delay the start of beam commissioning of the collider), 22 months for the MEB, 22 months for the LEB, and 24 months for the linac. These levels represent low risk except for the

HEB. The systems reviewed by this subcommittee do not drive the schedule for the HEB, and thus represent low schedule risk for that accelerator as well, provided that adherence to the schedule is monitored and corrective action taken as necessary.

The Laboratory's schedule for the reviewed systems is reasonable, with the caveats that the step-function in manpower at the beginning of 1991 will be difficult to achieve, and that specification of interfaces with civil construction will have to be established at an early time.

10.5.5 Management

Several issues which affect the systems reviewed by this subcommittee need to be addressed by management to ensure that the necessary work can be accomplished effectively.

Matrix management has been selected for use in the Accelerator Systems Division to ensure that redundant effort is not invested in each of the five accelerators that make up the SSC, and that operational maintenance is simplified through maximum standardization. It is important to ensure that the interfaces required by this arrangement are well defined and function smoothly.

The various technical groups within the Accelerator Systems Division need to increase their staffing levels by typically a factor of 3 at the beginning of 1991. This requires that the recruiting and personnel policies be monitored, and that adequate working space be provided at that time.

Management should consider changing the way in which EDIA/QA funds are tracked. The present arrangement appears to make it difficult to ensure that the cost account manager, who identified the need for these funds, has control over and responsibility for them.

10.6 Cryogenics, Installation, Commissioning, Operation, Vacuum, Survey/Alignment, and Spools

10.6.1 Summary, Conclusions, and Recommendations

This subcommittee's scope included cryogenics, installation,vacuum, survey/alignment, and spool pieces. The subcommittee agreed to the funds that had been included to implement the design and construction of these SSC components; however, we feel that the contingency estimates were understated and we have suggested a 5 percent increase in this category.

10.6.1.1 Cryogenics

The cryogenic systems present a mature design with a high probability of meeting cost and schedule objectives.

The change from 70-mm to 50-mm bore for the HEB dipole is cause for serious concern over the ability to remove the heat generated during the 4.5-min cycle.

10.6.1.2 Installation

The site-specific needs are well developed with manpower and times adequately estimated. Equipment requirements have been fully accounted for.

10.6.1.3 Vacuum

The vacuum systems for all of the machines have been described to detailed schematics but not to an engineering design; however; the subcommittee judged that this was sufficient for cost estimation. The subcommittee proposed studies relative to increasing the safety margin for the collider cold beam tube vacuum. Concern here is due to synchrotron radiation effects, especially when considering higher luminosity upgrades.

10.6.1.4 Survey/Alignment

An early satellite survey gave an accuracy sufficient to locate the 44 penetration pipes. The SSC footprint does not include land in fee simple for these shafts. The Laboratory has not yet resolved this dilemma.

The subcommittee endorses the developing plans to establish in the near future an SSC metrology group under a very experienced leader. The group would carry out the final precision survey tasks and establish a project-wide alignment database.

10.6.1.5 Spool Pieces

A collider spool piece conceptual design was presented along with plans to proceed through prototypes that would be tested in magnet string tests. The spool pieces are the most complex cryogenic components and should be cold tested prior to installation in the tunnel.

Recommendations

1. The subcommittee is convinced that the decision to implement the HEB with 50-mm bore collider dipole magnets is flawed. We base this opinion not on heat load, flow rates, operating temperature, or refrigerator capacity; but on the problems associated with the incorporation of the appropriately sized cooling channels that are needed to remove the 12.6 watts total cyclic loss as given in SCDR Table 4.2.3.2-1. We recommend that this decision be revisited in the near future.

2. We encourage efforts to specify a Laboratory-wide standard for interfacing to sensors and controls for vacuum, cryo and other subsystems. Industry will need lead time in order to develop specific modules. Prototypes should be used at the ASST wherever possible.

3. An early satellite survey gave an accuracy sufficient to locate the 44 penetration pipes. The SSC footprint does not include land in fee simple for these shafts. The Laboratory should try to resolve this dilemma speedily, perhaps through the good services of the TNRLC.

4. Two technical issues identified in the report need further review by SSCL:
   - Removal of the liquid nitrogen plants and main storage tanks from the project, and
   - The integration of magnets and cryogenics personnel.

5. A great deal of work has been achieved in the areas of static and dynamic simulations of the cryogenic system. We strongly encourage continuation of this work in order to improve cryogenic stability, MTBF, and MTTR.

6. Thirty percent of the professional staff is on board; this crew, internationally recruited, is an excellent starting point. The organization structure includes two groups for process and modeling, which we wholeheartedly endorse. The plan is marginal on the percentage of electrical people both during construction and operation. We believe at least 20 percent electrical specialties during construction and 40 percent during operation are needed.

7. The collider is being designed for future lowering of the temperature, adding refrigeration capacity at the E shafts, and doubling the capacity by adding refrigerators at the F shafts. We totally concur with these design decisions. The 4.1-K and 20-K heat-loads must be continuously monitored throughout the superconducting magnet production period of the project. This monitoring can be done as individual magnet checks, as well as section (1080-m) heat-load measurements.

8. The HEB needs to be modeled first for steady-state load, then for ramp cycle effects, and finally, for the effect of starting and stopping the ramp. These results must be integrated with both the magnet and accelerator people due to the large temperature gradients and changes as a function of time.

9. A life-cycle cost study must be undertaken to determine the source of the liquid nitrogen supply. (See recommendation 4 above.) While normally this could be deferred until FY 1995, non-DOE land set-aside must be addressed now.

10. The cryogenic system has received a great deal of failure mode and effect analysis, mean time between failure and mean time to repair analysis. These analyses need to continue and also be extended to the IR regions, HEB, and future bypasses.

11. Operating experience in monitoring and control of cryogenic contaminants must be developed as soon as hardware is on site. The on-line detection of contaminants, such as N_2, Ne, H_2, and H_2O, in the helium system is required at the 0.1-ppm level. The migration and removal of these contaminants must be understood and then addressed in the final design of components.

12. The refrigerator sector station was analyzed using a summary comparison with the CEBAF 4800-W 2.0-K refrigerator currently being commissioned. While they have vastly different operating temperatures, they are directly comparable in size and common components. The contingency for this item, we feel, should be raised from 18.4 percent to 25 percent, i.e., 10 percent for cost, plus 15 percent for changes in scope.

13. Hiring the non-professionals at the required rate should not be a problem. The required number of professionals is not available. The SSCL must send engineers to the universities to recruit graduates and train its own engineers.

14. At this early stage in the SSC project, planning associated with near term activities is of higher importance than that associated with commissioning. However, as in the case for installation, it would be prudent to appoint an individual for commissioning planning, or, as an alternative, identify a system integration task for such planning.

15. Since the commissioning effort is operating funded, no contingency is provided in the cost estimate. This situation is an obvious concern especially in a system of the size of the SSC where small errors in the estimates for individual tasks can accumulate due to the very large number of tasks. This concern adds emphasis to the recommendation to begin planning this work in more detail.

16. As in the case for commissioning, a limited effort to prepare for operation of commissioned systems should be initiated.

17. The commissioning concern regarding lack of contingency applies as well to operation.

18. The vertical alignment transfer from the surface to the tunnel needs to be accurate to 1 mm in three coordinates. Some experimental work has been proposed to develop techniques. We encourage early tests of that nature.

19. Experience at other sites such as Fermilab (with DUSAF) and LEP (interaction of in-house surveyors with contract surveying) leads us to recommend very strongly that an SSCL-based surveying group be created under a very experienced leader to perform specific tasks identified in the report.

20. The interconnect regions on either side of the spool have currently 25 and 19 electrical connections. These could increase by 16 each if the series quench heaters need to be isolated. The electrical configuration needs a comprehensive review, including consideration of the following:
    - Voltage taps to be brought out locally.
    - Quench heaters (if not series) to be brought out locally.

21. The spool holds the beam-position monitor, which needs to stay aligned with the nearby quadrupole to better than 0.5 mm. Large side forces will not break the spool post but may throw it out of the alignment tolerance. We encourage the Laboratory to study and resolve this potential problem.

22. The spool pieces are the most complex cryogenic components, and the subcommittee recommends that all spools be cold tested prior to installation in the tunnel.

10.6.2 Cryogenics

10.6.2.1 Summary and Conclusions

The refrigeration system is a mature design having been well developed over the last six years. It, together with its cost estimate, is consistent with 99.8 percent availability per sector. There were two technical issues that needed review:

1. Removal of the air separation plants and main storage tanks from the TPC, and

2. The integration of magnets and cryogenics.

The removal of the air separation plants from the TPC is a life cycle cost optimization issue (including roads), but the removal of half the liquid N_2 storage is a reliability issue. It requires about 1000 liquid tankers for each cool-down of the project and 15 tankers per day to operate.

The integration of magnets and cryogenics has been a classical problem at all laboratories. The SSC has done a much better than average job to date, but it still has a way to go. There are signs that with the magnet in a separate division and building, this integration is decreasing; this is especially obvious in the HEB, which has a long way to go before there is an integrated working design. Lack of integration traditionally shows up in three ways:

1. Commissioning time and cost

2. Mean time to repair (MTTR), and

3. Operating cost increases due to instabilities and non-optimum operation.

The subcommittee believes the cost of operating the refrigerators, ASST, MTF, HEB, and the collider during the project commissioning period is on the order of $100 million (manpower, He, N_2, power). The subcommittee, due to time limitations, was unable to locate all of the WBS's that contained these costs. These costs are spread over R&D, construction, pre-operations, and operations; and in many locations in the cost book, they are listed as consumables.

10.6.2.2 Scope

The scope of the cryogenic system is to keep the magnet coils below 4.35 K and provide 20-K and 80-K refrigeration. The system uses 10 6500-W 4.1-K refrigerators to cool the collider plus two more to cool the HEB. Helium refrigeration cools the inner shield while the outer shield uses subcooled liquid nitrogen. It is now planned to purchase this nitrogen rather than producing it in on-site air separation plants. The nominal refrigerator power is 45.6 MW with the installed power being 58 MW. If power were provided for a vendor-owned air separation plant an additional 13 MW would be required.

A total of 3 km of cryogenic spacers and bypasses are included in the cryogenic scope in order to complete the SSC cryogenic ring. The spacers are planned to be "empty" SSC CD cryostats, which is similar to the Tevatron where magnet end assemblies were used for spacers. For the cryogenic by-passes, the cost of dipole cryostats was used until a detailed design can be made.

The spool pieces, which are the heart of the tunnel cryogenic system, have been moved to the mechanical group. Close integration is required to obtain an optimum design.

Achievements

The cryogenic department initiated the SSC's first major procurement; the MTF/ AAST systems. At a green site, the first major procurement forces the formalized development of the internal and external procurement procedures. This is a major achievement.

The diameter of the gas return pipe has been increased from 2-1/2 IPS to 3 IPS. This diameter is the limiting item that determines how much refrigeration can be supplied to the magnets. This subject is discussed in detail in Ref. 1. This reference needs to be updated for the current heat loads.

A great deal of work has been achieved in the areas of static and dynamic simulations. We strongly encourage continuation of this work in order to improve cryogenic stability, MTBF, and MTTR.

Thirty percent of the professional staff is on board; this crew, internationally recruited, is an excellent starting point. The organization structure includes two groups for process and modeling which we wholeheartedly endorse. The plan is marginal on the percentage of electrical people both during construction and operation. We believe at least 20 percent electrical specialties during construction and 40 percent during operation are needed.

Evaluation

Since the CDR, the heat-load budget has increased by 40 percent while the capacity has increased by 38 percent. The factor for redundancy margin is now 125 percent. This seems acceptable since the heat-load is linear with the beam current but varies as the fourth power of energy. This provides an adjustment which could be used if the 25 percent margin is required to cover for a shut down refrigerator. It should be noted that the 1986 CDR evaluation recommendation that the "potential" factor for overall margin be increased from 150 percent to 200 percent has been accomplished if one uses the base of 3160 watts for the total estimated heat-load in the CDR since the SCDR refrigerator is now sized at 6500 watts.

Risk Assessment

The subcommittee feels that there are a number of activities that require early and/or continuing implementation. The current plan of procuring three 4-KW MTF/ASST refrigerators by September 18, 1990, provides the mechanism to greatly reduce the technical risk in the project. What is crucial is that this R&D facility at this or another location be kept operating for the entire construction period and be updated with all design revision components. One must avoid what has happened in the past: the facility is under utilized in the first half of the construction project and shut down in the latter, due to lack of funding and manpower.

The collider is being designed for future lowering of the temperature, adding refrigeration capacity at the E shafts, and doubling the capacity by adding refrigerators at the F shafts. We totally concur with these design decisions. The heat load must be continuously monitored throughout the superconducting magnet production period of the project. This monitoring can be done as individual magnet checks, as well as section (1080-m) heat-load measurements.

R&D Items (in priority order)

A significant amount of R&D has been accomplished in the last 4 years. As the construction phase begins, cryostat R&D must continue at an increasing rate. Due to schedule and resource limitations, there is enormous pressure to decrease the R&D at this stage of the project. This would be a major error. Some specific R&D and design areas deserving further attention are listed below:

1. 4.1-K and 20-K heat leaks must be measured semiannually on the superconducting magnet production run components to guarantee that changes have not increased the heat loads.

2. The HEB needs to be modeled first for steady state load, then for ramp cycle effects, and finally, for the effect of starting and stopping the ramp. These results must be integrated with both the magnet and accelerator people due to the large temperature gradients and changes as a function of time.

3. A life-cycle cost study must be undertaken to determine the source of the liquid nitrogen supply. While normally this could be deferred until FY 1995, non-DOE land set-aside must be addressed now. McAshan Note (Ref. 2), indicates that the optimum location for a single site is at the E1 - H8 cross connect.

4. The system has received a great deal of failure mode and effect analysis (FMEA), mean time between failure (MTBF), and mean time to repair (MTTR). These analyses need to continue and also be extended to the IR regions, HEB, and future bypasses.

5. Operating experience in monitoring and control of contaminants must be developed as soon as hardware is on site (ASST April 1992). The on-line detection of contaminants, such as N_2, Ne, H_2, and H_2O, in the helium system is required at the 0.1-ppm level. The migration and removal of these contaminants must be understood and then addressed in the final design of components.

10.6.2.3 High Energy Booster

The committee is convinced that the decision to implement the HEB with 50-mm bore collider dipole magnets is flawed. We base this opinion not on heat-load, flow rates, operating temperature, or refrigerator capacity; but on the problems associated with the incorporation of the appropriately sized cooling channels that are needed to remove the 12.6 watts total cyclic loss as given in SCDR Table 4.2.3.2-1. We recommend that this decision be revisited in the near future.

10.6.2.4 Cost and Contingency

The refrigerator sector station was analyzed using a summary comparison with the CEBAF 4800-W 2.0-K refrigerator currently being commissioned. While they have vastly different operating temperatures, they are directly comparable in size and common components. The bottom-line comparison is $12.8 vs. $12.5 million. The contingency for this item, we feel, should be raised from 18.4 percent to 10 percent for cost plus 15 percent for changes in scope.

The cryogenic transfer lines are estimated using a cost-model analogous to that for superconducting magnets.

10.6.2.5 Schedule

The schedule breaks down into two subtopics:

1. The MTF/ASST procurement, and
2. The main refrigeration procurement.

The first of the latter equipment is required by May 1995, which means it should be ordered by May 1992. This procurement should be relatively easy since most of the ground work has been completed as part of the MTF/ASST procurement.

The MTF/ASST schedule is as follows:

Order Units	September 18, 1990
Start Civil Construction	January 1, 1990
BOD/Start Compressor Installation	July 1, 1991
ASST Cryogenics Operational	April 1, 1992
String Test Complete	October 1, 1992

This schedule, which is on the project critical path, will require a super effort. The schedule borders on the impossible. In order to succeed, two items outside the control of the cryogenic group are required:

1. All DOE paperwork and permits on schedule, and
2. The civil BOD must not slip past July 1, 1991.

10.6.2.6 Manpower

The cryogenic group asymptotic staffing is 102 FTEs; 36 of these are professionals. Current staff is 11 professionals and 5 non-professionals. The budget shows a hiring rate of 3 per month, including 1 professional, for a period of 2 years starting now.

Hiring the non-professionals at this rate should not be a problem. This number of professionals is not available. The SSC must send engineers to the universities to recruit graduates and train its own engineers.

10.6.2.7 Commissioning and Operation

Accelerator Commissioning

This activity begins after individual systems have been installed. The costs, $130 million (FY 1990 dollars) are identified in WBS 4.1, Accelerator Pre-operations. In one instance, the refrigeration plants, the vendor is responsible for commissioning while SSCL maintains an oversight role. Commissioning by SSCL begins in FY 1993 with the linac staff level of about 100. The commissioning staff level reaches about 200 in FY 1996 and FY 1997 when commissioning of MEB, HEB, and some collider sectors is occurring and drops off to zero at the end of the project, September 1998.

SSCL developed the staffing levels from the input of engineers responsible for the various systems. In addition, some scaling of Fermilab experience was included. The staffing levels and commissioning durations were described only in summary form rather than in detail as was done for installation. The cryogen and power use during commissioning was reviewed in more detail with key engineers. The assumptions are that enough LN for four cooldowns (1000 truckloads each) and one system inventory of He will be required. About $16 million (FY 1990 dollars) of electric power will be needed.

Findings and Recommendations

1. At this early stage in the SSC project, planning associated with near term activities is of higher importance than that associated with commissioning. However, as in the case for installation, it would be prudent to appoint an individual for commissioning planning, or, as an alternative, identify a system integration task for such planning.

   The motivation here is twofold. First, by planning more thoroughly for commissioning, tasks may be identified that involve the construction and installation activities. Second, since commissioning is part of the TPC, there will be more scrutiny of these activities as the project proceeds.

2. Since the commissioning effort is operating funded, no contingency is provided in the cost estimate. This situation is an obvious concern especially in a system of the size of the SSC where small errors in the estimates for individual tasks can accumulate due to the very large number of tasks. This concern adds emphasis to the recommendation to begin planning this work in more detail.

Accelerator Operation

This activity begins after an individual system is commissioned and extends through project completion (as well as thereafter). The costs, $132 million (FY 1990 dollars), are identified in WBS 6.3.1, Accelerator Operations.

This activity is not part of the Total Project Cost (TPC). Operation begins in FY 1994 with the linac with a staff of about 40 and continues to grow to about 400 by the end of the project, September 1998. The SSCL rationale for excluding these activities from the TPC is that the individual systems will have reached an operational level and will in fact be staffed with operating personnel.

The individual systems will be operated to support other systems that are being commissioned, and in addition the commissioned systems can be operated to provide test beams for detector calibration. Again, the level of detail supporting this activity was only in a summary format, and less than that presented for commissioning. Cryogen and power use assumptions identified by SSCL are $11.7 million for LN and $7.5 million for He (2 system's inventories) and $27 million for electric power, all in FY 1990 dollars.

Findings and Recommendations

1. As in the case on commissioning, a limited effort to prepare for operation of commissioned systems should be initiated.
2. The commissioning concern regarding lack of contingency applies as well to operation.

10.6.2.8 References

1. Planning the SSC Cryogenic System for Future Expansion, Central Design Group, SSC-N-400, October 1987.
2. Liquid Nitrogen Supply for the SSC, M. McAshan, June 28, 1990.

10.6.3 Installation

10.6.3.1 Summary and Conclusions

The material presented to the subcommittee on installation of various accelerator systems was of high quality and was supported by a detailed plan which included manpower. The site-specific needs are well developed with the number of installation crews fully defined and appropriate hours for each task included. Equipment requirements have been specified and the subcommittee concurs with the funds included for this hardware. It seems appropriate to comment on the reason for the completeness and accuracy of this part of the SCDR. The work was carried out by Larry Sauer who did the installation of the 800 superconducting dipole magnets at Fermilab as well as the quads and spools for the Tevatron.

10.6.4 Vacuum

10.6.4.1 Summary and Conclusions

The conventional vacuum systems of the linac, LEB, MEB, test beams, HEB and collider (cryostat insulating and conventional UHV) are described to a level of detailed schematic layouts, but not yet to detailed engineering design. This level is quite sufficient for cost and installation estimating purposes, and incurs no significant risk. The designs follow good engineering practice and draw from experience at existing facilities, one of which is the Tevatron.

The collider cold beam vacuum is the only vacuum system with significant technical risk, all due to synchrotron radiation effects.

The experiments on desorption by the CDG/Fermilab at BNL have shown that the collider will work at the design luminosity without any additional design improvements, albeit without a very large safety margin. However, any upgrade to 10^{34} cm^{-2} s^{-1} luminosity is not guaranteed to be free of unacceptable hydrogen load in the beam tube. To provide an additional margin of safety against unacceptable hydrogen gas loading we endorse suggestions made jointly with SSCL personnel and others during this week. (See H.Jöstlein, informal note to SSCL, June 29, 1990.)

10.6.5 Survey/Alignment

10.6.5.1 Summary and Conclusions

The plans for machine alignment, proceeding from a site-wide Global Position System (GPS) network down to individual magnet alignment are well thought out and sufficiently detailed for planning and costing purposes. Some long lead time equipment has been ordered. A first GPS site survey has just been completed by an outside contractor, with a quoted accuracy of 5 mm. It was pointed out that the error is likely to be larger, perhaps around 25 mm, based on the fragile nature of the rod monuments and antenna mounts. This survey was, however, needed to locate the sites of the 44 deep penetration tubes. These tubes are approximately 800 mm in diameter to guarantee a free vertical line of sight through a pipe with a maximum slant of 1 degree from vertical.

When the 44 penetration pipes are installed a second round of GPS surveys needs to be taken to locate the tops of these pipes, with the utmost accuracy possible. Due to the technological demands, this survey should occur under the close supervision and active participation of a Laboratory surveying coordinator (yet to be named; see management recommendation below) and his group.

This GPS survey may occur in piecemeal fashion, as penetration pipes are sunk in a process governed by land-acquisition and funds timetables. It would seem worthwhile to explore the possibility to sink all 44 pipes in a single contract, followed by a GPS survey with smoothing. A second GPS survey of the deep pipes (perhaps a year later) would reveal invaluable information on accuracy and stability of these primary monuments.

Vertical Transfer to Tunnel Level

The vertical alignment transfer needs to be accurate to 1 mm in three coordinates. Some experimental work has been proposed to develop techniques. We encourage early tests of that nature. A possible site might be an additional penetration hole near the E1 shaft.

Land Availability for Alignment Shafts

The 44 vertical shafts are placed at 2-km intervals along the collider and HEB tunnels. The SSC footprint does not include land in fee simple for these shafts. The spacing of the shafts is governed by the need to guide the tunnel boring machine with about 50-mm accuracy.

Access is needed for the initial shaft boring and later on a few occasions to repeat GPS surveys. When the tunnel is completed the shafts can be filled with concrete and cut off below the surface.

When the SSC land was requested from the state of Texas these areas were not included in the request. We recommend that the Lab try to resolve this dilemma speedily, perhaps through the good services of the TNRLC.

Cost

The surveying cost analysis appears reasonably complete, with the possible exception of some costs associated with the creation of an SSC-based alignment lab, discussed below. The alignment time and cost for magnets has been estimated in very good detail and is believable and sufficiently conservative.

Technical Risk

Some of the alignment tolerances challenge the state of the art. Examples are the quadrupole radial and vertical placement, with an error budget of about 0.4 mm rms, a major fraction of which will be used up by potential cold mass motion in the magnets. We encourage the continuation of earlier studies on cold mass motion during temperature cycling and transportation as the final dipole magnet is being defined.

Another area of caution is the relative alignment of quadrupole magnets and the adjacent spool piece (containing a beam position detector). The external alignment is well within conventional technical capability, but cold mass motion needs to be understood. The relative alignment tolerance is 0.5 mm (3σ value).

A third area of technical risk is discussed in the next paragraph, and concerns consistency of techniques, quality control and data base management. We cannot emphasize enough the potential for extra cost and programmatic delay that can be introduced by inappropriate management structures in this area.

Management

Experience at other sites such as Fermilab (with DUSAF) and LEP (interaction of in-house surveyors with contract surveying) leads us to concur with the very strong recommendation made by Larry Ketchum (Fermilab) to create a SSC lab-based surveying group, under a very experienced leader, to perform the following tasks:

1. Layout of the 44 pipe transfer monuments
2. Oversee/execute the next GPS site survey.
3. Create and maintain a site-wide and self-consistent alignment data base, readily accessible by many users outside the survey group.
4. Perform consistency analyses and computer smoothing operations on a continuing basis.
5. Develop and acquire techniques for depth transfer and for stretched wire sagittal measurements that challenge existing performance standards.
6. Aid the magnet group in cold mass motion studies.
7. Support lab activities by performing quick response alignment tasks

The surveying group should control the Lab-owned state of the art satellite positioning equipment and become competent in its use. It should also own conventional alignment equipment, including computerized theodolites, and have its own instrument calibrational/verification lab. The search for a SSCL surveying coordinator should be initiated and pursued with the utmost vigor.

10.6.6 Spool Pieces

10.6.6.1 Summary and Conclusions

Required for both the collider and HEB, spool pieces are complex cryogenic components which serve to connect the individual magnet cryostats, allowing penetrations for instrumentation, current leads, vacuum and cryogenic fluids. To date, work on spool-piece design at SSCL has focused on those needed for the collider, which currently specifies 1878 units. A parallel effort at Fermilab has developed spool piece design and costs for the HEB. A collider spool-piece conceptual design was presented to the subcommittee; however, detailed aspects of the design are yet to be completed. This latter issue is not a major concern and we expect that prototype spool pieces will be available for testing as part of the string tests at Fermilab and later at SSCL.

It is the plan of SSCL to design the spool pieces separate from the correction magnets. An industrial contractor will "build to print" the spool piece. The correction magnets will be separately fabricated and installed either at the industrial contractor or SSCL in order to complete the spool piece. SSCL will have to control this interface very carefully to ensure that the magnets can be easily and reliably incorporated into the spool and that the alignment errors do not build up beyond the 0.5 mm (3σ value) allowance, which includes cold mass motion.

This approach further requires that SSCL do checkout and testing of the completed spool corrector assembly before installation in the tunnel. The present plan is for cold testing the first 10 percent of the spools produced followed by cold testing of only 10 percent of the remaining assemblies. Such an approach, which is identical to the testing and schedule for the collider and HEB dipoles, is quite risky. The spool pieces are among the most complex cryogenics components and consequently susceptible to some fault. We believe that cold testing of the spool piece assembles should be completed in advance of installation; otherwise consideration should be given to suitable procedures for repair or replacement of unacceptable units within the tunnel.

The corrector magnets are currently being developed at TAC and LBL, with the leading candidate designs being TAC's superferric magnets. Industrial contracts are scheduled to begin in late 1990. SSCL plans to control the production by specifying fabrication techniques and distribution of materials. Thus the industrial contractor will be primarily a fabricator. We believe that consideration should be given to making competitive fixed-price contracts at least for the dipole and quadrupole correctors. A procedure similar to that to be followed for the collider dipole magnets may be appropriate.

The cost analysis for the spool pieces appears reasonable at this stage of development of the design. It is noted that the SSCL and Fermilab cost estimates for the spools are similar, although they designed somewhat different units (one for the collider, theother one for the HEB). Should the HEB retain its aperture at 50 mm and use collider-type dipoles, serious consideration should be given to using an identical spool design to similarly reduce cost.

Spool Electrical Circuits

The CDR used a corrector configuration similar to HERA with a very large number of cryogenic electric lines that ran across the dipole magnets. These have been eliminated in favor of a system that uses the middle spool of a full cell as the electrical fan out.

The interconnect regions on either side of this spool have currently 25 and 19 electrical connections. These could increase by 16 each if the series quench heaters need to be isolated. The electrical configuration needs a comprehensive review.

We feel the following should be considered:

1. Voltage taps to be brought out locally, and

2. Quench heaters (if not series) to be brought out locally.

Spool Vacuum Break Strain Relief

The vacuum break in the spools experiences a force of 8500 pounds with one side at vacuum, the other at atmospheric pressure. In the worst case pressurization up to the relief pressure of 2.5 atmospheres absolute, the force becomes 21,400 pounds. [This is 7130 pounds per support post (3 posts)]. The collider dipole is designed for a side force (at 1-g acceleration) of 34,000 pounds for 5 supports, or 6800 pounds per support.

The spool holds the beam position monitor which needs to stay aligned with the nearby quadrupole to better than 0.5 mm. Large side forces will not break the spool post, but may throw it out of alignment tolerance.

We encourage the Laboratory to study and resolve this potential problem. An obvious remedy is to take the axial force directly into axial straps (force can act in either direction), e.g., G10 straps. The largest force occurs between the outer cryostat tube and the outer shield, because of the large area. The 4-K cold mass may not need any additional strapping. With this remedy, one may be able to eliminate the middle post, at some cost savings.

Coalesce Drift Spaces in the HEB

The lattice for the HEB has currently a drift space on either side of the dipoles in the chromaticity matching parts. If there is an acceptable lattice solution, one could combine the two drift spaces into a single device at some cost savings.

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10.7 I/C, Computers, Etc.

10.7.1 Summary, Conclusions, and Recommendations

Subcommittee 4d was charged with examining the SSC design and cost estimate relating to accelerator controls, instrumentation and diagnostics, machine safety systems, and general laboratory computing. The subcommittee in general was impressed with the thought and effort put forth in the planning that has been done so far. However, in some areas there is concern on the part of the committee caused by the number of system integration and interface issues that have surfaced. The scoping of the systems as presented appears to be appropriate, and the cost estimates reasonable.

It is the belief of the subcommittee that the controls system scope and challenge are well within the state of the art, and the project is achievable. However, the subcommittee also concludes that, for a variety of reasons, the controls group is not progressing as rapidly as it could because technical decisions required for substantial progress are being postponed. The overriding cause of the delay is a lack of system requirements definition and assignment of functional responsibility—presumably a responsibility of the system integration group. In the area of staffing, the level of the group is deemed to be low, and it appears that hiring the subgroup leaders expeditiously will be a major challenge. These are the major issues, we think, behind the seemingly immature control system design. While this is not viewed as a critical problem at the present time, additional attention by the system integration group and increased general support by management will be required soon.

The instrumentation and diagnostics group design and system philosophy are viewed as being in very good shape. While it also can be said to be hurting by the low level of system integration input, the group is making excellent progress nonetheless, because of strong leadership and good staff.

The machine safety system reviewed by the subcommittee addresses only personnel access to machine areas with potential radiation or electric shock hazards. Other safety issues, such as fire and oxygen deficiency, are addressed elsewhere. The functional requirements are well thought out, and the design is excellent. The cost estimate is good, but does require that transistor logic (rather than relays) be used in the system. It is conceivable that the safety review committees will not accept this approach; failure to accept it would lead to increased cost and substantial functionality losses. This is another area where the subcommittee feels that the SSC would be strengthened by the assignment of a permanent full-time employee.

The general computing is on a good track. The group has made commendable use of the planning homework of the last few years. They are beginning to implement an up to date approach to the general laboratory computing and communications needs. Even so, in the areas of CAD and database support, there is some evidence of the same type of system integration problems observed elsewhere.

Recommendations

1. Software timeliness appears to be the highest risk component in the SSCL control system design. Early implementations of controls for operation of the ASST and PIF will force compromises that require throwaway solutions. Therefore, the committee feels that a larger contingency is warranted in the early stages of control system design and installation.

2. Divisional and group interfacing requirements and responsibility identification issues may soon severely impede progress. The committee feels that the system integration group should lead the effort to form agreements and devise schedules for resolving issues.

3. The management of the controls group is providing the necessary strength of vision to this project, but the subcommittee is concerned by the manpower shortages and the slow start. We feel that the control group's position, particularly in negotiating interfaces with other groups, would be strengthened by the assignment of a permanent person in the role of control group leader.

4. The SSCL should assign responsibilities to a permanent in-house group on a time scale driven by the E1 construction project schedule.

5. The E1 complex and the linac offer significant opportunities for use of the iterative prototype solution. For this type of prototyping solution to be well exploited, senior management decision on whether to proceed in this manner should be made soon and detailed scheduling and implementation work begun.

10.7.2 Controls

10.7.2.1 Scope

The SCDR for controls describes two diverse designs. The first is based upon a Fermilab model and the second upon a CERN model. Current design and the costing analysis is based upon the latter. The controls scope encompasses four major elements: 1) the equipment interfaces, 2) communications, 3) computer systems, and 4) software required to operate the accelerator. This scope is shared in part by several other groups and divisions having responsibilities in these areas. The scope has changed from the original CDR in that responsibility for general purpose control interface modules and their software support has been moved into the controls group whereas more complex electronics such as beam position monitors, quench protection monitors, etc., remain in other support groups.

10.7.2.2 Scope Evaluation

The definition of areas of responsibility for controls is covered adequately. Design approaches are proposed in general terms. Equipment interfaces include standard analog-to-digital converters, ramp generators, and message broadcast receivers. A commercial kludge board strategy has been adopted for the many special purpose requirements to minimize local engineering and production efforts. A notable communication strategy employing time division multiplexing (TDM) technology, developed by the telecommunications industry, has been proposed in order to reduce the number of processors in the tunnel niches, reduce cost, and provide higher reliability. The computer strategy is based on the choice of the UNIX operating system. This choice allows use of computer systems from a variety of vendors with diverse performance, and takes advantage of the rapidly improving price performance of RISC-based architectures. Software solutions rely upon a variety of sources including the local staff, consultants, public domain, commercial products, and other laboratories. The group plans an iterated prototyping approach, applying software tools to early projects, which should evolve to the mature control system.

Software timeliness, as in most control systems, seems to be the highest risk component in the SSCL control design. The early implementations of controls for the operation of the ASST and PIF will force compromises and require that some throwaway solutions be employed.

10.7.2.3 Cost

The cost basis of the control system contains a detailed listing of hardware components, which are based upon catalog or vendor pricing where appropriate or scaled from other laboratory estimates. The software cost analysis is less detailed, but like the hardware compares favorably to other projects.

This subcommittee felt that a larger contingency was warranted in the early instances of the installed control system.

10.7.2.4 Schedule

The SCDR for the controls system contains many excellent concepts not found in existing accelerator control systems. The integration of databases from lattice to cable to equipment description is one example. Choosing a non-proprietary operating system, embracing other software standards, utilizing commercial software, and proposing integrated software tool kits are favorably received.

A schedule for the controls system completion is provided in general terms with only a few identifiable critical milestones. Several issues decrease the confidence factor of that schedule. The ambitions mentioned previously compound the always difficult task of control systems scheduling. The identification of reusable software components from other laboratories, the acquisition of public domain or commercial software solutions, and the establishment of preliminary user requirements seem to be behind schedule. Clearly, staffing difficulties are partially responsible for these problems. Of eleven important controls staff positions requiring individuals with leadership and experience, only three are filled.

Divisional and group interfacing requirements and responsibility identification may soon severely impede progress. For example, progress on the controls equipment database and its program interfaces appears to be stymied by the control group's perceived lack of computing department database support. That view is not shared by the computing department, which serves to highlight the fact that there are interfacing problems. This subcommittee feels that the system integration group should lead the effort to form agreements and schedules for resolving such issues.

The current level of planning and progress seems immature at this time. For the iterated prototyping solution to be well exploited in the ASST, PIF, or linac, decisions should be made soon and detailed scheduling and implementation work begun.

10.7.2.5 Management

The management of the controls group is providing the necessary strength of vision to this project, but we are concerned by the manpower shortages and the slow start. We also feel that the controls group position, particularly in negotiating interfaces with other groups, would be strengthened by the assignment of a permanent person in the role of control group head.

10.7.3 Instrumentation and Diagnostics

10.7.3.1 Scope

The SCDR succinctly and appropriately defines the scope of the Instrumentation and Diagnostics System to satisfy "the broad requirements of four different modes of operation: commissioning, routine operation, fault diagnosis, and advanced accelerator studies."

The high multiplicity systems are beam position monitors (BPMs), loss monitors, and the precision timing system. The designs for the BPM and precision timing systems are based on Fermilab, SLAC, and CERN experience and are at a satisfactory stage. System designs for BPMs and precision timing exist. Components have been counted, and preliminary functional requirements for BPM signal processing modules and precision timing modules have been developed. Detailed design of a prototype BPM electrode structure is underway. Three prototypes will be completed by September 1990, to be used for calibration, vacuum, and cryogenic testing. Cabling requirements are understood, and a conceptual proposal for the BPM component location in the tunnel exists. Similarly, a fiber plant proposal for the timing system exists.

10.7.3.2 Cost

The cost analysis of the BPM and timing systems is based upon a detailed breakdown of the components with engineering input for the various mechanical, vacuum, cryogenic, and electronic components. In addition, comparisons with Fermilab, SLAC, and CERN experience have been used where relevant. Many component prices are based on catalog pricing (in the case of BPMs) or estimates from catalog units of similar functionality (precision timing system modules). Needs for calibration and testing have been included.

For the larger accelerators (HEB and collider), the high multiplicity systems amount to almost half the I&D hardware cost. The functional requirements for the low multiplicity systems need more definition, most appropriately provided by the system integration group. However, the total I&D cost is insensitive to individual systems, and the lack of such requirements is not a critical issue now.

The I&D budget includes the application software for beam diagnostics in all the accelerators. The level of effort appears to be adequate.

10.7.3.3 Schedule

The schedule for the I&D effort is satisfactory. The hiring of applications software staff is the only potential schedule problem.

10.7.3.4 Management

The subcommittee is very impressed by the quality and quantity of work done at this stage. The professionalism, enthusiasm, and thoroughness of the team members with whom we talked is obvious. The I&D group leadership sets an excellent example.

10.7.4 Machine Safety

10.7.4.1 Scope

The machine safety system reviewed by the subcommittee addresses only personnel access to machine areas with potential radiation or electric shock hazards. Other safety issues, such as fire and oxygen deficiency, are addressed elsewhere.

The functional requirements were derived from experience at Fermilab, CERN, and SLAC. The design is very well done and is conservative with respect to the high assurance needed for preventing radiation and electrical accidents. It is implemented with careful consideration of personnel access logging and for high availability and good maintainability. However, it does use transistor logic to reduce cost and add functionality. It should be ascertained that this meets appropriate requirements for safety systems.

10.7.4.2 Cost

The system is reasonably costed. However, this system was included only for the machine and injector complex. The test beam facility and the experimental facilities were estimated differently, and there does not appear to be agreement over system scope in these areas.

10.7.4.3 Schedule

It is expected that this system will follow the construction schedule without difficulty.

10.7.4.4 Management

No explicit management plan or structure was presented. The conceptual design and cost estimate were developed by a Fermilab consultant. The SSCL will need to assign responsibilities to a permanent in-house group on a time scale driven by the E1 construction project schedule.

10.7.5 Computing/Communication/CAD

10.7.5.1 Scope

In general, the local computing division has taken good advantage of the homework done by several planning committees (e.g., SSCL-N-691) in the specification of the requirements needed for the project. This includes the selection of UNIX as the operating system of choice and a general computer hardware acquisition plan. This is viewed by the subcommittee to be a reasonable approach for a modern "central" computer service. We are impressed by the networking and personal computing facilities available to the SSCL staff. The communications facilities being planned are modern, comprehensive, and well thought out.

The CAD emphasis in the Laboratory technical systems group concentrates on mechanical CAD, which seems to be appropriate. Given the dynamic state of the technology and marketplace in electronics CAE/CAD, low risk decisions in this arena are impossible. The SSCL, as other laboratories, will have to pursue a number of different approaches in order to adequately support the electronic design needs.

10.7.5.2 Costs

The cost estimates are in two sections, Laboratory General Computing and Physics Computing. The Physics Computing costs are based on a plan for acquisition of workstations, servers, compute engines, and processor farms in the period of FY 1990 through FY 1998. This plan is based on the strategy for physics computing, and the hardware unit prices seem reasonable. The Laboratory General Computing cost estimate is based on list prices for non-RISC computers, and is probably high. There is insufficient detail in the system description to validate the cost estimate. We feel that the cost estimate is largely "top down."

10.7.5.3 Schedules

Hardware delivery schedules seem reasonable. However, we have some concern with the staffing schedules and the scheduled central support for Laboratory-wide databases. The staffing profile needed to accomplish the general computing support is aggressive, going from 25 people to over 50 next year. Database support will be needed at all levels of the Laboratory.

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10.8 Conventional Facilities

10.8.1 Summary, Conclusions, and Recommendations

The design of the conventional facilities as proposed in the SCDR for the SSC is conceptually adequate. However, due to the preliminary nature of the design and potential risks associated with underground facilities, the subcommittee recommends an increase of $63.5 million (5 percent) in the conventional construction total estimated cost (TEC).

With a limited staff and consultant base, SSCL has produced an adequate and reasonable site-specific conceptual design for the conventional facilities. The most expensive facilities, involving unique conventional designs, were well presented. The scope, constructibility, and cost of the collider tunnel were studied from several perspectives, including labor and material breakdowns and construction contractor's experience on similar, albeit smaller, projects. The scoping of the experimental halls included detailed structural designs and proposed construction methods normally expected of post-Title I efforts and included some provision for solving problems associated with Eagle Ford shale. Because the major facilities are well-conceived and the cost estimates approached Title I detail the subcommittee is confident that the current scope of the point design, with a reasonable contingency, is feasible. The term point design refers to a point of reference in the ongoing design development and optimization for the purpose of evaluating cost and schedule.

The conceptual design for the surface facilities, such as the office buildings, service or utility buildings, and industrial facilities, was based on several detailed models of specific building types. The floor areas were based on the estimated needs of the technical groups and were usually confirmed by comparisons with similar facilities at other accelerator laboratories; however, the validity of the SCDR for the surface facilities will depend upon later confirmation of the actual space requirements. Therefore, the contingency for surface facilities is related to unknown floor areas rather than unusual or undefined construction techniques.

The subcommittee identified several concerns in regard to conventional construction. As detailed later in this report, the most serious concern regarding the conventional facilities arose from the unknown characteristics of the Eagle Ford shale strata intercepted by the collider tunnel and the western IR cluster. The selection of each detector and its experimental hall will impact the final foundation design, particularly in Eagle Ford shale. Because some time and effort will be required to adequately evaluate this shale strata, the subcommittee recommends early action, including a detailed site exploration program, instrumented field measurements of Eagle Ford shale (EFS) response to excavation at the E1 shaft or through the use of the large-diameter drilled hole (LDD), a workshop in which geotechnical construction experts participate, or other investigative procedures. As a parallel effort, consideration should be given to optimizing the location of the four detectors at the different IR regions in an attempt to mitigate the effect of the EFS.

The construction schedules presented for the conventional facilities were derived as a result of critical technical component milestones and their completion dates (collider magnet development and delivery) and from the beneficial occupancy date of the accelerator enclosures. Taken as a conceptual bar graph schedule, the activities were broadly scoped and generally serial. The subcommittee believes the summary conventional-facility schedule to be inherently ambitious. For example, the collider tunnel construction has been scheduled in nine separate but concurrent contracts. The beneficial occupancy of the experimental halls corresponds with the start of the utility buildings necessary for providing a working environment in the halls. The final year of collider installation is coincident with the cooldown and commissioning of the collider ring, thereby requiring phased efforts for both activities. Many activities in the conceptual schedule represent large facilities that have significant long-lead procurements or require more detailed schedules. Subsequent schedule development should establish integrated milestones and identify the critical activities, their durations, and their floats, the needed control to successfully manage the conventional construction.

Critical milestones for the start of construction are AE/CM Notice to Proceed, Record of Decision (ROD) for the Supplementary Environmental Impact Statement (SEIS), and successful testing of industrial magnets. The schedule dates for these critical milestones must be achieved for the construction schedule to be valid. A critical milestone, which is already overdue, involves the Notice to Proceed for the AE/CM. While recent efforts to use available support and subcontractors (as presented in the SCDR conventional facilities sections) has been notable the mobilization of the AE/CM is critical to attaining the early conventional construction milestones of the project, including the prototype installation facility (PIF), the magnet development laboratory (MDL), the magnet test laboratory (MTL), and the ASST (string test) facility. Negotiating final contract, mobilizing on site, establishing criteria development interfaces, integrating the organizations of the joint-venture component firms, reconfirming the conceptual schedule and cost estimates, integrating the existing design work, master site planning, developing vocabulary, and similar early activities will dilute the initial AE/CM productivity.

Staffing is a related area of concern. The Conventional Construction Division (CCD) of the SSCL must also be augmented quickly. A permanent manager needs to be appointed and additional professional staff should be brought on board rapidly. To manage the AE/CM work, a positive, well-defined line of communication between the organizations needs to be established for transmitting firm design criteria and reviewing designs. The proposed CCD staff level of 25 persons appears marginal and may require a project management group in place of a matrix management system. Once the AE/CM is aboard and the interfaces established, a concentrated effort will be required to produce Title I and II documents for the initial facilities. If the scheduled beneficial occupancy dates are to be realized, a fast-track contracting scenario will be required. In addition, receipt of the ROD for the SEIS by the scheduled December date is imperative.

Finally, the subcommittee recommends that the diamond bypass tunnel at both the east and west IR clusters should be reinstated in the work scope if cost experience during construction permits. These tunnels are an inherent feature of the conceptual design. Their construction (and, optimistically, the installation of the magnet strings) would enhance the machine performance and provide the operational flexibility to construct detectors while commissioning the collider.

The subcommittee made several specific recommendations, which are summarized here and discussed further below. The recommendations include:

1. Increase the TEC for conventional construction by $63.5 million. This includes increased contingency for the experimental halls and tunnel to reflect the potential risk of underground construction.
2. Augment the limited construction schedules to include integrated milestones and identification of critical activities, their durations, and floats.
3. Increase the staff of the SSCL Conventional Construction Division and appoint a permanent manager.
4. Proceed with early construction of the 55-ft-diameter shaft at the proposed E1 complex or the LDD to obtain additional geotechnical data on the Eagle Ford shale areas of the site.
5. As early as possible consider optimizing the location of the four detectors at the different IR regions.
6. Consider construction of the diamond bypass tunnel at both the east and west IR clusters, if cost experience during construction permits.
7. Expedite negotiations with the AE/CM and issue a notice to proceed.

10.8.2 Scope of Work

The subcommittee found the conventional facilities scope to be well conceived and consistent with the requirements of the SSCL technical systems. There has been a logical development from the CDR to reflect accelerator changes and the evolution of the experimental areas. Continued coordination of the interface between the SSCL and TNRLC will determine the final scope of the SSCL responsibility for infrastructure work. The one area of concern noted by the subcommittee involves the geotechnical characteristics of Eagle Ford shale. Since approximately 12 percent of the collider tunnel circumference and, most importantly, the experimental halls in the west cluster are to be constructed through or immediately above this geologic zone, expeditious exploration and instrumentation of the shale strata is strongly recommended. While the scope of the SCDR point design does include some provisions for special construction of the west cluster experimental halls, the final geologic impact represents the most obvious risk factor in the conventional facilities scope.

The conventional facilities consist of all tunnels, enclosures, buildings, and appurtenant structures required to accommodate the SSC technical systems, experimental facilities, and auxiliary support functions. Infrastructure items such as power, utilities, and site preparations are included in this category. The baseline scope of the SCDR was identified as a point design, described above. For purposes of illustrating the expanse and variety of an accelerator complex highlighted by a collider ring 54 miles in circumference, a brief itemization of the conventional facilities follows.

The accelerator cascade consists of the injector complex, composed of the linac, low-, medium-, and high-energy boosters (LEB, MEB, and HEB), and the collider, the dominant feature of the facility. Table 10.8.1 lists the major conventional construction parameters of the underground accelerator enclosures.

Table 10.8.1

Major Conventional Construction Parameters of the Underground Accelerator Enclosures

Accelerator	Cross Section (ft)	Circumference (ft)	Construction Method (ft)
Linac	12 x 12	800	Cut and Cover-25 berm
LEB	12 x 12	1,800	Cut and Cover-25 berm
MEB	10 Diameter	13,000	Tunnel
HEB	12 Diameter	35,700	Tunnel
Collider	12 Diameter	285,800	Tunnel (50 - 240 deep)

The accelerator complex also includes a number of surface buildings and access structures for personnel, technical components, and connection of utilities and services. The building areas required for each accelerator component are summarized in Table 10.8.2.

Table 10.8.2

Accelerator Component Required Building Areas

Accelerator	Number of Buildings	Area (sq ft)
Linac	1	15,400
LEB	6	11,140
MEB*	11	31,600
HEB	11	51,775
Collider	20	212,750

* Includes the central utility plant, 3200 sq ft.

An underground test-beam facility, which provides for 200 GeV beams from the MEB, includes 8800 ft of tunnel, underground magnet enclosures, connecting beam pipes, three underground target stations, surface utility buildings, and a test/calibration hall of approximately 30,000 ft^2.

The experimental facilities for the baseline design include the construction of four (4) underground collision halls divided equally between the east and west IRs with provision for four (4) additional halls located along the future collider diamond bypass tunnels. The initial complement of four large experimental halls will be constructed by cut and cover methods and have been scoped for the SCDR to meet the requirements of the current status of four specific colliding detector designs resulting in the following hall parameters shown in Table 10.8.3. These experimental halls include heavy-crane coverage, one or more equipment access shafts, utility and personnel access shafts, and utility bypasses around each hall. Surface buildings associated with the east and west experimental clusters include headhouses with crane coverage, utility buildings, heavy work/assembly buildings, and administration/laboratory buildings. The west cluster with 12 buildings totals approximately 250,000 ft^2, while the east cluster with 11 buildings totals 170,000 ft^2.

Table 10.8.3

Detector Hall Parameters

Hall	Detector	W (ft)	L (ft)	H (ft)	Crown to grade (ft)
IR1	LSD	92	262	95	114
IR4	L*	131	354	113	108
IR5	DO	75	161	79	110
IR8	BCD	59	197	66	96

The west campus has been sited south of the linac and east of the IR1 experimental area and includes the office building(s), auditorium, and central services, such as control rooms, computer facilities, laboratories, and other space to support a proposed staff of approximately 2700. Nearby facilities include an emergency services building, shops, maintenance building, warehouses, and assembly buildings totaling approximately 640,000 ft^2. The north campus on the west side of the site includes the MTL, the MDL, compressor building (combined with the nearby E-1 compressor requirements), ASST and the magnet acceptance and storage building (MAAS), adding another 280,000 ft^2 of surface building area. This latter group of facilities has been targeted by the SSCL as a critical early need for the development, production, and testing of the collider magnets.

The conventional facilities also include site work and infrastructure development to provide access, utilities and services, including new or improved roads, parking areas, hardstands, electric power, communications, gas, water and sewer service, cooling ponds, landscaping, and fencing.

There has been considerable effort by the SSCL to adapt the facility to the Ellis County site and to quantify, organize, and consolidate the conventional facilities requirements. Of major impact was the increased circumference of both the HEB and the collider, which resulted from significant changes in the technical scope of the machine. Additionally, a detailed study of the collider tunnel diameter with respect to the magnet size, the magnet supports, installation, and servicing requirements and other space allocation resulted in a diameter increase from 10 ft ID to 12 ft ID. A significant number of niches to house power supplies and equipment were added around the collider's circumference. Another major change since the 1986 CDR was the decision to install fixed detectors in their permanent positions within the halls. The CDR proposed clustered IRs with the movable detectors to be constructed in underground assembly areas separated from the adjacent collision halls by large movable shield doors. The current fixed design with a beam bypass at each cluster region eliminates the requirement to move massive detectors (now projected to weigh as much as 60,000 tons) and therefore eliminates the requirement for separate underground assembly areas and shield doors. In retrospect, the fixed detector/bypass concept was a fortuitous decision, since the proposed detectors have continued to expand in size and complexity with an accompanying demand for increasingly larger collision halls. It is apparent that the cost of the underground assembly halls and shield doors that would have been required by the current detector concepts would far exceed the cost of the diamond cluster bypasses with their significant complement of magnets. The test-beam facility has also been expanded from one to three beam lines. Adaptations to the Ellis County site (including collider orientation, construction techniques, tunnel depths, geological constraints and infrastructure requirements) have been incorporated into the baseline design. A summary of the scope and cost comparison between the CDR and SCDR, excerpted from SSCL studies, are included as Tables 10.8.4 and 10.8.5.

Table 10.8.4

Comparison of CDR and SCDR Costs
Base Cost Estimate (all costs in FY 1990 $K)

		CDR Cost*	SCDR Cost*
2.	Conventional Construction	775,742	1,051,493
2.1	Conventional Construction, Accelerator	455,937	635,853
2.1.1	Administration	10,040	37,662
2.1.2	Linac	2,002	2,869
2.1.3	LEB	1,533	5,141
2.1.4	MEB	12,605	34,738
2.1.5	HEB	23,680	74,024
2.1.6	Collider	400,068	464,274
2.1.7	Test Beam	5,989	17,146
2.2	Conventional System, Experimental	70,622	126,376
2.2.1	WN Region	17,408	29,732
2.2.2	WS Region	17,408	38,870
2.2.3	EN Region	17,903	21,288
2.2.4	ES Region	17,903	28,458
2.2.5	Support Functions	---	8,027
2.3	Site and Infrastructure	97,942	110,480
2.4	Campus	49,209	54,666
2.5	AE/CM	102,032	124,119

* Contingency and escalation not included.

Table 10.8.5

SSC Conventional Construction CDR vs. Current Requirements

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CDR		DESCRIPTION	CURRENT	
Parameter	**WBS**		**Parameter**	**WBS**
	2.3.1	LINAC		2.1.2
494'-12'x12'		TUNNEL	800'-12'x12'	
410'-8'x 8'		TRANSFER TUNNEL	364'-8'x8'	
2@15'id w/stairs		ACCESS/SHAFTS	3 @ 8'x12'	
15,300 sf - 1 bldg		BUILDING	15,407 sf	
8'/20'		SHIELDING COVERAGE/DEPTH	~20'/0'	
2.5 MVA		INSTALLED ELECTRICAL POWER	4.0 MVA	
1.2 MW		AVERAGE ELECTRICAL POWER	3.1 MW	
1,550 gpm		PEAK CIRCULATING COOLING WATER	408 gpm	
25 gpm		MAKE-UP WATER AVERAGE	4 gpm	
• Central Cooling Plant w/ Cooling Tower • 42'x6' eqmnt. hatch		MISC	• Central Cooling Plant w/Cooling Pond	
	2.3.2	LEB		2.1.3
817'-8'x8'		TUNNEL	1771'-12'x12'	
40'-8'x8'		TRANSFER TUNNEL	720'-8'x8'	
11,590 sf - 5 bldgs		BUILDINGS	11,140 sf - 6 bldgs	
2 @ 15'id w/stairs		ACCESS/SHAFTS	1 @ 20'x10' 1 @ 10'x10'	
8'/16'		SHIELDING COVERAGE/DEPTH	~25'/0'	
4.0 MVA		INSTALLED ELECTRICAL POWER	13.3 MVA	
1.4 MW		AVERAGE ELECTRICAL POWER	2.0 MW	
290 gpm		PEAK CIRCULATING COOLING WATER	5,808 gpm	
6 gpm		MAKE-UP WATER AVERAGE	13 gpm	
• Cooling Tower • 24'x6' eqmnt hatch		MISC	• Central Cooling Plant (3200 sf) w/Cooling Pond • 1-10 ton crane @ L1	

SSC Conventional Construction CDR vs. Current Requirements

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CDR		DESCRIPTION	CURRENT	
Parameter	**WBS**		**Parameter**	**WBS**
	2.3.3	MEB		2.1.4
6,233'-10'id		TUNNEL	12,989'-10'id	
3,230'-10'id (2)		TRANSFER TUNNEL(S)	10,252'-10'id (2)	
11,680 sf - 6 bldgs		BUILDINGS	28,400 sf - 10 bldgs	
6 @ 15'id x 20' w/stairs		ACCESS/SHAFTS	6 @ 8'id w/stairs 2 @ 30'id w/ stairs & elevator 2 @ 15'id w/ stairs (transfer lines)	
11'/20'		SHIELDING COVERAGE/DEPTH	~25'/0-75'	
~40.0 MVA		INSTALLED ELECTRICAL POWER	63.5 MVA	
9.53 MW		AVERAGE ELECTRICAL POWER	5.2 MW	
4,435 gpm		PEAK CIRCULATING COOLING WATER	22,536 gpm	
95 gpm		MAKE-UP WATER AVERAGE	24 gpm	
• Cooling Tower • 24'x6' eqmnt hatch		MISC	• Central Cooling Plant w/Cooling Pond • 1-15 ton crane @ M-7	
	2.3.4	HEB		2.1.5
19,666'-10'id		TUNNEL	35,719'-12'id	
5,446'-10'id (2)		TRANSFER TUNNEL(S)	4,126'-10'id (2)	
29,730 sf - 15 bldgs		BUILDINGS	51,775 sf - 11 bldgs	
5 @ 15'id w/stairs 1 @ 30'id w/stairs		ACCESS/SHAFTS	4 @ 15'id w/ stairs 1 @ 30'id w/ stairs & elevator 1 @ 55'id w/ stairs & elevator 3 @ 3'id conduits	
14'/22'		SHIELDING COVERAGE/DEPTH	35'/~130'-215'	
~32 MVA		INSTALLED ELECTRICAL POWER	70.9 MVA	
15.0 MW		AVERAGE ELECTRICAL POWER	16.3 MW	
4,775 gpm		PEAK CIRCULATING COOLING WATER	19,542 gpm	
110 gpm		MAKE-UP WATER AVERAGE	148 gpm	
• Cooling Towers		MISC	• Cooling Ponds • 2-15/5 ton cranes • 3-Underground equipment galleries	

SSC Conventional Construction CDR vs. Current Requirements

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CDR		DESCRIPTION	CURRENT	
Parameter	WBS		Parameter	WBS
	2.4	COLLIDER		2.1.6
10' id		TUNNEL CROSS-SECTION	12' id	
51.54 miles		TUNNEL LENGTH	54.14 miles	
19.805 miles		NORTH ARC	21.92 miles	
19.805 miles		SOUTH ARC	21.92 miles	
5.965 miles		EAST CLUSTER	5.15 miles	
5.965 miles		WEST CLUSTER	5.15 miles	
~792,000 cf		BASIC TUNNEL VOLUME	~1,197,000 cf	
492: 60x11.7cf & 432 X 35.6 cf = ~16,000 cf		POWER ALCOVES/ELECTRICAL NICHES	140: 70 x 2600 cf & 70 x 4400 cf= 490,000 cf	
20 x 220 sf		REFRIGERATION ALCOVES	20 x 220 sf	
~82,500 sf		ACCESS ENCLOSURES	~55,000 sf	
2 x ~400 cy		RF GALLERY(S)	1 x 3,500 cy	
		INJECTION KICKER GALLERIES	2 x ~2,700 cy	
		COLLISION OPTICS GALLERIES	8 x ~900 cy	
2 x ~ 3,600 cy		ABORT/BEAM DUMPS	2 x ~5,200 cy	
3120'		ABORT/BEAM DUMP LENGTH	~3500'	
50' x 24' x 24'		BEAM DUMP	65'x26'x15'	
128,740 sf - 44 bldgs		BUILDINGS	232,430 sf - 31 bldgs	
10 @ 30' id w/stairs & elevator		ACCESS/SHAFTS	5 @ 55' id w/ stairs & elevator	
10 @ 20' id			5 @ 30' id w/ stairs & elevator	
8-30"id conduits (rf)			8 @ 15' id w/ stairs	
20'/varies with model, 28'-150'		SHIELDING COVERAGE/DEPTH	40'/~60'-250'	
188 MVA		INSTALLED ELECTRICAL POWER	152 MVA	
71.6 MW		AVERAGE ELECTRICAL POWER	74.6 MW	
18,050 gpm		PEAK CIRCULATING COOLING WATER	87,468 gpm	
490 gpm		MAKE-UP WATER AVERAGE	854 gpm	
• Cooling Towers		MISC	• Cooling Ponds • 5-20 ton cranes (@ odd E-site Head Houses, 55'id shafts) • 10-5 ton cranes (@ E-site compressor bldgs) • 2-5 ton cranes (@ rf buildings)	

SSC Conventional Construction CDR vs. Current Requirements

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CDR		DESCRIPTION	CURRENT	
Parameter	WBS		Parameter	WBS
	2.3.5	TEST BEAMS		2.1.7
700' - 8'x 8'		TUNNEL	1,482' - 10' id 7,446 - 6' id	
6,020'-14"id (6 segments)		BEAM PIPES	861' -16"id (6 segments)	
8,820 sf (1)		TARGET HALL(S)	3,312 sf (3)	
19,950 sf		TEST/CALIBRATION HALL	29,920 sf	
1,350 sf (1 bldg)		UTILITY BLDGS	6,300 sf (10 bldgs)	
480 sf (2 enclosures)		ADDN'L MAGNET ENCLOSURES	17,476 sf (20 enclosures)	
14'/10'		SHIELDING COVERAGE/DEPTH	35'/~35'	
Included in HEB & MEB		INSTALLED ELECTRICAL POWER	33.4 MVA	
~5.0 MW		AVERAGE ELECTRICAL POWER	16.5 MW	
2035 gpm		PEAK CIRCULATING COOLING WATER	35,136 gpm	
47 gpm		MAKE-UP WATER AVERAGE	17 gpm	
Cooling Tower		MISC	Cooling Ponds	
2-30 ton cranes in Test Hall			1-50/5 ton crane in Calibration Hall	
			2-20/5 ton cranes in Calibration Hall	
			3-10 ton cranes in Target Halls	

SSC Conventional Construction CDR vs. Current Requirements

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CDR		DESCRIPTION	CURRENT	
Parameter	**WBS**		**Parameter**	**WBS**
	2.5	EXPERIMENTAL FACILITIES		2.2
4 - 6,002,000 cf (total)		COLLISION HALLS	4 - ~13,350,000 cf (total)	
(2 @ 1,459,000 cf)			(1 @ ~3,100,000 cf)	
(2 @ 1,542,000 cf)			(1 @ ~7,900,000 cf)	
			(1 @ ~1,150,000 cf)	
			(1 @ ~1,200,000 cf)	
228,800 sf - 8 bldgs		EXP. AREA BUILDINGS	330,330 sf - 19 bldgs	
*80,200 sf - 2 bldgs**		HEAVY WORKS/ASSEMBLY BUILDINGS *	129,730 sf - 6 bldgs	
18 MVA		INSTALLED ELECTRICAL POWER	64.2 MVA	
13.6 MW		AVERAGE ELECTRICAL POWER	52.90 MW	
5,400 gpm		PEAK CIRCULATING COOLING WATER	111,040 gpm	
490 gpm		MAKE-UP WATER AVERAGE	893 gpm	
		HALL CRANES	*5-100/100 ton cranes*	
			1-100/20 ton crane	
			2-50/20 ton cranes	
4-50 ton & 4-25 ton (1-50 ton & 1-25 ton in each of the 4 staging halls)		EXP. AREA BUILDING CRANES	5-30 ton cranes	
			4-100 ton cranes	
*4-30 ton cranes (2 @ each bldg) **		HVY WRKS/ASSMBLY BLDG CRANES *	3-30 ton cranes	
			2-100 ton cranes	
• Cooling Towers		MISC	• Cooling Towers & Cooling Ponds	

* from CDR 2.3 Campus - Heavy Works Buildings
Not included in CDR 2.5 Costs

SSC Conventional Construction CDR vs. Current Requirements

Final Draft 6/4/90 D. Earsom

CDR		DESCRIPTION	CURRENT	
Parameter	**WBS**		**Parameter**	**WBS**
	2.1	SITE & INFRASTRUCTURE		2.3
6,718 acres		AREAS	10,268 acres (w/out stratified fee estate)	
2,378 acres		WEST AREA	7,376 acres	
528 acres		EAST AREA	1,841 acres	
62 acres		E & F SERVICE AREAS	1,051 acres	
3,750 acres		COLLIDER RING/MONITORING STRT.S	6,390 acres (stratified fee estate)	
102 bldgs		BUILDINGS	124 bldgs	
1,130,960 sf		BUILDING SF	1,629,351 sf	
3,000 persons		OCCUPANCY	2,725 persons	
294.1 MVA		INSTALLED ELECTRICAL POWER	431.1 MVA	
117.3 MW		AVERAGE ELECTRICAL POWER	184.53 MW	
2,233 gpm		TOTAL MAKE-UP WATER	2,440 gpm	
37,535 gpm		TOTAL PEAK CIRCULATING WATER	260,708 gpm	
150,000 gpd Treatment Plant		SANITARY SEWAGE	230,000 gpd (no plant)	
2,000 gpm Treatment Plant		POTABLE WATER	170 gpm (no plant)	
6 tanks @ 300,000 gallons each		FIRE PROTECTION STORAGE	(use cooling ponds)	
4,000 lines		TELECOMMUNICATIONS	10,000 points	
55,000 mbh		PEAK HEATING	62;500 mbh	

SSC Conventional Construction CDR vs. Current Requirements

Final Draft 6/4/90 D. Earsom

CDR		DESCRIPTION	CURRENT	
Parameter	WBS		Parameter	WBS
	2.2	CAMPUS		2.4
675,000 sf - 20 bldgs		BUILDINGS	787,407 sf - 25 bldgs	
371,000 sf - 1 bldg		CENTRAL LAB/OFFICE	405,717 sf - 4 bldgs	
______ sf - 1000 seats		AUDITORIUM	15,000 sf - 1000 seats - 1 bldg	
161,000 sf - 6 bldgs		HEAVY WORKS	290,150 sf - 5 bldgs	
(2 x 40,100 sf)			(Magnet Test Lab - 60,000 sf)	
(4 x 20,200 sf)			(Magnet Development Lab -109,000 sf)	
			(Magnet Acceptance/Storage - 45,000 sf)	
			(Accelerator Shop - 70,650 sf)	
			(Pump House - 5,500 sf)	
30,100 sf - 3 bldgs		SHOPS	28,000 sf - 2 bldgs	
(Machine Shop - 11,550 sf)			(Weld/Machine Shop - 14,000 sf)	
(Carpenter/Sheet Metal Shop - 9,275 sf)			(Elect/Instr/Maint. Shop - 14,000 sf)	
(Piping/Cryo Shop - 9,275 sf)				
80,000 sf - 2 bldgs		WAREHOUSES	40,000 sf - 2 bldgs	
(General - 2 x 40,000 sf)			(Tech Services - 20,000 sf)	
			(Accelerator - 20,000 sf)	
32,900 sf - 8 bldgs		MISC/SUPPORT	9,040 sf - 11 bldgs	
(Emergency Facilities - 2 x 11,560 sf)			(Emergency Facilities - 2 x 4,250 sf)	
(Hose Tower - 360 sf)			(Env. Monitoring Stations - 9 x 60 sf)	
(Vehicle Services - 7,200 sf)				
(Water Treatment -840 sf)				
(Sewage Treatment - 580 sf)				
(Visitor Control - 2 x 400 sf)				
2,100 persons		OCCUPANCY	1,863 persons	
9.6 MVA		INSTALLED ELECTRICAL POWER	30.0 MVA	
5.0 MW		AVERAGE ELECTRICAL POWER	14.5 MW	
1000 gpm		PEAK CIRCULATING COOLING WATER	8520 gpm	
770 gpm		MAKE-UP WATER AVERAGE	588 gpm	

Several significant facilities have been deleted from the SCDR baseline design and reserved as future projects in an effort to contain the TPC of the project. These future facilities include several hazardous waste handling/storage buildings that will not be required until commissioning of the machine commences. The visitor's center will be postponed, although it is proposed to use an existing structure temporarily for this function. Several surface facilities, including warehouses and industrial buildings, as well as those facilities associated with the four future IRs, are also beyond the current baseline scope. A tunnel connection between the HEB and the test beam facility has been provided for as a future upgrade. And, most importantly, the diamond bypass tunnels at the east and west IR clusters are presently proposed as a future project.

Geotechnical aspects of the Texas site have a direct impact on the constructibility, schedule, and cost of the underground conventional facilities. Exploration of the site geology and characterization of various rock formations in which the SSC will be built appears to be proceeding in a well-organized and comprehensive manner. The subcommittee was favorably impressed with the level of detail with which geotechnical aspects have been evaluated as a basis for conceptual design and cost estimation. Some uncertainties exist with respect to in-situ rock performance, in particular, that of the Eagle Ford shale (EFS) will require additional investigation to help clarify its behavior as a foundation medium for the detectors and its response to deep excavation, especially at the bases of open cuts for experimental halls and the injection tunnels from the HEB to the collider.

The subcommittee recognizes that careful consideration has been given to EFS in establishing the SSC footprint. The overall project tradeoffs associated with varying the elevation and/or tilting the collider ring have been evaluated by SSCL management to arrive at the current site specific conceptual design. The subcommittee strongly recommends that continued interest in EFS should now be channeled to proper characterization of the medium, especially the use of instrumented field measurements during shaft and tunnel construction. From this standpoint, it seems prudent to reconsider the early construction of the LDD as an addition to the geotechnical exploration effort. Measurements of the response of in-situ EFS during the initial phases of construction will provide valuable input for design of the entire experimental hall structure, especially the foundations, and will provide valuable input to detector designers regarding provisions needed for adjustments to leveling of detectors after commissioning. Moreover, characterization of in-situ EFS behavior will provide crucial information regarding the potential foundation movements during and after detector construction.

It is important that the detectors be designed with due consideration of the geologic medium on and in which they will be founded. It will be advantageous to consider an optimal location for each detector which takes into account the properties of the rock formations and attempts to match detector design with geotechnical characteristics and prospective foundation performance. Close communication between detector designers and geotechnical engineers is crucial. The detector designer must recognize the potential for long-term foundation movement, especially in EFS and, with geotechnical support, develop a detector that can accommodate long-term displacement either by releveling or other appropriate means of adjustment.

10.8.3 Cost

Traditionally, large projects have been estimated on a square foot (generic) basis. The technical design proposed for the SSC, however, is based on one construction option for each feature. No attempts have been made to optimize the design by investigating various options, but a complete design has been costed. In most cases, common practices were utilized. For special cases, a constructible option was pursued. A contingency was assigned to allow for increases in actual costs over estimates.

10.8.3.1 Methodology

Cost estimates are based on roll up of designs more than sufficiently detailed for a conceptual level design. In some cases standard methods were chosen, while in other cases a constructible design was done in sufficient detail for estimating. Standard labor rates on national systems, such as Means Estimating, were used. In cases, where it was judged necessary, vendor quotes were obtained. For the case of the collider tunnel, independent estimates were prepared in the design and cross checked with a recent, local case history. This method produced an exceptionally good estimate for budgeting purposes, With sufficient contingency, this method is completely appropriate for budgeting purposes. Assurance that the schedule associated with this estimate is reasonable must continue to be a priority.

Some items appear to be missing from the estimate. Examples of such items are radiation shielding and refuge equipment. They are very low-cost items; however, their omission points out a need for an overview of the project to assure safety issues have been resolved.

Schedule and cost will be influenced by the contracting methods. Sufficient time must be allowed to bid and award contracts. In the contract documents, value engineering clauses should be used to assure that advantageous cost savings can be obtained from the contractor. An in-house value engineering program is also recommended. Additionally, the contracts awarded should be versatile enough to allow adjustments to the schedule. As an example, an optional-quantities clause in the initial one or two tunneling contracts may allow the initial contractors to continue with subsequent phases of the tunnelling should the schedule slip and not require tunnel contractors to be on the site simultaneously. The incentive to the initial bidders for large lengths of tunnel will produce lower unit costs and encourage use of new equipment. Lower construction costs will result; less management will be required; and the overall project will benefit.

10.8.3.2 Underground

The major cost component of the underground construction is the tunnelling for the main collider, the supporting shafts, and the short areas off the tunnel referred to as niches. The construction time for these features was estimated, as were the labor costs, mechanical, and electrical components. Because of the importance of the collider, the SSCL commissioned two independent estimates covering all items. The first was performed by the engineering subcontractor, Raymond/Tudor/Knight (RTK). The second was by a consulting firm, Lachal/Piepenberg & Associates (LPA). One case history from a recent job (Govalle Project) in the same Austin chalk and Taylor Marl was also studied with unit costs adjusted to the same size tunnel with similar support. These estimates are summarized in Table 10.8.6. The subcommittee also examined data for other machine-bored tunnels for which it had information. Table 10.8.7 lists the characteristics, advance rates, and cost information associated with the additional tunnels that were considered.

Table 10.8.6

Cost Per Linear Foot of Tunnel Construction

Source	Unit Price ($/ft)	% Difference [(X-920)/920]
RTK Estimate	1153	25.3
RTK Estimate Adjusted to Govalle Project	1141	24.0
U.S. Bureau of Reclamation Data - Soft Shale	1041	13.1
LPA Estimate Adjusted to Govalle Project	1027	11.6
LPA Estimate	920	0.0

Table 10.8.7

Machine Bored Tunnels

Source: Tunnels: Machine Excavation – Rate of Progress – Machine Date
U.S. Bureau of Reclamation

Project	Date	Diameter	Unconfined Comp. Strength (psi)	Rock	Length (feet)	Contract $	Average Advance Working Day – feet		$/Foot	$1/foot - FY90$ (1)
Azotes Tunnel – MN*	1965–1967	10' 11" *	1400-6000	Shale *	67010	13791000	155ft–Shale only		205	775*
Blanco Tunnel – MN*	1965-1967	8' 7" *	4000-6000	Shale *	45576	9188752	154		201	806*
Buckskin Tunnel – AZ	1976-1979	22'	1100–5000 (2)	???	35721	53483355	49ft	(3 shifts)	1489	2963
Current Tunnel – UT	1972	12' 4"	38000	Conglomerate	8935	3223243	133.4		353	999
Mades & Rhodes - UT	1980-1981	10' 8"	4000–30000	Sandstone	26259	34833948	86	(3 shifts)	1326	2215
Layout Tunnel – UT	1971–1972	12' 11"	to 38000	Shale *	17261	6126315	114	(3 shifts)	353	1059
Oso – CO	1966–1967	10' 7"	6000	Shale	24536	5301816	98.56 (3)		216	816
River Mountains – NV	1968–1969	12'	to 16700	Rhyditle	9933	3572128	108		179	639
Santa Clara – CA	1981–1982	9' 8"	1750–15200	Shale	5066	7738897	70	(3 shifts)	1527	2412
Starvation – UT	1967	9' 6"	?	Shale	5345	870065	64.4	(2 shifts)	162	612
Stillwater – UT*	1977–1984	10' 3" *	2600–12850	Shale *	47000	41000900	189	(3 shifts)	872	1543*
Tunnel 1–Navajo – MN	1965–1966	20' 6" *	4000-6000	Sandstone	9979	3257960	51.5		326	1385
Tunnel 3&3A Navajo	1971–1973	20' 6"	2100-6000	Sandstone	15198	8957553	52.4 (3)	(3 shifts)	589	1666
Tunnel 5 Navajo	*–1976*	13'	?	Sandstone	7437	3697380	84.5	(2 shifts)	497	1113
VAT – UT	1976–1981	8' 3"	1857–8260	Sandstone	38768	51107787	50		1318	2477
Water Hollow – UT	1968–1970	8' 3"		Sandstone	21043	5236142	96	(3 shifts)	248	835
SLAC – CA (4)	1982				18735	14000000			747	1180
					403,794				Avg. =	1,382

(1) – Assuming 6% inflation – per year
(2) – Predominantly: Also higher strengths
(3) – Estimated from calendar day progress
(4) – Personal communication at Review Conference Accelerator Tunnel; not from source above
* – Discussion in text; all shale; all lower strength; diameter similar

Road Header

Project	Date	Diameter	Unconfined Comp. Strength (psi)	Rock	Length (feet)	Contract $	Average Advance Working Day – feet	$/Foot	$1/foot - FY90$ (1)
Delores Tunnel – CO	1982-1983	11'	4770–11000	Sandstone	6732.5	4860002	35	721	1075
Strawberry – UT	1981-1982	10' 9"	11000–14000	Shale	2310	50459770	12.8 (5)	2184	3458
								Avg. =	2,263

(5) – Connecting Tunnel

The cost per linear foot is the highest in the RTK estimate. However, this estimate does not appear to be excessive and is believed to be acceptable. It is noted that the Govalle Project and the Bureau of Reclamation (BOR) data represent projects mobilized from the ground surface. Because the SSC tunnel starts below ground, higher costs may be expected. Also tabulated for convenience in Table 10.8.7 are road-header data. The high cost per foot of this method of construction, which will be used in the niches, suggests the need to increase the costs based on BOR experience to a higher value more typical of the RTK estimate.

The current contingency the underground construction is 20 percent. The difference of 25 percent between the two prepared estimates demonstrates the potential for variation. Considering the preliminary nature of the design, it is believed that a contingency of 25 percent is appropriate to account for (1) potential design changes, (2) potential variations in costs of construction such as in long tunnels, and (3) unknowns in geology due to currently incomplete geotechnical data. Many contracts allow +/- 25 percent of the engineer's estimate as tolerance. The subcommittee recognizes that the cost estimate is based on considerable data, but suggests that the project will likely need a 25 percent tolerance in the estimates of costs.

The large underground experimental halls require containment of exceptionally massive structures, the largest being 60,000 tons, and require wide spans underground. Although the halls are underground, the current plan is to construct the halls using cut-and-fill techniques. Design of these structures needs to give special consideration to the construction technique and needs to take advantage of open-pit construction as much as possible to implement special design features. The costs estimate for these unusual structures, which will require extraordinary designs and construction, must take account of difficult foundation conditions. The subcommittee has raised the current contingency estimates to 30 percent to alleviate cost pressures; design costs have also been increased to account for the non-traditional designs.

10.8.3.3 Surface

The surface structures contain both unusual, specialized structures, as well as more standard buildings. The current designs and cost estimates of ordinary office buildings represent an excellent costing effort to a feasibility-level design. In contrast, the large specialty buildings are currently costed using footprints and very preliminary estimates of building sizes. Much more detailed design is required to assure adequate space for all technical support equipment. Some contingency has been added to account for this latter point.

No estimates were mentioned for monitoring surface or underground effects, such as subsidence, ground-water drawdown, and contamination. Considerable attention will be given to such topics and a cost estimate needs to be generated for them.

10.8.3.4 General

Many of the general costs associated with labor have been estimated using Davis-Bacon labor rates. There is general agreement within the full ERC that some of the rates appear low. In some cases, estimates lowered Means Estimating data to produce costs. This may make cost estimates less conservative than they actually appear based on the level of detail.

In the discussion of burdened rates for laboratory staff, the basis for the direct labor multiplier is unclear. Direct costs, such as consumable supplies, equipment, consultants, travel, and relocation expenses, are mentioned but not quantified. Fringe benefits of 45 percent are also included for vacation, holidays, sick leave, other leave, payroll taxes and insurance. The full direct laboratory multiplier needs to include costs for travel, specialized training, unusual equipment and tooling needs, and other items associated with a new state-of-the-art facility. The hourly burdened rates may be low for a project of this type, which will affect the cost estimates when the rates are multiplied by hours worked.

10.8.3.5 Funding, Staffing Profile

Staff on-board for the project does not seem sufficient for the current needs. As discussed in the management section, the lead time for staffing needs to be considered. Conversely, it is imperative that staff not be brought into the project prematurely. Obviously, if staff is employed too early, their salary must by integrated over the time in which they are employed. The staffing needed is closely linked to the activities ongoing at any one time. Thus, it is imperative to have an accurate schedule in order to construct necessary staffing.

Based on the current schedule, the SSCL staffing for the CCD appears low. Because much of the work both in services (design and construction management) and construction is to be by contractors, only a minimum level of on-board staff is required. The functional cluster of the staff in the SSCL organization needs to be reevaluated in view of the complexity of the project which requires interfacing with TNRLC, AE/CM, and technical divisions within SSCL. Based on current industry experience and considering the technical complexity of this project, the subcommittee believes the contractor percent of the total construction schedule to be too low. This funding was raised to 9 percent and 7 percent for the A/E and C/M, respectively.

It is unclear whether or not a significant percentage (e.g., 10-20 percent) of the general staff time will be devoted to requirements placed on the project, such as preparing status reports, configuration change reports, and quality assurance documents. If this should be the case, additional staff time is required beyond what typical estimating practices would predict.

10.8.4 Schedule

The schedules represent the planning-to-date on the point design described in the scope presentation.

The proposed project construction schedule appears optimistic. Key potential constraints are the stated funding profile and the time frames for magnet delivery and procurement. The availability of tunnel-boring machines and long-lead procurement items (e.g., transformers and switch gear) could seriously impact the early stages of the project. Also, the finalization of conceptual designs for technical systems (e.g., detectors) and the successful testing of the industrially assembled magnets are required for the timely start of major portions of the conventional construction activities.

The detail presented in both the underground-construction and the component-installation schedules was noteworthy. The logic planning in the collider component installation presentation was thorough and detailed to a high degree.

The subcommittee feels that the near-term construction schedule will be difficult to achieve. For example, the PIF currently is planned as a two-phase operation, with the first phase scheduled for start of design in May 1990 and start of construction in January 1991. The second phase is scheduled with similar assumptions for a January 1991 design start and a May 1991 construction start. Given that the AE/CM is not yet aboard and considering the constraints of the procurement approval process, it is unlikely that such a schedule can be met. Moreover, the schedule calls for the AE/CM to begin design in May 1990, a date that has passed.

The schedule currently calls for the simultaneous or near simultaneous construction of 11 tunnel segments, including eight collider segments, HEB, MEB, and Test Beams. Construction on such a large scale should be evaluated in the context of a national demand for tunneling during the same time periods. The potential effects of this demand with respect to available tunnel-boring machines, contractor expertise, and bid prices should be considered. Changes should be made to conventional facilities schedules as other portions of the overall schedule, such as magnet procurement, are developed.

Improvement is recommended in several areas of the schedule. A summary integrated schedule showing the critical path, activity durations, float, and constraints for the major subsystems is needed to make management assessments of planning issues pertaining to the overall project. Activity planning and integration is needed for the detectors with the experimental halls, collider dipole magnet production with collider-component installation, and land acquisition with conventional facilities. A criterion for the identification of key control milestones that account for costs and schedule criticality is also needed.

Careful consideration, should be given to optimizing preconstruction activities and to the scheduling of activities during the first year of construction. The SSCL's proposal for starting the first tunneling in EFS (PIF activity) is endorsed by the subcommittee. The EFS material is the most difficult to excavate, and the first tunneling will provide valuable information that can be applied to subsequent underground design and construction.

The construction schedule depends on the ROD for the SEIS, which is needed to establish a starting date from which construction can proceed. Accordingly, any delay in the ROD has an immediate and important effect on schedule and cost. The immediate consequences of ROD delay is postponement of construction of the PIF. The long-term consequences can be significant, eventually affecting starting times for collider tunnel segments and experimental halls. It is imperative, therefore, that every effort be made to facilitate a decision on the SEIS and for the appropriate governmental agencies to be aware of the ramification of ROD delay.

10.8.5 Management Aspects

The subcommittee felt that the management applied to the project and specifically the management approach of preparing estimates was exceptional. The contractor has taken a sound approach of basing the conceptual design cost estimate on take offs rather than the conventional method of basing the cost on the number of sq ft. Additionally, the project organization takes a tiered approach with DOE oversight of the CCM, CCM management of the AE/CM, AE/CM QA/QL of the constructor, and construction by the low bidder. This approach has been well tested by use on other large projects and is expected to be successful here. A schedule based on the schedule expected for experimental facilities has been developed and some configuration project management (CPM) schedules have been developed for critical construction activities. There is a good working relationship between the contractor and TNRLC. The subcommittee did, however, have management concerns in the areas of schedules, staffing, internal organization, AE/CM mobilization, the degree to which systems engineering activities have been implemented, and the coordination of requirements between the contractor and TNRLC.

Although schedules exist as indicated above and further explained in other parts of this report, the subcommittee is concerned that an overall integrated CPM-type schedule does not exist. Additionally, the conventional facilities schedules are optimistic, especially in the first year and may overload the construction industry's ability to respond. The subcommittee notes that the first final-design start date has already been missed and the contractor is already playing catch-up. Concern was expressed by the subcommittee that the initial award of large tunneling contracts did not allow adequate time for DOE approval and that the extraordinary methods required to obtain this approval have not been identified.

Although the contract has been awarded and work underway for approximately 17 months, the SSCL CCD is not fully staffed with permanent employees. This was of particular concern regarding the chief position that is filled with an acting employee who is scheduled to resume other duties by the end of the summer. This is considered to be a critical time in the schedule, and the subcommittee believes that filling this key position on a permanent basis is absolutely necessary to ensure success.

The subcommittee feels that, because of the delay in bringing the AE/CM aboard, the SSC CCD staff has spent too much time performing AE/CM functions (i.e., designing, scheduling, and cost estimating). This activity has moved the detailed work but has diluted the effort toward establishing of long-range management plans, organization, and staffing directed toward carrying out overall managerial responsibilities of the CCD and the SSCL. The CCD should function as a client directing and monitoring a major, complex construction project under difficult conditions with tight schedules and budgets rather than performing engineering and construction management activities. Staff requirements will call for different skills and abilities than have been employed. Coordinators and facilitators will be needed to bridge between SSCL technical divisions and the AE/CM and other engineering and construction contractors. A management philosophy needs to be established that would require the CCD to formulate tasks, assign them to the appropriate contractor (usually the AE/CM) together with assignment of responsibility and commensurate authority to perform, monitor performance, and provide assistance in resolving road blocks and problems.

A CCD staffing plan, including an organization chart and job descriptions or responsibilities, lines of authority and reporting channels should be developed as well as planned dates for filling jobs (e.g., construction supervisors later than design managers). Organization and staffing should be made flexible to meet changing developments. In view of the known lead time for recruiting employees, actions should be taken as soon as possible to establish and define the positions and to undertake recruiting and employment activities.

That the AE/CM is not on board at this critical time is affecting the CCD's and, therefore, the SSCL's ability to perform long-range planning, organization, and staffing as well as near-term and immediate problem identification and resolution. Action at both DOE and SSCL levels should be speeded up to complete contract negotiations and allow the full utilization of the AE/CM capabilities and resources at the earliest date possible. This would permit the phase-out of people and contractors who have been doing piece-meal tasks of design, costing, and scheduling that the AE/CM should be doing in an overall, comprehensive, coordinated and long-range manner. The bottom-line concern is that delayed design results in delayed or expedited construction, which may produce missed schedules or increased costs or both.

Systems-engineering activities, such as configuration management and data management, are planned but have not been implemented in the conventional-facility program at this time. The subcommittee feels that the requirement documents that have been developed need to be finalized to document facilities requirements for support of technical systems needs. These data then need to be placed under configuration control, so that facilities budgets and schedules can be managed and proper tradeoffs between facility and technical needs can be accomplished.

Both the contractor and TNRLC are performing infrastructure and real estate activities that must be well defined and coordinated. For example, land acquisition must be accomplished in a manner that allows facility construction to proceed in a timely manner for support of technical systems needs. The subcommittee recommends that these activities be scheduled, identified, quantified, and integrated with facility construction in such a way that both parties understand and perform assigned tasks and nothing falls through the cracks. These interfaces must be documented and changes managed by the DOE SSC project office (OSSC). At this time, the OSSC may not be adequately staffed to fulfill this requirement and must place high priority on this activity.

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10.9 Management, Cost, Schedule, and Funding Summary

10.9.1 Summary, Conclusions, and Recommendations

Management issues at the upper organizational levels were the primary focus of the review by the Subcommittee on Management, Cost, Schedule, and Funding. In particular, the subcommittee assessed:

- The readiness of the SSCL to manage the project as presented.
- The overall completeness of the cost estimate with particular emphasis on WBS 4.0, Project Management, and WBS 6.0, Laboratory Operations Support; and
- The master schedule for overall compatibility.

This project represents a unique Department of Energy endeavor to establish a large new national laboratory at a green-field site. The SSCL organization thus must reflect an R&D planning, design, construction, and commissioning capability with a continuous buildup to allow operations of the Laboratory following commissioning. To this end, the relationships of the SSCL organizational divisions were assessed including responsibilities, staffing, interface, supervision, WBS responsibilities, and authority. Particular emphasis was placed on assessing the management responsibilities of the directorate and the project manager's organization. A significant amount of time was also dedicated to assessing the systems engineering function and the configuration management function within the SSCL. The specific, detailed presentation of the Accelerator Systems Division's role within the SSCL served to identify the organizational requirements and interfaces that must exist throughout in order for the Laboratory to successfully accomplish its activities.

The subcommittee met with SSCL management and reviewed the following documentation and issues:

- Cost Estimate Report (Project Management WBS 4.0 to Level 4; Laboratory Operations Support WBS 6.0 to Level 4).
- Schedule Planning.
- Funding Profile and Escalation Strategy with Options.
- Project Management Plan (PMP) and SSCL Management Issues.
- Contingency Planning.

- Configuration Management Plan.
  - Project Requirements Notebooks.
- Systems Engineering Management Plan.
- Site-Specific Conceptual Design Report.
- Procurement Issues.
- Engineering Standards.
- Document Control.
- SSCL Project Manager Recruitment Status.
- Project Manpower Roll-ups.
- Accelerator EDI and Preoperations.
- 1986 Conceptual Design Comparisons.
- DOE Organization and Interactions.

Management functions were described in summary presentations and supported by detailed presentations by the acting Project Manager, the Technical Director and each of the Associate Directors. Each of these presenters described the structure of his individual organization, the areas of responsibility assigned to it, and its manpower and budget requirements.

Presentations by approximately 150 SSCL personnel to all the subcommittees during the course of the review indicate the development of substantial technical and managerial depth within the Laboratory. Continued development of the chain-of-command is mandatory to ensure that decisions are made at the lowest appropriate level.

Cost of the project was presented to this subcommittee at the summary WBS level and selectively examined in detail to a lower appropriate level. The subcommittee assessed the integrated roll-up of the individual WBS cost elements, contingency allocation, Davis-Bacon considerations, a baseline funding profile (and several alternative profiles) and escalation application. Specific assessment was made of the estimate of the cost for WBS 4.0, Project Management, and 6.0, Laboratory Operations Support. This subcommittee relied on the other subcommittees to assess the technical, cost, and schedule for other WBS categories at the level required.

The master schedule for the project was presented and the logic incorporated in this schedule was explained in detail. The development of this schedule and its buildup based on input from the divisions was explained. The subcommittee assessed the general completeness of the schedule, durations, the critical activities, and major milestones.

A key question is: can the organization, as described, complete the project on the schedule and within the budget requested? The subcommittee believes that both of these objectives can be accomplished, but only in an environment where there is a smooth working relationship between the key players. Successful recruitment of a competent staff of accelerator physicists who are given the required responsibility and authority to perform as system leaders for the various accelerators making up the injector must also occur.

Recommendations

The subcommittee made the following recommendations, which are developed further in the remainder of this report:

1. The SSCL key personnel such as the Project Manager, the Procurement Officer, the Conventional Construction Manager, and the Accelerator System Manager should be selected as soon as possible.

2. The DOE-OPO organization also needs to be permanently in-place as soon as possible. It is vital that all required contractual/regulatory authority is available to the DOE-OPO in order to accomplish contractual actions in a timely fashion.

3. To limit administrative delays, the management system should include a time limitation for approvals by all involved parties.

4. The official validation of a procurement system and procedures by DOE must be pursued expeditiously so that required levels of procurement authority can be delegated to the Laboratory.

5. An agreement with the TNRLC to address use of its funds and the management relationships among the TNRLC, DOE, and SSCL is needed and should be part of the PMP.

6. Further schedule/funding profile analysis is required to assess sensitive interfaces, possible reductions in the completion dates for the alternate schedules, and to identify the critical path. Provide additional early milestones for tracking.

7. The subcommittee recommends expeditious implementation of document control systems in all areas, and recommends that the requirements be passed down to subcontractors.

8. The process of tracking the milestones and related activities must begin immediately—even prior to actual baseline approval.

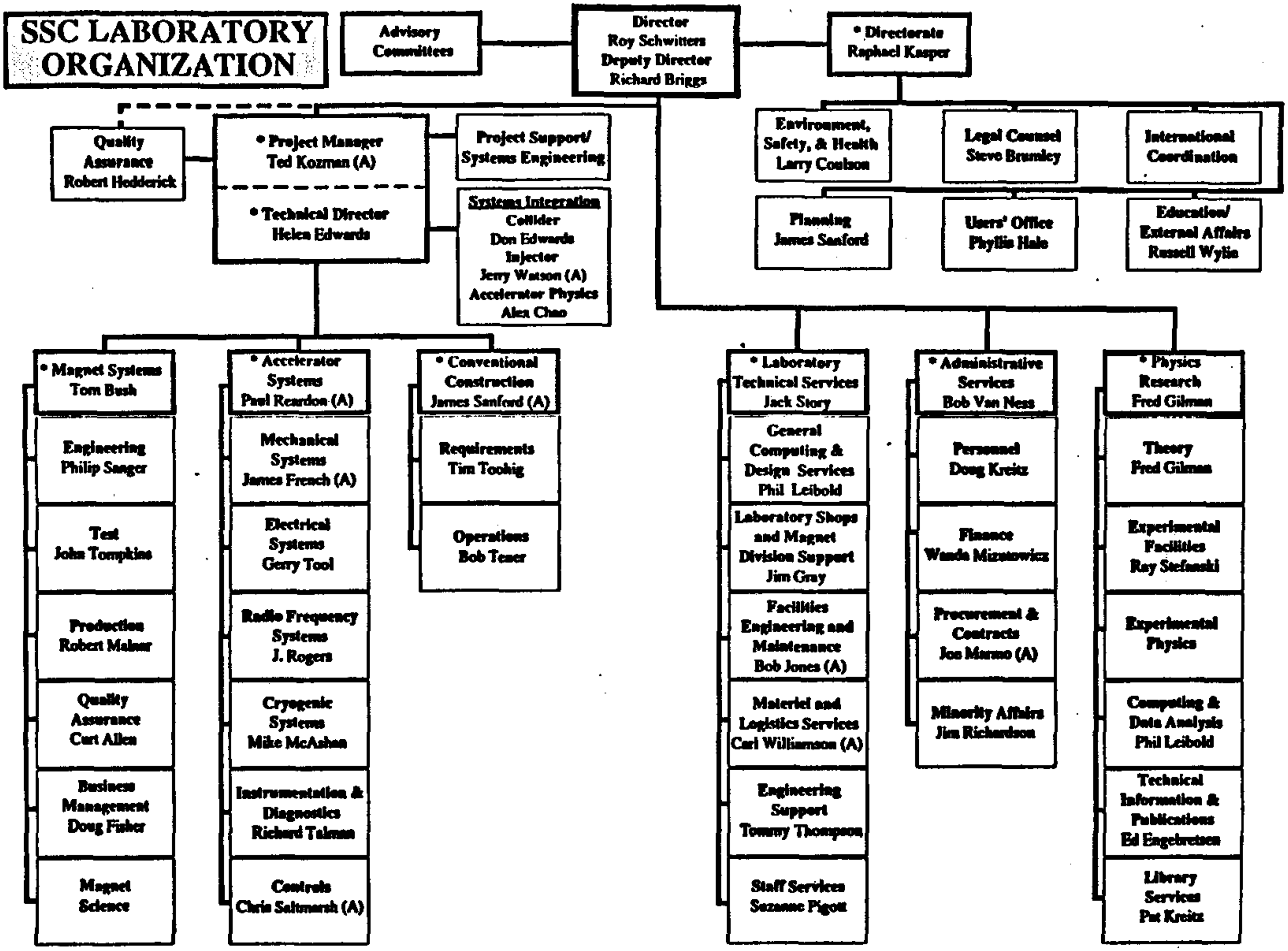
9. The WBS needs to be optimized to ensure a self-consistent approach.

10. The magnitude of the costs for administering a major international program should be assessed.

11. The SCDR must be finalized as a fully consistent document.

10.9.2 Management

The organization of the SSCL is shown in Fig. 10.9.2-1. The organizational concepts presented to this subcommittee for both the SSCL and the DOE Office of the SSC, particularly the DOE-OPO, are deemed appropriate to accomplish project goals. It is, however, important, especially in the Project Manager/Technical Director area, that a continuous dialogue and participative management style be initiated and expanded between personnel in the magnet systems, accelerator systems, conventional construction, project support/systems engineering, and systems integration groups. Each of the SSC players brings his own culture (motivators, organizational structures, working methods,



** Laboratory Associate Director*
(A) = Acting

June 21, 1990
SSCL

Fig. 10.9.2-1

techniques, communications, etc.) to the SSC project. This can make it a stronger and better project, but each player must learn to value and work effectively with professional styles different from his or her own style. Communications are perceived to be on-track to meet present organizational goals but must be improved as design evolves and the rate of decision-making increases. The achievement of technical goals consistent with project management objectives are dependent, in this type of environment, on a clear definition of individual and organizational roles and responsibilities expressed from SSCL top management. This requires that SSCL key personnel such as the Project Manager; the Procurement Officer; the Conventional Construction Manager; and the Accelerator Systems Manager be selected as soon as possible.

The evolution of the Accelerator Systems Division is commendable as an example of good management maturity. The planning for their activities is thorough and the planned staffing levels and budgets were well defined with their responsibilities.

The DOE-OPO organization also needs to be permanently in-place as soon as possible. The staffing levels and technical disciplines proposed appear to be adequate to accomplish its mission. It is vital that contractual/regulatory authority is available to the DOE-OPO in order to accomplish contractual actions in a timely fashion. The magnitude of that authority should be the maximum necessary for a project of this magnitude and complexity. This will contribute to effective on-site project management and minimize delay in processing contract documentation necessary to meet the project milestones. The DOE-OPO procurement authority will be an essential element in the potential success of the project. Augmentation of the DOE-OPO staff with technical consultants on an as-needed basis can also strengthen this office's ability to cope with the multitude of contractual, quality assurance, construction, and contract administration issues in the future. This organization must have a broad interdisciplinary mix. This mix will contribute to the office's ability to resolve R&D, EDI, construction, commissioning, contractual, and cost/schedule issues for maintaining project baselines for technical, schedule, and cost activities. It is also important that the position of Director of the Office of SSC in DOE headquarters be filled as soon as possible.

The SSCL and DOE have been working closely together to develop a Project Management Plan (PMP) for design and construction of the baseline design. The draft plan has progressed through six revisions and is a sound basis for finalization. Since the manager of DOE-OPO has only been on-site for approximately 30 days, it was best to delay finalization of the PMP until necessary input from the DOE-OPO could be obtained. This would permit an acceptance of the PMP by all key project personnel.

The incorporation of an agreement with the TNRLC to address use of its funds and management relationship with SSCL is needed and should be part of the PMP. Since the PMP is a living document, future revisions will be necessary as project status and situations dictate. The PMP in its present form permits this necessary flexibility.

To limit administrative delays, the management system should include a time limitation for approvals by all involved parties. Short administrative channels require less time, thereby enhancing the probability of meeting schedule milestones. Advance notices are necessary to eliminate surprises and to keep all parties within agreed upon time limits for decision making.

Systems engineering and configuration management practices have been instituted in the project's structure. These functions are being adapted to SSCL needs and will contribute to the project's success. Systems engineering personnel have been integrated into technical divisions in advisory roles. This is proving to be successful in developing technical baselines and cost/schedule control documentation. The Systems Engineering Management Plan developed to define this process will be formally approved in the near future after organizational consensus is reached. The priority goals of systems engineering established by SSCL are the establishment of:

- A technical, cost, and schedule baseline
- A configuration management system
- Interface Controls
- Engineering standards
- An availability program
- A risk analysis and technical performance measurement system
- A safety system plan
- Software development processes
- Test plans and procedures

Personnel are committed to meet these goals during the course of the project's life.

The established configuration management system will formally document any changes to project baselines. Proper approval levels for changes exist within this system. It may be beneficial for the Project Manager and Technical Director to co-chair the Configuration Control Board (CCB) to further ensure technical input in the change process.

Consideration and action on changes will be gained through consensus of technical, cost, schedule, and scientific factors prior to final approval or disapproval. The composition of the CCB ensures proper change control. This subcommittee recommends that the CCB include the following members:

- Project Manager/Technical Director—co-chairpersons
- Deputy Project Manager
- Associate Directors
- Systems Engineer Head
- Configuration Manager
- Designated technical or support representatives as required

In order to make the change control process most effective, management should continue to project an attitude of "no change" unless absolutely required for cost or schedule savings or for the facility to function as described in the technical baseline.

10.9.3 Cost Estimate

The current cost estimate prepared by the SSCL staff was made using the site-specific baseline conceptual design. It was apparent that a substantial amount of detail estimate work has occurred subsequent to January 1990 review. The cost estimate presentations by the SSCL staff were excellent. Estimates were based on in depth information using work break down (WBS) packages to Levels 6 to 8. The WBS showed various inconsistencies and needs to be optimized to ensure a self-consistent approach. One particular problem is the rollup of all EDIA for a Level 2 WBS item as a single Level 3 account. This makes it difficult to determine the total cost of a subsystem or component. Furthermore, it appeared that the lowest level activity managers did not know what their allocation of EDIA and systems management support was. Several estimating methodologies were used for the different packages as described in Table 10.9.3-1. Labor rates used in estimating were those of SSCL employees, averages of industrial rates and Davis-Bacon wages for construction crafts.

Cost saving schemes must be investigated.

Table 10.9.3-1

SSC Technical System Cost Estimate Basis

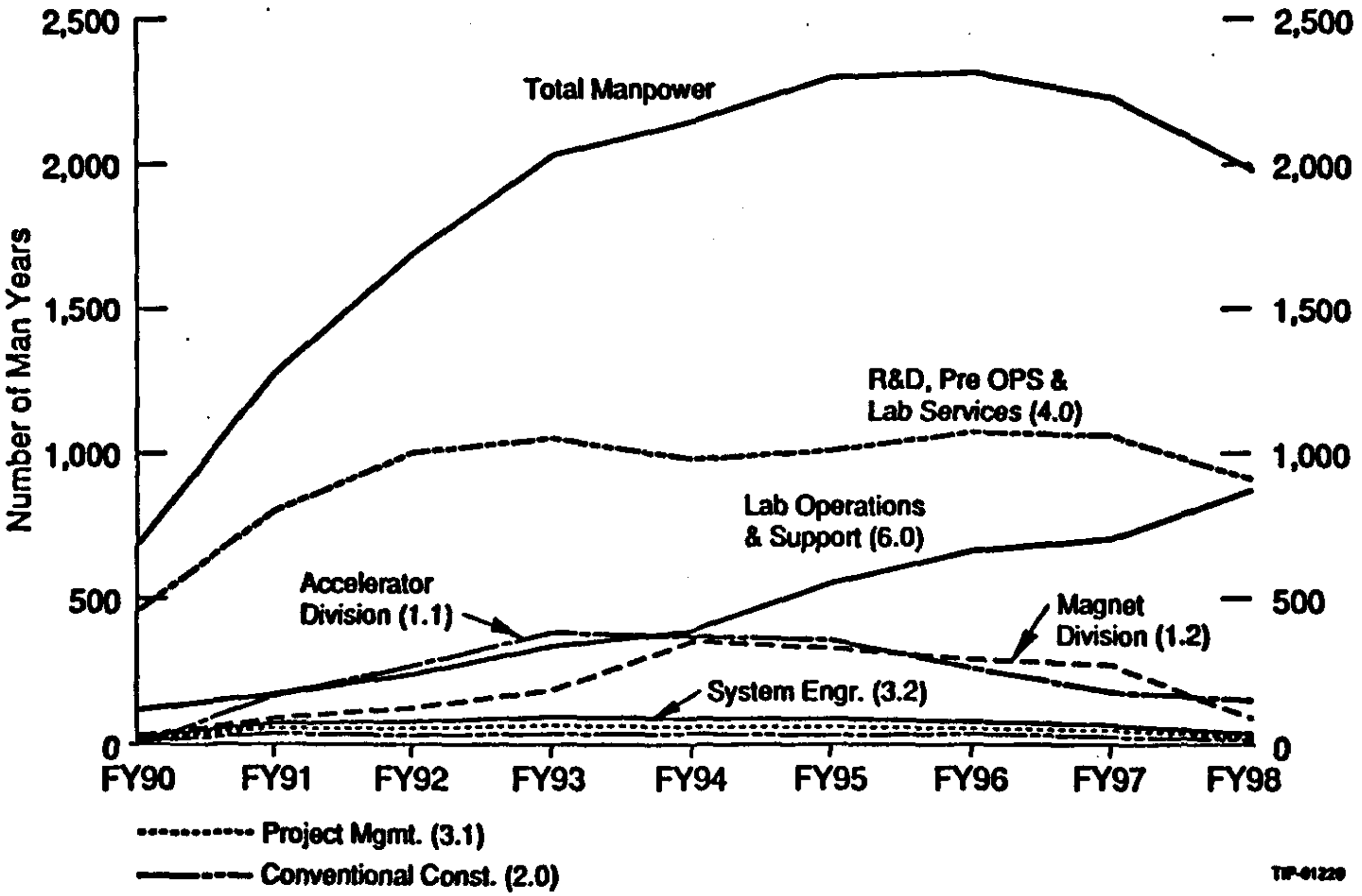
Source of Estimate	% of Estimate
Actual Costs	0
Catalog Prices	2
Vendor Estimates	25
Eng. Est. Based Upon Vendor/Lab Est.	28
Eng. Est. Based Upon Experience	45

Does not include SSCL labor (18%) and contingency (19%)

SSCL staff assessment of cost and technical risk for each WBS was used as the basis for the Contingency Analysis Report. Escalation is based on DOE and OMB recommended rates to the middle of the fiscal year for contract award.

The Site-Specific Conceptual Design and estimates are the results of in-depth study by the SSCL administrative, management, and technical personnel. This combined design effort and estimating methodology has produced a credible estimate against which the subcommittee could assess risk at this point in the project.

The manpower projections for the SSCL for the years FY 1990 through FY 1998 are shown in Fig. 10.9.3-1. The buildup is credible.



SSCL Manpower Analysis
FTEs in Primary WBS Elements
Reflects Manpower in Baseline Cost Estimate

Fig. 10.9.3-1

Table 10.9.3-2

Summary of Contingency Analysis

Overall Contingency = 18.4% Of TEC

Accelerator Systems	17.6% Allocated
Magnet Systems	19.3% Allocated
Conventional Systems	17.9% Allocated
Maximum Contingency	24.1% - Collider Instrumentation
Minimum Contingency	6.0% - Linac Vacuum System

Sensitivity Analysis Performed; shown in Contingency Plan

Contingency for the project has been assigned to all subcategories of the cost estimate based on SSCL assessments of risks. A summary of the contingency analysis is contained in Table 10.9.3-2. In some cases the subcommittee has recommended allocation of different contingency levels from the SSCL staff.

No additional costs for administering a major international program were included. The magnitude of such a program should be assessed.

No provision has been made for funding spare parts for the project. However, the Laboratory administration is aware of this and will prepare the appropriate budget request for transmittal to the DOE for disposition.

10.9.4 Procurement Issues

Planned SSCL procurement systems were well described by the SSCL. The official validation of a procurement system and procedures by DOE must be pursued expeditiously so that some levels of procurement authority can be delegated to the Laboratory. Meanwhile it is imperative that local procurement authority be established within the DOE/OPO. It is the subcommittee's understanding that the DOE/OPO will soon have such authority.

The subcommittee strongly recommends that the position of SSCL head of procurement and contracts should be filled with a permanent individual as soon as possible.

Planning for minority procurement, make-buy decisions and Davis-Bacon decisions, etc., is being developed and is consistent with this stage of the Laboratory development.

10.9.5 Engineering Standards

The adoption of engineering standards is in progress. All of the presentations on these matters were reasonable, however, the subcommittee is concerned that adopting the metric system for technical components will add substantially to the project cost. The SSCL estimated cost increase of 3 percent of technical components is sufficient to warrant a re-examination of this decision in conjunction with the DOE.

For economy and efficiency of operation, the subcommittee recommends that standardization of electrical and mechanical components and procedures should be considered at an early time.

10.9.6 Document Control

Presentations by the SSCL of plans for document identification and control were thorough and complete. The subcommittee recommends expeditious implementation of these systems in all areas, and recommends that the requirements be passed down to subcontractors.

10.9.7 Schedule and Funding Profile

Fig. 10.9.7-1 shows the proposed project summary schedule for the construction of the SSC. The SSCL has developed a schedule with supporting logic that justifies a nine-year program. The schedule incorporates the R&D program, manpower loading, and contract projection in a consistent manner. The schedule is very aggressive and depends on early initiation and completion of critical milestones. It has several activities (magnets, tunneling, injector) near the critical path. The scheduling database contains both the R&D

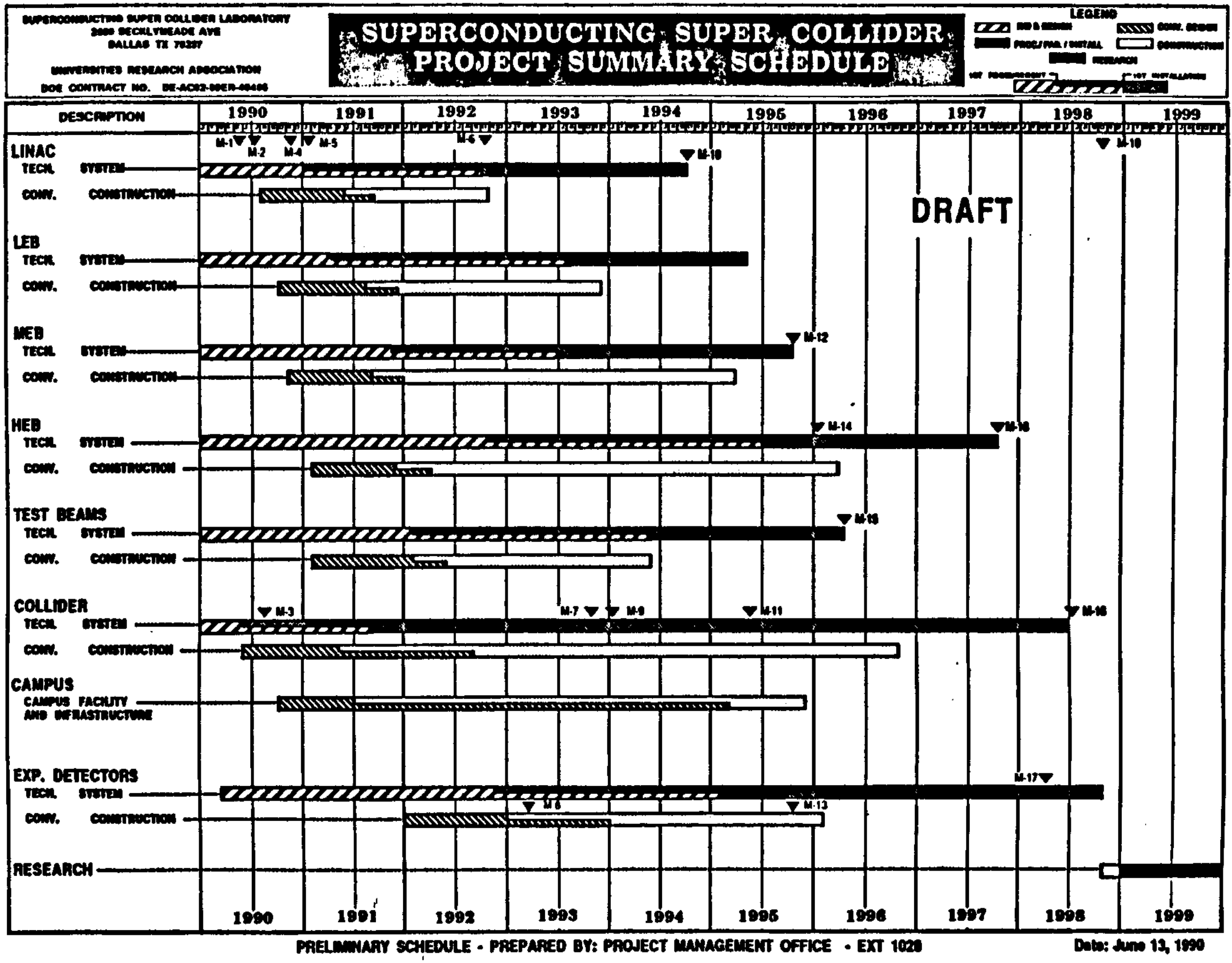

SUPERCONDUCTING SUPER COLLIDER LABORATORY
2550 BECKLEYMEADE AVE
DALLAS TX 75237
UNIVERSITIES RESEARCH ASSOCIATION
DOE CONTRACT NO. DE-AC02-89ER-40486
SUPERCONDUCTING SUPER COLLIDER
PROJECT SUMMARY SCHEDULE
LEGEND
CONV. DESIGN
PROC./FAB./INSTALL
CONSTRUCTION
RESEARCH
DESCRIPTION
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
LINAC
TECH. SYSTEM
CONV. CONSTRUCTION
M-1
M-2
M-4
M-5
M-6
M-10
M-19
DRAFT
LEB
TECH. SYSTEM
CONV. CONSTRUCTION
MEB
TECH. SYSTEM
CONV. CONSTRUCTION
M-12
HEB
TECH. SYSTEM
CONV. CONSTRUCTION
M-14
M-16
TEST BEAMS
TECH. SYSTEM
CONV. CONSTRUCTION
M-15
COLLIDER
TECH. SYSTEM
CONV. CONSTRUCTION
M-3
M-7
M-9
M-11
M-18
CAMPUS
CAMPUS FACILITY AND INFRASTRUCTURE
EXP. DETECTORS
TECH. SYSTEM
CONV. CONSTRUCTION
M-17
M-8
M-13
RESEARCH
PRELIMINARY SCHEDULE - PREPARED BY: PROJECT MANAGEMENT OFFICE - EXT 1028
Date: June 13, 1990

Fig. 10.9.7-1

and the construction program, thereby giving the SSCL added ability to explore options. A baseline funding profile and several alternative cases were developed that are consistent with the schedule. The SSCL has done a credible job of developing the analytic tools necessary to allow it to examine cases other than the baseline, and to assess the schedule changes and associated cost increases. This analysis of cost impacts due to schedule changes and funding profile changes emphasizes the need to meet the early milestones. This analysis also shows the critical nature of the sharp funding increase required in FY 1992 to meet the baseline schedule. Further schedule/profile analysis is required to assess the completion dates for the alternate schedules.

The SSCL has developed a set of key milestones (shown on Fig. 10.9.7-1) consistent with the project schedule. However, the number of milestones at various organizational levels should be re-examined to ensure that a sufficient number exist for schedule control. To date there has been no evidence of tracking actual progress against previously established milestones. The process of tracking the milestones and related activities must begin immediately—even prior to actual baseline approval.

The proposed project funding profile (Fig. 10.9.7-2) shows an accelerated ramp-up in early project stages, and approximately equal large expenditures for a 4-year period. Thus a small slip in the aggressive project schedule could cause a significant change in the funding profile. The SSCL must constantly monitor and be aware of the effect of changes causing individual activity slippages and impacting the overall project schedule. The SSC scheduling system has the ability to assess changes that could arise which may impact the project schedule and funding profiles.

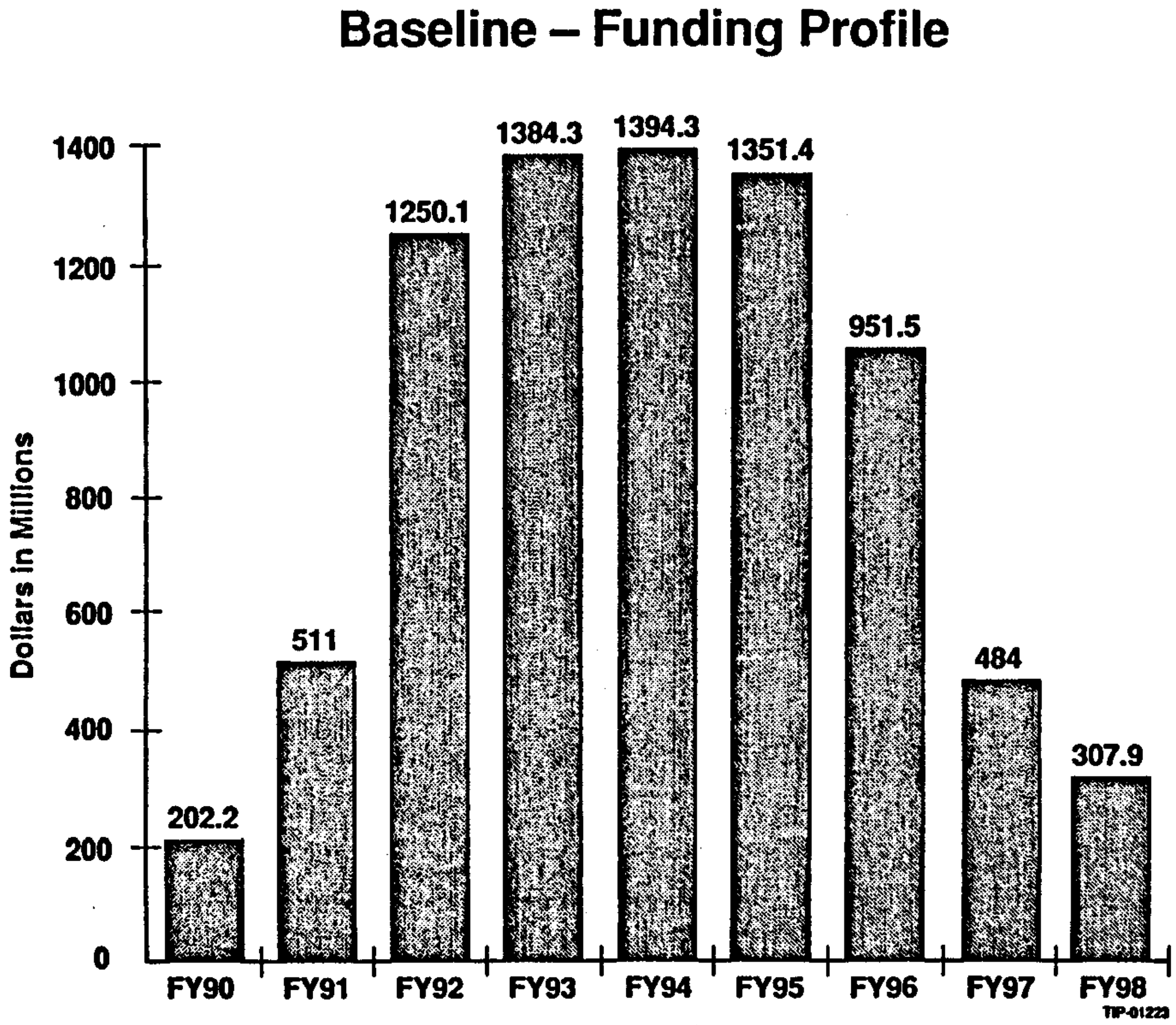

Baseline – Funding Profile
Dollars in Millions
0
200
400
600
800
1000
1200
1400
202.2
511
1250.1
1384.3
1394.3
1351.4
951.5
484
307.9
FY90
FY91
FY92
FY93
FY94
FY95
FY96
FY97
FY98
TIP-01223

Fig. 10.9.7-2

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10.10 Environment, Safety, and Health

10.10.1 Summary, Conclusions, and Recommendations

The Environment, Safety, and Health (ES&H) Subcommittee reviewed the relevant portions of the Site-Specific Conceptual Design Report (SCDR), the pre-decisional draft of the Supplemental Environmental Impact Statement (SEIS), and other pertinent documents. From these reviews and discussions with personnel from the SSC Laboratory (SSCL) and DOE, the subcommittee concludes that the SSC can be constructed and operated with acceptable environmental impacts and in a manner that will minimize risk to the health and safety of workers or the public. There are some environmental improvements expected from the project (e.g., preservation of existing habitat, wetlands creation, and socioeconomic benefits).

The ES&H organization, staffing plans, and plans for documentation (e.g., policies, procedures, ES&H manual, etc.) were reviewed by the subcommittee. It appears that the ES&H organization gets top management support; the head of the ES&H organization is an Assistant Director, reporting to the SSCL Director. It is clear that a great deal of thoughtful planning is taking place in the SSCL ES&H organization, as it anticipates the initiation of construction and work, toward having an appropriate program in place. This planning represents a unique opportunity at a new national laboratory to develop an ES&H program that complies with today's strict ES&H requirements and that has the benefit of the current DOE emphasis on ES&H performance.

There are no ES&H issues that should have any significant impact on the overall SSC cost and schedule. There are two potential issues that require near-term management attention (by both DOE and SSCL) to prevent schedule (and thus cost) impacts. These issues are 1) the need to finalize as many design parameters as possible now so that the SEIS can adequately assess potential impacts, and 2) the need within DOE to clearly assign responsibilities for providing ES&H guidance and oversight on items such as safety analysis reports (SARs) and the application for a permit to construct as required by the National Emission Standards for Hazardous Air Pollutants (NESHAP).

Recommendations

1. Finalize as many ES&H-related design parameters as possible *now* or identify the range of options for those parameters.
2. Clarify DOE organizational responsibilities for providing ES&H guidance and oversight.
3. Perform an analysis of the Life Safety Code requirements for the LEB, MEB, HEB, test beam areas, and experimental halls.
4. Evaluate alternative materials for calorimeters or detectors to minimize the amounts of hazardous or toxic chemicals used.
5. Initiate the process of obtaining a waiver from DOE Order 5480.7, Fire Protection, with respect to the experimental halls and the provision for blank walls for fire separation.
6. Adjust the Safety Analysis Review System schedules so that final SARs are completed 6-9 months before scheduled operation.
7. Evaluate the need of sprinklers in the experimental halls.

10.10.2 Discussion

One key issue that could have an impact on schedule is the definition of the "proposed action" for the SEIS. The design of many of the elements of the SSC project is still evolving. This has resulted in inconsistencies of numbers in the pre-decisional draft of the SEIS and in the SCDR, as well as inconsistencies between the SCDR and the SEIS. For example, most of the current plans for the facilities and development of the E-1 area are not included in the SEIS. There is discussion among SSCL staff of the need to drill 36-in. holes every 1 or 2 km around the ring for accurate guidance of tunnel-boring machines. There are impacts of such a plan (e.g., archaeological investigations) that need to be addressed, yet there currently is no mention of these potential plans in the SEIS. Another example relates to the potential sources of water for cooling water make-up and for fire suppression. A number of potential sources (a combination of surface and ground water) are still being considered. It is imperative that these parameters be finalized so that they can be assessed in the SEIS. For those that cannot yet be finalized, the range of options needs to be clearly defined so that the range of impacts can be analyzed in the SEIS. If this is not done, there are risks of delays due to legal challenges of activities that are not bounded by the SEIS analyses, or delays due to the need to conduct additional National Environmental Policy Act (NEPA) reviews for actions that are not considered in the SEIS.

An issue that was discussed along with the need for an accurate definition of the proposed action was the Magnet Development Laboratory (MDL) that is proposed to be constructed in the E-1 area. There is a need to begin construction of the MDL before the SEIS ROD is completed. Until DOE issues the ROD (now scheduled for 12-31-90), no action can be undertaken that 1) will have an adverse effect, or 2) will limit the choice of reasonable alternatives. Currently, this action (construction of the MDL) is the subject of a separate NEPA review and a draft memorandum to file has been prepared. It was the view of the subcommittee that if a sufficiently quantitative description of the MDL is prepared (especially with regard to potential air emissions and liquid discharges) and it can be demonstrated that any impacts are clearly insignificant, then the memorandum to file should be all that is required to authorize early construction of the MDL. The reviews of the MDL and the SEIS are proceeding independently of this design review.

The SCDR shows personnel exits at E areas, which are about 5.4 miles apart. This greatly exceeds the egress spacing requirement of 200 ft found in the Life Safety Code (NFPA 101). Although not shown in the SCDR, the current SSCL plan is to have stair exits at each E and F area, thus reducing the exit spacing to 2.4 miles. In addition, some electronics niches will be modified with fire-rated doors and will contain breathing air and other emergency equipment. These emergency refuges will be no more than 2500 ft apart (or 2500 ft from an E or F exit), thus providing either an egress or a refuge every 1250 ft. There is agreement between EH and ER about this general approach and an analysis has been prepared by the SSCL to demonstrate that the level of safety provided by this approach is equivalent to that specified by the Life Safety Code. Once this equivalency document has been forwarded to ER, it will need to be reviewed and approved by ER and then by EH. This approach to egress was judged to be reasonable by the subcommittee. It is further recommended that a similar analysis be applied to other underground facilities, including the LEB, MEB, HEB, and test-beam areas.

An additional concern was raised during the subcommittee review regarding egress from experimental halls. The SCDR notes (Section 5.5.5.4) that there may be up to 30,000 gallons of flammable liquids used in calorimeters in the halls. This could result in the halls being considered high-hazard facilities, which would require that exit paths be limited to 75 ft. The experimental halls should be carefully examined with regard to their compliance with the Life Safety Code. It is also suggested that alternative materials be evaluated for calorimeters or detectors in an effort to minimize the amounts of hazardous or toxic chemicals that will be used. At any rate, the use of these materials must be carefully considered in the SARs for the experimental halls.

The SCDR contains relatively little information with regard to detailed plans for the experimental halls. At times, there could be an occupancy load of up to 200 persons. There will be large masses of shielding material and detectors that will require handling or movement. In addition, as mentioned above, there will be large volumes of flammable materials in the halls. The combination of these elements in an underground environment represents a situation that could result in an incident in which there could be serious multiple injuries (with significant damage and program delays). As the design of the SSC becomes more defined, special attention should be given to the experimental halls, and the SARs must treat these areas very carefully. Among other things, the likely need for sprinklers in the experimental halls should be considered as the design progresses.

DOE Order 5480.7, Fire Protection, Section 9.c.(3), requires that "When the maximum possible property loss exceeds $50 million, redundant systems are provided as in subparagraphs 9.c.(1) and (2), ...such as blank walls or physical separation...provided to limit the maximum property loss to $75 million." Since the value of the detectors in the experimental halls has been estimated to be above the $75 million amount, and it appears that the provision of blank walls for fire separation will not be possible due to the size and operational characteristics of the detectors, a waiver from this requirement will be necessary.

The Advanced Photon Source (APS) project at Argonne National Laboratory (ANL) has recently gone through the process of obtaining a waiver from this requirement for its experimental hall. The waiver request followed the process outlined in DOE Order 5480.4, and the design of the facility included special fire protection features that have been found to equal or exceed the requirement for redundant fire protection. This waiver process will involve a significant amount of preparation and time, as well as a fire protection system designed to provide protection that can be considered equivalent to a redundant system. The APS experimental hall fire protection system design included such features as sprinkler systems fed from two risers supplied from two separate fire protection mains, very sensitive smoke detection systems, smoke removal systems, and other non-standard fire protection techniques. The review process took approximately 6 months to complete and required many revisions to the final exemption request document. Early involvement by the ANL fire protection Engineer, the CH fire protection staff, and the EH fire protection engineer was essential in getting this waiver accepted in a reasonable period of time. The SSCL should pursue a similar waiver process.

Currently, the SSCL has a vacancy for a fire protection engineer. The subcommittee believes that this position is a key one at this time, and urges the SSCL to continue earnest efforts to recruit a fire protection engineer. Review of designs at an early stage by a fire protection engineer is cost effective in the long term.

The current plan for compliance with the requirements of DOE Order 5481.1B, Safety Analysis Review System, is to produce a site-wide preliminary SAR by January 1991. Presumably, the preliminary SAR would focus on construction aspects since many other elements of the SSC design are only at the early conceptual stage. Even if this site-wide preliminary SAR is intended primarily to cover construction, the January 1991, completion date seems ambitious and will require significant near-term efforts to meet that date. Final SARs would be prepared for each major facility and be available 3 months prior to facility operations. The subcommittee believes that the facility SAR schedules should be adjusted so that final SARs are completed at least 6-9 months before scheduled operation. This will allow time for preparation and review of detailed operating procedures, operational safety requirements if needed, or conduct of operational readiness reviews. As the scope and the time required to prepare these procedures or reviews becomes better known, it may be determined that the facility SARs should be completed more than 9 months prior to operations. The table of contents for a Preliminary Hazards Analysis (PHA) was reviewed and appeared to be comprehensive. The current schedule is to have the PHA completed at the same time as the Laboratory-wide Preliminary SAR.

While discussing the timing and content of SARs, a potential management concern was raised. There are currently a number of DOE organizations involved in the SSC (e.g., ER-8, ER-90, EH, CH, and the on-site project office). It is not clear, however, what the on-going role of each of these organizations will be with regard to ES&H activities. For example, who will have responsibility for providing guidance to the SSC with regard to the content and timing of preliminary and final SARs? Who will be responsible for the detailed review of SARs in appropriate disciplines (e.g., industrial safety, industrial hygiene, radiation protection, fire protection, etc.), and who will have responsibility for approval within ER and submittal to EH? Similar questions could be raised with regard to preparation and review of an application for a permit to construct required by the NESHAP regulations. There needs to be a clear assignment of responsibilities and roles among DOE elements for all ES&H related activities.

Additional specific observations made by the subcommittee are as follows:

- A number of the documents and plans that are being prepared by the ES&H organization are designated as safety documents (e.g., Safety Manual). In fact, many of these actually do contain environmental information. These should more correctly be termed ES&H documents. This is more accurate and recognizes the heightened emphasis on environmental compliance in the DOE now. Furthermore, it may help to make individuals more cognizant of their personal responsibilities for environmental compliance and protection in the same way that they are responsible for their own and co-workers' safety.

- The SCDR specifies the use of halon as a fire suppression medium. It is anticipated that halon will not be approved for this use when SSC facilities are constructed. Guidance is expected from EH soon.
- It does not appear that there are plans for providing water to the tunnel for fire protection. An evaluation needs to be made of the need for a dry standpipe within the tunnel.
- In the final cost estimate, the safety services staff (which could be up to 46 persons in 1998) appears to have been left out. However, discussions with the Project Manager indicated that, due to currently anticipated personnel level adjustments in other areas, the total cost estimate is probably too low by about 18 FTEs. This would result in an increase to the cost estimate of something on the order of $11.6 million.
- The projected ratio of ES&H staff to total SSCL staff at the time of full operation is expected to be close to that currently found at similar facilities. While this level seems reasonable now, it can be anticipated that ES&H requirements, and thus staffing needs, are likely to increase in the future.
- EH has recently indicated that the SSCL will not be eligible for exemption from Department of Labor OSHA requirements. DOE and the SSCL need to begin discussions of the implications of this decision and need to establish responsibilities and procedures to implement this decision (e.g., procedures for accommodating OSHA inspections, dealing with citations and fines, investigation of serious accidents or other jurisdictional concerns, interactions with the A-E/CM and subcontractors in conjunction with OSHA inspections and fines, etc.).

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10.11 Detectors

10.11.1 Focus of the Review

The SSCL has made detailed plans for the implementation of an experimental program at the SSC. The Review Committee's attention was focused on the following six topics:

- The initial set of detectors
- The detector R&D program
- Experimental halls and facilities
- Test beams
- Computing for the experimental program
- SSCL support staff and management of the experimental program

10.11.2 Summary

The SSC Laboratory has coordinated an extensive program of detector R&D in the high energy physics community. It has also made a detailed plan to prepare for the experimental program, including the experimental halls and support facilities, test beams, computing, management, and on-site support staffing for the experimental program. The SSCL Physics Research Division is to be commended for this thoughtful and thorough planning, which seems sensible and appropriate for the present stage of the project.

A very ambitious plan has been developed to select, design, and construct the set of detectors for the initial operation of the SSC with the aim of having operating detectors when the SSC turns on. The timetable for the selection and design of the initial detectors should be achievable with the full cooperation of the high energy physics community. The first Expressions of Interest (EOIs) for building these detectors have been received, and the scope of the initial set of detectors will be chosen with the advice of the Program Advisory Committee later in 1990. Thus, the initial experimental program is not defined at this time.

However, a desirable initial set of detectors has been described, consisting of the following: Two large general purpose 4π detectors, one medium size special purpose detector, and several small highly specialized experiments. The two large general purpose detectors are important to provide competition, complementary capabilities, and cross checks in the major physics results. Some number of smaller experiments are crucial to provide the breadth and diversity necessary for the SSC program.

A total of $842 million in actual year dollars has been budgeted for the experimental program. It is reasonable to assume that substantial foreign contributions for this program. The amount of such contributions is hard to predict at this time, but an amount around one half or more of the U.S. funds might be a reasonable assumption. The funds budgeted for detectors, together with the addition of foreign funds at half that level, should be sufficient for a viable initial experimental program. However, the initial program at this level of funding will have to be less ambitious than the desired initial set of detectors discussed above. In the initial program, one would either have to delay one of the large general purpose 4π detectors, or the two large detectors would have to be initially at a scope reduced from those envisioned in the EOIs To implement the desired initial set of detectors of the scope envisioned in the EOIs would require both Federal and non-Federal funds of about 1.5 times the amounts discussed above.

Recommendations

1. Adequate contingency must be included in the planning for detector costs.

2. The SSCL and its advisory subcommittees should focus and prioritize the R&D effort so those areas critical for initial detector operation be adequately supported.

3. Assess the subsystem program progress and determine if any changes in proposal guidelines and/or MOU format are necessary. Decide if the SSCL staff scientists should play a larger role in both the technical assessment of proposed R&D and in participation in ongoing detector R&D efforts.

4. Identify interferences between main ring and detector installation since they are scheduled to occur at the same time. Integrate the experimental facilities group's detector assembly and installation schedule with the collider installation and the conventional construction schedules.

5. Provide an adequate number of personnel elevators from the surface to the detector halls.

6. Include appropriate means of adjustment in the detector designs to accommodate possible foundation movement, especially for detectors in halls in or near the Eagle Ford shale.

7. Identify office space needs for experimenters.

8. Decisions on the initial detectors are needed as early as possible this year in order to meet the scheduled SSC start-up date in 1998. Obtain adequate engineering support as soon as possible in order to keep to the present schedule. Try to have all experimental halls ready by mid-1995 in order to allow sufficient time for detector assembly and installation.

9. Maintain very close collaboration between the SSC staff and the detector groups on the support, management, and oversight issues.

10.11.3 Initial Complement of Detectors

The Laboratory has presented a detailed set of plans for implementing an experimental program for the SSC. According to this plan, the first 3 years (1990, 1991, and 1992) will be occupied by the process of selecting the initial set of detectors, design of the detectors and the submission of detailed design reports, and subsequent stage I and stage II approvals. The following 6 years (1993 through 1998) will be the prototyping, construction, assembly, and commissioning of the detectors. This schedule is very ambitious. However, with the involvement of a sizeable fraction of the U.S. high energy physics community, as well as sizeable non-U.S. collaboration, the goal of having operational detectors by SSC turn-on time should be achievable.

The process of selecting the detectors started with the submission of Expressions of Interest (EOIs). Fourteen EOIs were received in May 1990, involving over 300 institutions and over 1900 participating scientists. These EOIs will be discussed by the Program Advisory Committee (PAC) and the scope of the initial complement of major detectors will be identified later in 1990.

It is quite important that the selection of the large detectors proceed expeditiously so that both serious detector design and the planning of the experimental halls and support facilities of SSCL can get started. Both of these are on the critical path toward having operating detectors at SSC turn-on time.

Proposals for the detectors will be due in late 1991 and detailed design reports in mid-1992. Stage I approvals, based on the proposals, and stage II approvals based on the detailed design reports, are envisioned in early 1992 and toward the end of 1992, respectively, so that prototyping and major construction of the detectors can start in early 1993.

At the time of this review, the initial set of detectors has not yet been defined. However, the Laboratory did present some ideas on a desirable initial set of detectors. This would include two large general purpose 4π detectors, one medium size special purpose detector, and some number of quite specialized small experiments. Two large general purpose detectors are important to provide competition, complementary capabilities, and cross checks on major physics results. Some number of smaller experiments are crucial to provide breadth and diversity to the program.

The costs of these detectors are not well known at this time. Only rough estimates can be made until the initial detectors are chosen and their scope is defined. The Laboratory described the results of recent detector cost estimating panels. The EOIs also include cost estimates for the proposed detectors. The agreement between the cost estimates from the cost estimating panels agree quite well with those in the EOIs with one exception. The

EOI estimates had contingencies varying from 0 to 27 percent. It is the strong recommendation of this subcommittee that adequate contingency, which historically has been of the order of 40 percent of the estimated detector costs, must be included in the planning for detector costs. With such a contingency included, the cost estimates for the large fully instrumented general purpose 4π detectors is around $700 million (FY 1990 dollars), with one of the EOIs somewhat more. The medium sized special purpose detectors are estimated, with a 40% contingency added, to be in the vicinity of $250 million (FY 1990 dollars).

It should also be noted at this point that detector-specific R&D to do prototyping, etc., past the design report stage will have to be included in the detector costs because there is no other apparent source of funds for this work. This has not been the custom in the past when R&D cost was not included in the detector costs. Another possible problem will be the costs of writing both on-line and off-line software for the detectors. In the past, these costs were not included in detector costs. For the SSC detectors, these will be substantial amounts, with no apparent alternate source of funds.

There is a fund of $842 million in as-spent dollars set aside in the SSC construction budget for detectors. This corresponds to $752 million (FY 1990 dollars), using the OMB inflation indices. This fund has in it $40 million (FY 1990 dollars) for detector R&D, and $87 million (FY 1990 dollars) for computing. This leaves a total of $625 million (FY 1990 dollars) for actual detector construction. It is reasonable to assume that there will be non-U.S. contributions in addition to the U.S. funds. The amount of these non-U.S. contributions is not known at this time with any certainty, but judging from the amounts discussed in the EOIs, a reasonable expectation is that the non-U.S. contributions might be about half or more of the U.S. funds discussed above. With this assumption, one can compare the funding set aside for detectors with the estimated detector costs. Even though these numbers have considerable uncertainties at this time, the following qualitative conclusions become apparent:

- A viable initial physics program is possible with the $842 million set aside in the SSC budget and the expected non-U.S. contributions. However, to stay within this budget, the initial program will have to be less ambitious than the desired initial set of detectors discussed above, i.e. two large 4π detectors, one medium size detector, and some number of small experiments. One would either have to have only one large 4π detector initially, or the two 4π detectors would initially have to have a scope reduced from that envisioned in the EOIs.

- The desired initial set of detectors discussed above, if scoped at the level envisioned in the EOIs, would require about one and one-half times as much as the $842 million set aside for detectors, even with a very sizeable non-U.S. contribution.

10.11.4 Detector R&D

SSC detector R&D is currently being supported by the generic and the major detector subsystem programs. The generic program started in 1987 by the DOE and the CDG to initiate the development of technologies deemed necessary for SSC detectors. In FY 1990 ($6.4 million) was allocated to continue a broad range of investigations that are being done by groups at single institutions. SSC funding will not continue for this program and the projects will either terminate or be continued in the subsystem program.

The subsystem program was started in FY 1990 to fund multi-institutional, multi-year projects that would take the more advanced technologies and demonstrate their feasibility for use at the SSC. Ten million, five hundred thousand dollars was allocated from SSC funds for this program for FY 1990. The DOE and the State of Texas contributed an additional $3 million to this program. This was substantially less than the $44 million requested. An $18-million funding level is anticipated for FY 1991 and $5 million is projected in FY 1992 for completion of the program. Many of the R&D topics now under study have been mentioned in the EOIs as necessary for the proposed detectors.

Funding awards have been based on recommendations stemming from review committees' evaluation of submitted proposals. Detector-related proposals have been evaluated by an international committee established by the CDG. The SSCL formed a committee for evaluation of the computer and computing related proposals and one for the data acquisition and triggering. Written progress reports from the subsystem collaborations are due in September 1990. The SSCL is sponsoring a Symposium on Detector Research and Development for the Superconducting Super Collider, October 15-18, 1990, in Fort Worth in which results from both programs will be presented along with contributions from other workers in this field.

Following the Symposium, the international detector R&D review committee will meet to consider renewals and new proposals. The committee will be augmented by some members of the PAC in order to coordinate information between the two committees. Detector R&D and EOI funding recommendations to the SSCL Director will be made at the November 1990 PAC meeting.

The R&D program covers critical problems such as the development of detectors and electronics having the needed radiation hardness and speed of response to operate in the SSC environment. Also some less critical problems such as the application of neutral nets, artificial intelligence, and advanced semiconductor detectors which would enhance the performance of the SSC detectors are being pursued. Clearly a transition from these broadly based programs to more focused detector specific R&D will have to occur as the program evolves toward specific detectors. The R&D review committee and PAC meeting schedules set by the SSCL provides an excellent framework for making any needed program adjustments.

We recommend that the SSCL and its advisory committees focus and prioritize the R&D effort so those areas critical for initial detector operation be adequately supported.

As the subsystem R&D proposals and EOI R&D funding requests indicate, the $40 million allocated for pre-approval detector R&D is not sufficient to cover the full range of topics that the SSC's user community is interested in pursuing. However, it is too early to judge whether the $40 million will provide the critical technologies needed for a viable complement of initial detectors. The evaluation of the generic and subsystem program results and status along with a critical assessment of the EOIs R&D funding requests that are scheduled for this fall should yield an estimate of funds needed to complete this stage of SSC detector R&D.

No funds have been explicitly set aside for post-approval R&D. Experience with current smaller detectors indicates that 10-20 percent of the construction cost of the detector is needed for R&D to, for example, cover prototype work on the design report subsystems prior to the start of manufacture. While the percentage for the larger SSC detectors will be somewhat smaller, the $40 million in WBS 5.1 will not cover any of these necessary post-approval expenses. The funds needed for these purposes will further reduce the WBS 5.2 amount available for the actual construction of the detectors.

The scheduled termination of the generic program in FY 1991 and the end of the subsystem program in FY 1992 are reasonable provided that careful attention is paid to providing orderly transition to the necessary follow up work. There will undoubtedly be highly promising generic work that should be supported outside of SSC funding. Subsystem work extending beyond FY 1992 will have to be completed as detector specific R&D. Funds for these activities will necessarily be charged against the detector allowance.

The SSCL inherited the generic program from the CDG/DOE and instituted the subsystem program. Both groups have relied on advisory committees for the program evaluation and guidance. The subsystem program used Memoranda of Understanding to detail the scope of work undertaken by each collaboration and the amount and distribution of funding. There were delays at both the SSCL and the DOE in getting the approved funds to the participants. Steps have been taken to prevent future delays or disconnects in approved funding.

We recommend that the SSCL, based on the October review assess the subsystem program progress and determine if any changes in proposal guidelines and/or MOU format are necessary. It should also consider if its own staff scientists should play a larger role in both the technical assessment of proposed R&D and in participation in ongoing detector R&D efforts.

The SSCL has shown that it is cognizant of the importance of the detector R&D program in establishing a successful physics program. Although its allocation of resources to this activity is not overly generous, it may be enough to develop a sufficient technological base for the initial complement of detectors.

10.11.5 Experimental Halls and Facilities

In preparation for the approved experimental program the SSCL experimental facilities group has been using several of the large detectors proposed in the EOIs as models for detailed extensive planning exercises. These have included planning for the civil construction for general buildings and the underground halls associated with the detectors. Schedules for installation and assembly were developed and estimates of the required detector support staff was made. A study of control rooms and other buildings needed by the experimental groups is in progress.

The work done by this group since the May 25, 1990, submittals of the EOIs is very impressive. It was not an easy task as much of the necessary information was not included in the EOIs. This highlights the necessity of close collaboration between the EOI proposers and the laboratory. All of the information about the proposed detectors are summarized in a resource requirement report that allows for efficient work and interaction with the experimental groups. The work presented by the experimental facilities group was well done and professional. The subcommittee was very impressed with their performance.

Based on experience at other laboratories with the installation of large detectors, we offer the following comments and recommendations:

We believe it more efficient in time and money to construct and subassemble experimental equipment in surface buildings.

A careful study of interference between main ring and detector installation is needed as they are scheduled to occur at the same time. We strongly urge that the experimental facilities group's detector assembly and installation schedule be integrated with the collider installation and the conventional construction schedules.

Care will be required in designing the detectors to accommodate possible foundation movement, especially for detectors in halls in or near the Eagle Ford shale. Appropriate means of height adjustments must be included in the detectors.

An adequate number of personnel elevators from the surface to the detector halls should be provided to prevent bottlenecks from occurring when large numbers of workers are present on site.

The SSCL crane policy is sound and is consistent with the experience at other laboratories. SSCL's plan is to have 100-ton permanent cranes in the large detector halls, and rent large (1000 to 2000-ton) capacity cranes for brief periods to lower heavy loads to the experimental halls. However, we note that the very large cranes are booked early, so that advanced arrangements are necessary.

The assumed number of 200 persons/collaboration on-site used in estimating office space requirements may be too low for the large collaborations. A firm number should be established in consultation with the collaborations. To achieve some flexibility, space for barracks style offices should be considered.

From the preliminary detector installation and assembly schedules, it is clear that early decisions on the initial detector complement are needed. A first decision later than Summer 1990 seriously endangers the present scheduled startup date of 1998. It should be emphasized that engineering support now is absolutely imperative to keep to the presented schedule and that funds for this support should be made available soon. Realistic planning and scheduling can be achieved with the continued close collaboration of SSCL staff and the experimental groups. Also, a strong effort should be made to have all experimental halls ready by mid-1995 to allow sufficient time for detector assembly and installation.

10.11.6 Test Beams

The SSCL plans to provide three fully instrumented test beams for the development, testing, and calibration of detector modules. Electron, muon, and pion beams will be provided with momenta from 1 GeV/c up to about 150 GeV/c. The beam line instrumentation will provide particle ID and energy resolution of 1/3 percent. The calibration halls are positioned to have adequate radiation shielding and low muon flux. The test stand/fixture is designed to hold large detector modules and position them so as to vary the incident beam angle.

The experimental facilities group has provided an excellent design of the beam line, its instrumentation, and the calibration halls. The SSCL test beam facility will be an important component of the experimental program and deserves full laboratory support. With the choice of three test beams, there should be one available for each of the major detectors selected for the initial program. We endorse their decision not to provide additional beams from either the MEB or the HEB. Although the MEB test beams will most certainly be fully utilized, we do not recommend additional funding for additional beams. A 2 TeV test beam from the HEB would certainly be valuable, but its $50 million cost and late availability (1998) lead us to conclude that it should not be included in the TPC as a test beam facility.

The lack of test beams with momenta up to 1 or 2 TeV/c at the SSCL makes it extremely important that a strong effort be made to provide a TeV test beam at Fermilab for the SSC detector tests and calibration. In addition, test beam availability at BNL and SLAC should be explored.

10.11.7 Computing for Experiments

The SSCL Physics Research Division's computation group is responsible for providing the division's computer environment and for supporting physics related software, data analysis, and archiving. They have designed a computing environment to meet the simulations requirements for physics computing as described in several SSCL reports. It will be a distributed system interconnected by local and wide area networks to serve both local and remote users. It will contain workstations, computer engines, servers, processor farms, and archiving media. Ultimately the system will acquire a minimum of 4000 MIPS by March 1992. It is designed to support the computing needs of 100 FTE users. A three phase acquisition plan has been developed. In phase I, a 500-MIPS detector simulation capability is scheduled for acquisition by October 1990.

The computing group has developed an excellent plan which is responsive to the physics users' needs. Their proposed system is imaginative and capable of staged expansion. Thus they will be able to take advantage of developing computer technologies while matching their funding profile to the anticipated growth in needed computing power. Staff requirements, acquisition, and funding schedules seem quite reasonable.

10.11.8 SSCL Support Staff and Experimental Program Management

Three main topics were discussed:

1. Support staff at the SSCL for the experimental program
2. Strong inhouse physics groups
3. Management of large collaborations

Projected staffing levels for the SSCL's experimental facilities group were presented (WBS 4.6). This group consists of system integration, safety, cryogenics, electrical engineering, mechanical engineering, and physics liaison personnel. The staffing levels are based on a one-to-one ratio of experimental physicists to engineers, which we believe is sound. The staff composition and buildup to the projected full size of 215 was also believed appropriate. An additional projected staff of 98 involved with detector-specific electronics, data acquisition software, systems integration, and experimental systems computing is also planned. The funds for this support would be contained in the detector allowance, WBS 5.2.

The support of the SSC staff from the detector allowance was not fully supported by all members of the review subcommittee. It was stated that although this support mechanism may be appropriate for a collaboration with a substantial fraction of its support from the DOE, it may be very inappropriate for collaborations with international participation and unique subdetector construction arrangements. It, thus, may be necessary for the collaborations and the SSCL directorate to negotiate a different method of support for these collaborations.

The SSCL presented an outline of its detector project management policy. Its main points are:

1. Each design report for an approved experiment will be subject to intensive review by the laboratory and funding agencies.

2. Overall detector project management organization inside the SSC Laboratory.

3. Separate project management for each detector for overseeing and supporting the construction, installation, and commissioning of the detector and associated experimental facilities.

4. Individual agreements with each participating institution giving detailed contribution, schedule, and cost.

5. Laboratory liaison to each experiment with respect to experimental facilities, computing, engineering support, assembly, visitors, etc.

6. Inside experimental groups associated with SSC experiments — large, strong SSC groups involved with the big detectors.

We believe that strong inhouse physics groups are necessary to achieve and maintain a lively scientific atmosphere and therefore support the SSCL's plans. It is appropriate that separate DOE support be given to this effort.

The SSCL does not yet have an implementation plan for the overall detector project management organization, nor for each detector's project management arrangement. The staffing, selection, funding, authority, responsibility, and reporting structure for the detector's project management personnel were not specified. Since the large collaborations will be multinational with many separate sources of funding, schedule, and cost monitoring may not be straightforward. In addition, we believe that each collaboration may require different management and oversight policies.

The review committee believes that very close collaboration with the SSC staff and the detector groups on the support, management, and oversight issues is essential for the successful completion of the detector projects.

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Appendix A

U.S. Department of Energy
SSC SCDR REVIEW COMMITTEE

June 25-30, 1990

Chairman: L. Edward Temple, Jr. (DOE)

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Lou Ianniello
Garry Gibbs
John Scango
Bob Diebold
Dan Lehman
Dick Woods
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Art Robinson (LBL)
Rob Johnson (LBL)
Bob Barton (LBL)
Joe Chew (LBL)
Joyce Lewis (DOE)
Linda Staples (DOE)
Robbie Green (DOE)
Pete Devlin (SMS)
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Gina Simpson
Julie Stitely
5

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Ron Ruth (SLAC)
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Siegfried Wolff (DESY)
Vic Karpenko (Consultant)
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* Chairperson
(P) Headquarters Point of Contact for Receiving Subcommittee Comments

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Bob Bell (SLAC)
Gordon Danby (BNL)
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(P) Warren Marton (DOE)

4b. rf, Power Supplies & Linac

Ron Sundelin (CEBAF) *
Don Reid (LANL)
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(P) Eddie Sims (DOE)
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4c. Cryogenics, Vacuum, Spool, & Installation

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Claus Rode (CEBAF)
Steve Van Sciver (WIS)
Hans Jostlein (FNAL)
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4d. I/C and Computers

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Subcommittee No. 6
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Bill Crean (Gilbert Commonwealth)
Bob Powers (Powers & Associates)
Bruce Strauss (Powers & Associates)
Validation: Ruben Sanchez

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DOE F 1325.8
(10-88)

United States Government **Department of Energy**

memorandum

DATE: April 19, 1990

REPLY TO
ATTN OF: ER-1

SUBJECT: Validation Review of Site-Specific SSC Conceptual Design

TO: Lewis E. Temple, Director, Construction Management Support Division, ER-65

Since its inception in early 1989, the SSC Laboratory has been preparing a site-specific SSC conceptual design including cost and schedule estimates. The site-specific design builds upon the March 1986 Conceptual Design and includes characteristics of the SSC site, results of continuing magnet R&D, and advances in accelerator design.

As you know, the Secretary has requested thorough DOE reviews of the site-specific design and cost by both the Department's Independent Cost Estimating Group, the Office of Energy Research, as well as an outside group which we presently envision as a HEPAP subpanel. Results of these reviews are needed to establish the SSC technical, cost, and schedule baselines, and to support the FY91 and subsequent budgets.

Based upon your experience in chairing many project reviews, Lou Ianniello and I request that you assemble a peer review team and perform a review of the site-specific conceptual design. Also, please work with the Office of SSC and SSC Laboratory staff as appropriate to assure that the review will be highly successful.

The Charge to the review committee is as follows:

> The DOE Review Committee should assess the technical design proposed, in particular, whether the design is consistent with the SSC performance objectives. The Committee should carefully review the cost estimates for the Conceptual Design, understand in detail the basis for the estimates, note identified uncertainties, and judge the overall validity of the estimates. The realism of the proposed construction schedule and funding profile should be addressed. The manner in which the work will be accomplished, including how it will be managed, should be reviewed and assessed. Thus, in summary, the Committee is to review and assess the proposed SSC design and the credibility of the associated cost and schedule estimates as well as the adequacy of present and planned management arrangements to accomplish the scope of work.

The review is presently scheduled to begin at the SSC Laboratory on June 4, 1990, and to continue for about five days. Additional time may be needed to complete the tasks set forth in the charge. It is anticipated that selected DOE staff and consultants will remain at the Lab until the report is drafted.

Currently, the DOE Independent Cost Estimating committee and a HEPAP subpanel are planning to review the SSC project concurrently with the ER Review.

Please provide to me a verbal report of your findings within ten days after the on-site review and a written report one month following the review.

James F. Decker
Acting Director
Office of Energy Research

Appendix C

SSC Site Specific Conceptual Design Review
SSC Laboratory, Dallas, Texas
June 25-30, 1990

AGENDA

<u>Monday, June 25</u> -

8:00 a.m.	DOE Executive Session	
9:00 a.m.	Overview of the Site Specific Conceptual Design Report (SCDR) Technical Cost Schedule Management	R. Schwitters
9:30 a.m.	Accelerator Overview (WBS 1.1) Scope -- Major design parameters Status of design Changes from CDR Open design issues and plans for resolving	H. Edwards
10:30 a.m.	BREAK	
10:45 a.m.	Collider Magnets Overview (WBS 1.2.3) Scope Changes from 4cm to 5cm bore dipoles R&D program to date Future plans and schedules Organizations involved -- currently future Magnet Development Plan Industrial Plan	T. Bush
12:00 Noon	LUNCH	
1:00 p.m.	Experimental Systems (WBS 5.0) Definition of allowance Scope of basic set of detectors Plan for obtaining detectors	F. Gilman
1:30 p.m.	Conventional Construction Overview (WBS 2.0) Site Layout Accelerator Enclosures (Injector-Collider) Utilities and Roads Experimental facilities Campus facilities	B. Matyas/ T. Toohig

2:00 p.m.	Cost Estimate Overview Address the estimate methodology: • Who prepared the estimates? • How was the estimate prepared? • What information was available to the estimators? • Qualifications (i.e. , escalation rates, wage rates, etc.) Summarize the estimate (TEC and TPC) and address: • Baseline cost in FY 1990 dollars (without contingency and escalation) • Contingency (including method of derivation) • Escalation factors used • Baseline cost in escalated dollars including contingency • Staffing summary by year • Potential decapitalization Compare the SCDR to the CDR at the summary level in FY 1990 dollars	J. Sanford/ T. Elioff
3:00 p.m.	BREAK	
3:15 p.m.	Schedules and Funding Profile Address the schedule methodology Present the Project Summary Schedule and associated funding profiles (BA) for the following scenarios: • optimistic case (base case) • Start tunneling after magnet production release -- assume FY 1991 budget appropriation. Address the: • summary level milestones for the above scenarios	W. Simmons T. Kozman
4:00 p.m.	Near term plans, schedule for E1 Areas and String Test through 9/92	H. Edwards T. Toohig
4:30 p.m.	Management Overview Address the present and planned laboratory organization and proposed staffing levels (i.e., engineers, physicists, administration, etc.) Discuss the current plan for accomplishing the project • Long term overview • Near term -- more detailed presentation Discuss how the SSCL plans to control the technical, cost, and schedule baselines at the summary level. • i.e., Configuration Management Plan Who will have approval authority?	R. Schwitters/ T. Kozman
5:15 p.m.	TNRLC Participation in SSC	E. Bingler
5:30 p.m.	DOE EXECUTIVE SESSION	

Tuesday, June 26

Accelerator Requirements Overview
Subcommittees 1, 2, 3, 4a, 4b, 4c, 4d

8:30 a.m.	Collider Requirements	D. Edwards/ M. Syphers
9:30 a.m.	HEB Requirements	D. Johnson
	(Group 3 splits off into subcommittee meeting following the HEP presentation)	
10:00 a.m.	BREAK	
10:15 a.m.	MEB-LEB-Linac Requirements	J. Watson/ W. Funk
11:15 a.m.	Test Beams Requirements	R. Stefanski
11:45 a.m.	Schedule	R. Morse
12:15 p.m.	LUNCH	
1:00 p.m.	SUBCOMMITTEE MEETINGS START	

Construction Requirements Overview
Subcommittees 5, 8

8:30 a.m.	Research Requirements	R. Stefanski
9:30 a.m.	Schedule	R. Morse
	(Group 8 splits off into subcommittee meeting following Research presentation)	
10:30 a.m.	BREAK	
10:45 a.m.	Accelerator Requirements	J. Gannon/ T. Lundin
11:45 a.m.	Safety Requirements	L. Coulson
12:15 p.m.	LUNCH	
1:15 p.m.	SUBCOMMITTEE MEETING STARTS	
5:00 p.m.	DOE Subcommittee Executive Sessions Each Subcommittee Develops Findings and Comments for Full Committee Executive Session	
5:30 p.m.	DOE Full Committee Executive Session Subcommittee Chairpersons Report Status	

Wednesday, June 27

8:30 a.m.	Subcommittee Reviews
12:00 Noon	LUNCH
5:00 p.m.	DOE Subcommittee Executive Session Each Subcommittee Develops Findings and Comments for Full Committee Executive Session
5:30 p.m.	DOE Full Committee Executive Session Subcommittee Chairpersons Report Status

Thursday, June 28

8:30 a.m.	Subcommittees Continue Reviews and/or Write Report
12:00 Noon	LUNCH
4:30 p.m.	DOE Full Committee Executive Session Subcommittee Chairpersons Report to the Full Committee on: Findings and Recommendations Status of Report

Friday, June 29

8:00 a.m.	Subcommittees Continue Writing Reports
11:30 a.m.	LUNCH
12:30 p.m.	DOE Full Committee Executive Session

Saturday, June 30

11:00	DOE Subcommittee Chairpersons Meeting to Discuss Report

Appendix D

Glossary

AC	Alternating Current
AE/CM	Architect-Engineering/Construction Management
ASST	Accelerator Systems String Test
BNL	Brookhaven National Laboratory
BPM	Beam Position Monitor
CAD	Computer Aided Design
CCD	Conventional Construction Division
CCL	Coupled-Cell Linac or Coupled Cavity Linac
CDF	Collider Detector Facility
CDG	Central Design Group
CDM	Collider Dipole Magnet
CDR	Conceptual Design Report
CEBAF	Continuous Electron Beam Accelerator Facility
CERN	European Laboratory for Particle Physics located outside of Geneva, Switzerland
CESR	Cornell Electron Storage Ring
CP	Cost Plus
CPFF	Cost Plus Fixed Fee
CPM	Cost Plus Materials
CQM	Collider Quadrupole Magnet
CR	Collider Ring
CS/CS	Cost Schedule Control System
DESY	Deutsches Elektronen-Synchrotron laboratory in Hamburg, W. Germany

DOE	Department of Energy
DPF	Division of Particles and Fields
DTL	Drift Tube Linac
EDIA	Engineering Design, Inspection, and Administration
EFS	Eagle Ford Shale
EIS	Environmental Impact Statement
EOIs	Expressions of Interest
ER	Office of Energy Research
ERC	Energy Review Committee
ES&H	Environment, Safety, and Health
Fermilab	Fermi National Accelerator Laboratory
FMEA	Failure Mode and Effect Analysis
FODO	An accelerator lattice cell consisting of focusing and defocusing quadrupoles
FP	Fixed Price
FY	Fiscal Year
GeV	One billion electron volts
GPS	Global Position System
HEB	High Energy Booster
HEPAP	High Energy Physics Advisory Panel
HERA	Hadron-Elektron-Ring-Anlage
ICE	Independent Cost Estimating
ID	Inside Diameter
IR	Interaction Region
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory

LCW	Low Conductivity Water
LDD	Large Diameter Drilled Hole
LEB	Low Energy Booster
LEP	Large Electron-Positron project
LPA	Lachal/Piepenberg & Associates
LRIP	Low Rate Initial Production
MAAS	Magnet Acceptance And Storage
MDL	Magnet Development Laboratory
MEB	Medium Energy Booster
MTBF	Mean Time Between Failure
MTL	Magnet Test Laboratory
MTTR	Mean Time To Repair
NESHAP	National Emission Standards for Hazardous Air Pollutants
OMB	Office of Management and Budget
OPO	On-site Project Office
OSSC	Office of Superconducting Super Collider
PAC	Program Advisory Committee
PB/MK	Parsons Brinckerhoff/Morrison Knudsen
PEP	Positron-Electron Project
PIDS	Prime Item Development Specification
PIF	Prototype Installation Facility
QA	Quality Assurance
QC	Quality Control
QF	Quadrupole Focussing
QD	Quadrupole Defocussing
RDS	Reference Designs Study

RFP	Request for Proposals
RFQ	Radio-frequency Quadrupole
ROD	Record of Decision
RTK	Raymond/Tudor/Knight
SAR	Safety Analysis Report
SCDR	Site-Specific Conceptual Design Report
SCDR.DIC	SCDR Point Design of Injector Complex
SEIS	Supplemental Environmental Impact Statement
SLAC	Stanford Linear Accelerator Center
SLC	Stanford Linear Collider
SSC	Superconducting Super Collider
SSCL	Superconducting Super Collider Laboratory
TBD	To Be Determined
TDM	Time Division Multiplexing
TEC	Total Estimated Cost
TeV	One trillion electron volts
TNRLC	Texas National Research Laboratory Commission
TPC	Total Project Cost
UHV	Ultra High Voltage
UNIX	UNIX Computer Operating System
URA	Universities Research Association, Inc.
WBS	Work Breakdown Structure