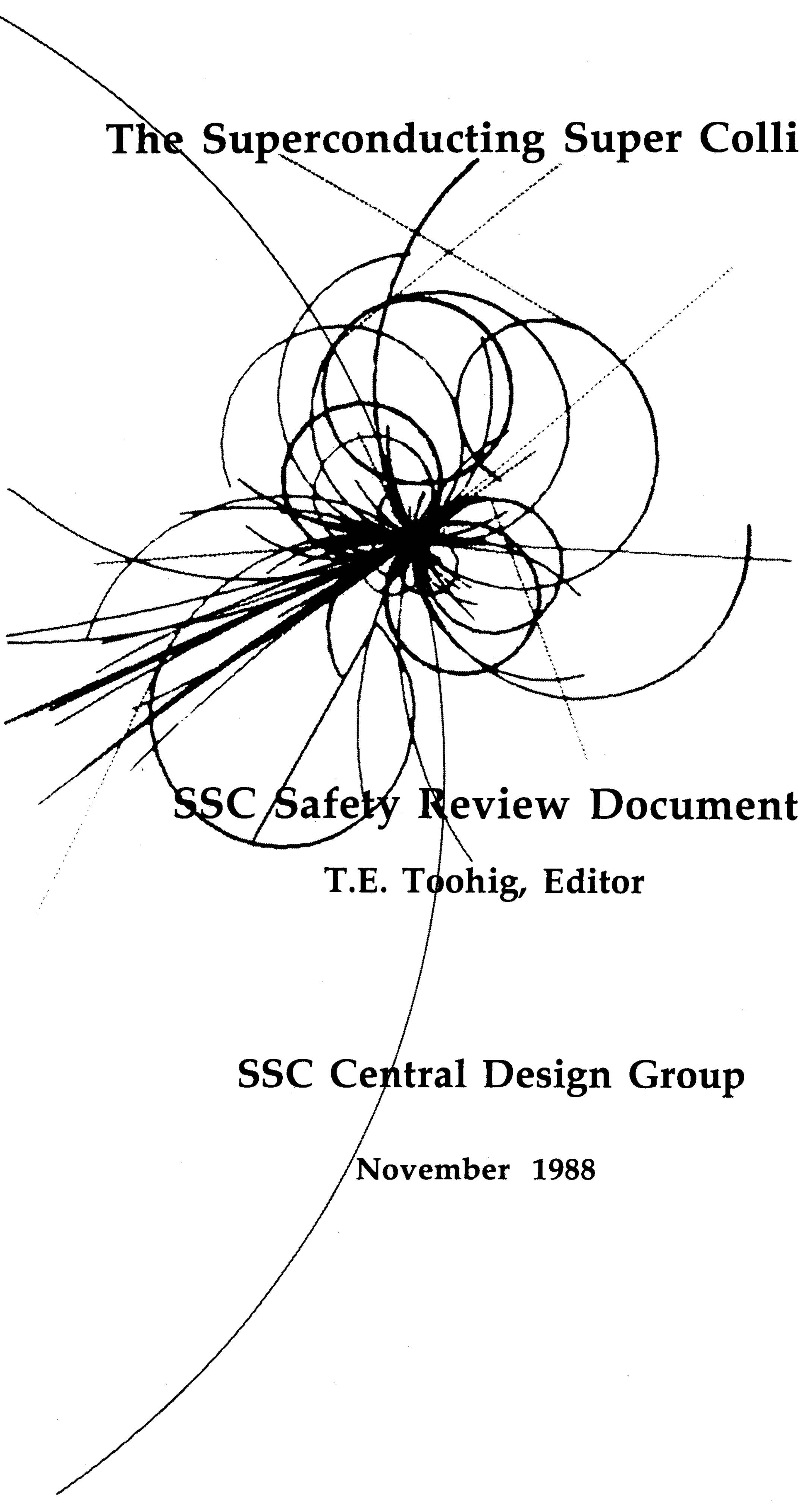
SSC-SR-1037

The Superconducting Super Collider



SSC Safety Review Document

T.E. Toohig, Editor

SSC Central Design Group

November 1988

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c/o Lawrence Berkeley Laboratory, Berkeley, CA 94720

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* Operated by Universities Research Association for the U.S. Department of Energy.

EXECUTIVE SUMMARY

INTRODUCTION

The safety strategy of the Superconducting Super Collider (SSC) Central Design Group (CDG) is to mitigate potential hazards to personnel, as far as possible, through appropriate measures in the design and engineering of the facility. The Safety Review Document identifies, on the basis of the Conceptual Design Report (CDR) and related studies, potential hazards inherent in the SSC project independent of its site. Mitigative measures in the design of facilities and in the structuring of laboratory operations are described for each of the hazards identified.

IDENTIFICATION OF POTENTIAL HAZARDS

The potential hazards are grouped under three headings: Infrastructure and Campus, Accelerator, and Experimental Facilities. The hazards in the first category are similar to those of a university or industrial research park. To identify potential hazards in the second category, it is possible to draw on the experience of existing accelerator laboratories in the U.S. and abroad; of special relevance here are the Tevatron at Fermi National Accelerator Laboratory (Fermilab) for identification of cryogen-related hazards and the SPS/LEP at CERN for identification of hazards related to placement of the accelerator in a deep tunnel. The experimental program for the SSC cannot be defined until sometime after project approval; therefore, for the third category, potential hazards related to the experimental facilities, only a general treatment is possible as inferred or projected from detectors that are presently in operation or under construction for the new generation of accelerators. In none of the three categories does the SSC present any qualitatively new potential hazards.

SITE DESCRIPTION

The SSC facility encompasses an area of approximately 16 by 20 square miles. The facility itself occupies only a narrow band of land, approximately 1000 ft wide, constituting an oval with a perimeter of approximately 53 miles. Some of this land will be owned in fee simple by the laboratory, while more will be held as a stratified fee estate. The area inside this perimeter is unaffected by the presence of the laboratory, except for laboratory vehicles sharing the public road system to access remote facilities.

There will be large concentrations of personnel at the campus, which houses the main control center (MCC) and the administration and support activities for the facility, and at the experimental areas, which house the research facilities. Of a total of approximately 3000 personnel at the laboratory, approximately 2300 will be in the near cluster, between the campus and the two adjacent experimental areas, while the remainder will be at the experimental areas in the far cluster, some 15 miles distant. At 5 mile intervals around the periphery, there will be service areas housing the refrigeration systems, power supplies, and controls for the sector of the accelerator contiguous to it. All of the accelerator systems will be operated from the MCC, so the service areas will be unoccupied except for periodic maintenance and security checks.

DESCRIPTION OF TECHNICAL FACILITIES

The SSC complex as presented in the CDR consists of five cascaded accelerators, beginning with the 600-MeV (million electron volts) linac and leading to the 20-TeV (trillion electron volts) collider. As the name implies, the linac is a linear accelerator, 410 ft in length. The second stage of acceleration is the Low Energy Booster (LEB), a rapid-cycling synchrotron, or circular accelerator, with a circumference of 820 ft. It boosts the energy of the 600-MeV protons from the linac to 8 GeV (billion electron volts). In the next stage, the Medium Energy Booster (MEB) boosts the energy of the protons from 8 GeV to 100 GeV with a circumference of 6200 ft. All three of these initial stages of acceleration employ conventional, room-temperature magnets and acceleration systems. The final booster stage, from 100 GeV to 1 TeV (1000 GeV) is accomplished by the High-Energy Booster (HEB), which has a circumference of 19,700 ft. The HEB, like the 53-mile collider ring, uses superconducting magnets cooled to liquid-helium temperatures by a helium liquefier/ refrigerator located at the HEB service area. The HEB refrigerator is similar to the collider ring refrigerators located at the collider service areas. All of these accelerators are housed in underground enclosures that are interlocked against access and monitored from the MCC.

Access to the underground enclosures is through the service areas, which house power supplies, utility distribution, refrigeration, and controls for the section of accelerator adjacent to the area. For the collider ring, ventilation shafts halfway between the service areas will serve as emergency exit points. The distance between accesses will conform to applicable federal and state regulations[1] and be consistent with the practice at existing underground accelerator facilities.

The experimental detectors will be housed in underground enclosures at the interaction points (IP's). The largest of these detectors will weigh up to 40,000 tons and require an enclosure approximately 25 m wide by 80 m long by 35 m high.

Except for the matter of scale, the technical facilities for the SSC are similar to those at existing Department of Energy (DOE) and overseas accelerator laboratories, so the experience of those laboratories can be used with confidence to guide the design of the SSC facilities.

SAFETY AND MONITORING PROGRAMS

Design features to mitigate potential hazards inherent to operation of the SSC will be complemented by site-wide monitoring and alarm systems under 24-hour surveillance from the MCC. Fire and security alarms will be available at the emergency services center and utility information and alarms will be available at the site maintenance facility. This system will be designed in compliance with appropriate sections of DOE Orders.

The monitoring and alarm systems are one component of the organizational structure designed to ensure the safe functioning of the laboratory. The authority and responsibility for safety in the laboratory originates with the director of the laboratory. This is a line responsibility, delegated through a clearly defined supervisory chain through the heads of divisions with operational responsibility to the line supervisors directly responsible for specific activities. Ultimately, the individual employees are made aware of their own responsibility for safety. A safety organization reporting to the director assists in instituting safety training programs, monitoring compliance with laboratory safety policies, and conducting regular safety audits. A safety group within each operational division assists the division head in conducting safety training courses, monitoring compliance, and implementing safety directives within the area of his responsibility.

CONDUCT OF OPERATIONS

The conduct of operations is the responsibility of the director of the laboratory. This is delegated to the head of the accelerator division for accelerator operations and to the head of the division responsible for the experimental areas for operation of the experiments. The accelerator and experiments operate on a 24-hour/day schedule with functional responsibility for operations delegated to the shift crew chiefs on duty, one for accelerator operations, and one for the experimental operations.

An Operational Readiness Review (ORR) will be required prior to commissioning each major component of the facility, such as the cryogenic system of a sector of the collider ring.

Training programs for accelerator operators and maintenance personnel will be required for qualification and for maintenance and updating of skills. Safety training programs will be required for all personnel consistent with their responsibilities. The training programs will be supplemented by a laboratory-wide program of accident prevention and awareness.

Laboratory emergency planning will include analysis of possible emergencies and establishment of plans and procedures appropriate to the various contingencies. These plans and procedures will be part of the training programs for all personnel noted above.

QUALITY ASSURANCE

It will be the policy of the SSC laboratory to ensure that the required standards of quality, inherent reliability, and reproducibility consistent with the scope and nature of each activity are achieved in all laboratory programs. In pursuing this goal, the laboratory will adhere to ANSI and other standards as applicable. The implementing programs will include Quality Assurance/Quality Control Programs, Configuration and Change Control Procedures, and Testing and Inspection Programs.

ANALYSIS AND MITIGATION OF POTENTIAL HAZARDS

The potential hazards described in Chapter 2 are analyzed in detail in the light of site, systems, operations, and organizations described in the subsequent chapters. For each potential hazard, the design features adopted to eliminate or mitigate it consistent with DOE guidelines are described. Relevant guidelines, orders, and federal regulations are cited. At this generic level, the design of the facility conforms fully to all of the mitigative measures described.

WASTE HANDLING, STORAGE, AND DISPOSAL

The kind and amount of waste from the SSC will be a function of the type and level of waste-generating activities. Since no activities will be carried out at the SSC qualitatively different from those at presently operating accelerator facilities, the SSC waste stream can be scaled from experience. The integrated amount of beam energy accelerated in the SSC is approximately a factor of ten less than that accelerated in the fixed-target mode at Fermilab, so the amount of radioactive waste will be less than that from Fermilab, or about 10 Ci (curies). The waste stream is similar at both facilities, so all of the SSC radioactive waste will be Low-Level Class-A waste, the lowest category. Hazardous waste will be on a similar scale to existing accelerator laboratories, or approximately 10,000 gal/yr. No mixed waste is anticipated.

DECOMMISSIONING

An analysis of the decommissioning of the SSC at the end of its useful life has been carried out in connection with the *Draft Environmental Impact Statement*. No obstacle is found to restoring the site to unrestricted use.

REFERENCES

[1] P. Gilbert, SSC-N-544, "A Review of Current Practices for Providing Integrated Systems for Life Safety of Tunnel Occupants — Application to SSC Tunnel Requirements," SSC Central Design Group internal report (August 1988).

PREFACE

In March 1986, the SSC Central Design Group (CDG) presented to the U.S. Department of Energy a Conceptual Design Report for the SSC. Of necessity, it was non–site-specific. The CDR, which was reviewed in depth by the DOE, established the feasibility and cost for the SSC. Subsequently, in April 1987, the DOE issued an *Invitation for Site Proposals* (ISP), based on the CDR. A final site decision is scheduled for January 1989, with transfer of land to the federal government beginning in March 1990.

At the present time, major construction projects for new accelerator facilities, some approaching the scope of the SSC, are underway at SLAC in the U.S. (SLC), at CERN in Switzerland (LEP), at DESY in Germany (HERA), and at Serpukhov in the USSR (UNK). All of these are at more advanced stages than the SSC, so the CDG has drawn on the experience and expertise of these centers in evaluating and devising mitigative measures for the potential hazards involved in the SSC project. Furthermore, data and experience from the existing accelerators at these centers, as well as at Brookhaven National Laboratory (BNL) and Fermi National Accelerator Laboratory (Fermilab) are directly applicable or can be readily scaled to the SSC. Through workshops, task forces, and the direct participation of personnel with particular skills and experience, the CDG has made every effort to understand and minimize any potential hazards associated with the project.

The approach of the CDG to safety considerations for the SSC has been to identify potential hazards early in the design process in order to mitigate them, as far as possible, by design and engineering. This Safety Review Document (SRD) analyzes those potential hazards that are inherent to the operation of the SSC, independent of site-specific considerations, and indicates the approaches that will be taken to eliminate or mitigate potential hazards. By this approach, the document serves as a preparation for the Preliminary Safety Analysis Report (PSAR) to be written when the DOE has named a site for the SSC.

The experimental program for the collider cannot be defined until some time after project approval; however, through various summer studies, workshops, and task forces, the parameters of detectors for several classes of experiments have been examined. The results of these studies provide sufficient clarity to undertake the design of the experimental facilities to house the detectors and to understand and mitigate the potential hazards for the facilities. The range of potential detector safety hazards is examined here in a generic fashion to determine possible mitigative measures that may be designed into the facility.

Once the experimental program is defined, a specific design review including safety considerations will be required for each detector prior to its approval for construction.

Certain classes of hazard, such as a gassy tunnel or a tunnel with an unusually high influx of water, will be specific to the choice of a site. These types of hazard, along with the specific measures to mitigate them, will be treated in detail in the PSAR, which will be site-specific. The construction phase of the SSC project is explicitly not treated here, since occupational safety and health in the workplace for the construction industry is regulated in detail by codes specific to the industry and is enforced by the appropriate regulatory agencies. However, the installation phase of the technical components of the facility is the responsibility of the operating contractor. Potentially, this phase involves the highest density of personnel in the underground enclosures. The actual situation depends on funding profiles, magnet production rates, and other factors not yet defined by DOE. A supplementary document analyzing the potential hazards during the installation phase, together with measures to be taken in eliminating or mitigating them, will be produced once these factors are defined and prior to the start of installation.

In the design and operation of the SSC, all relevant health and safety standards and guidelines such as ANSI, OSHA, NRC, DOE Orders, NFPA, and MSHA will be followed as applicable. Specific standards and guidelines used in the analysis of potential hazards and the design of mitigative measures are referenced in the appropriate sections of this document.

This Safety Review Document has been prepared by the staff of the Central Design Group assisted by Dr. Per Dahl on leave from Brookhaven National Laboratory, Professor Lawrence Jones on sabbatical from the University of Michigan, Professor Kenneth Edwards on sabbatical from Carleton University, and Dr. Victor Bremenkamp of Associated Universities, Inc. Comments from the DOE Chicago Operations Office, the DOE Office of Energy Research, and the DOE Office of the Assistant Secretary for Environment, Safety and Health have been very helpful.

Various members of the SSC Central Design Group Administrative Group helped with the typing and production of this document. Particular thanks to Ms. Donna Matthews, who coordinated and copy-edited the document through its many iterations, and to Ms. Nancy Talcott who helped manage the production.

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1 INTRODUCTION

1.1 THE SSC PROJECT

The U.S. Department of Energy (DOE) has announced its intention to build a new basic research facility, the Superconducting Super Collider to probe the basic structures of matter at energies twenty times higher than those currently available. These new energy levels will be achieved by accelerating intense, counter-rotating beams of protons to 20 TeV (trillion electron volts) in two accelerators built in a common, racetrack-shaped tunnel with a circumference of approximately 53 miles. At a number of locations (initially four) around the ring, the two beams of protons will be brought into head-on collision providing 40 TeV of available energy to create new states of matter. The collision points will be surrounded by massive detectors to study the interactions that will take place. The layout of the SSC laboratory, as described in the SSC report *Conceptual Design of the Superconducting Super Collider* prepared for the DOE, is shown in Fig. 1-1. This report, the CDR, established the technical feasibility and provided a cost estimate for the project. It supported DOE's submission of the project for inclusion in the FY89 Federal Budget.

The DOE initiated a site selection process to identify a site for the SSC with the *Invitation for Site Proposals* (ISP) issued in April 1987. An essential part of that process is the preparation of an Environmental Impact Statement leading to a Record of Decision when the final site is selected. In the DOE's timetable this site identification is scheduled for January 1989.

1.2 SAFETY ANALYSIS AND REVIEW

As part of the design process, a Preliminary Safety Analysis Review (PSAR) will be carried out by the management and operations (M&O) contractor for the project and submitted to the DOE.[1] The relevant DOE Operations Office and the Office of Energy Research will review the document and provide authorization for construction based on the review. Concurrence by the Office of the Assistant Secretary for Environment, Safety and Health within DOE is also required for certain hazard levels.

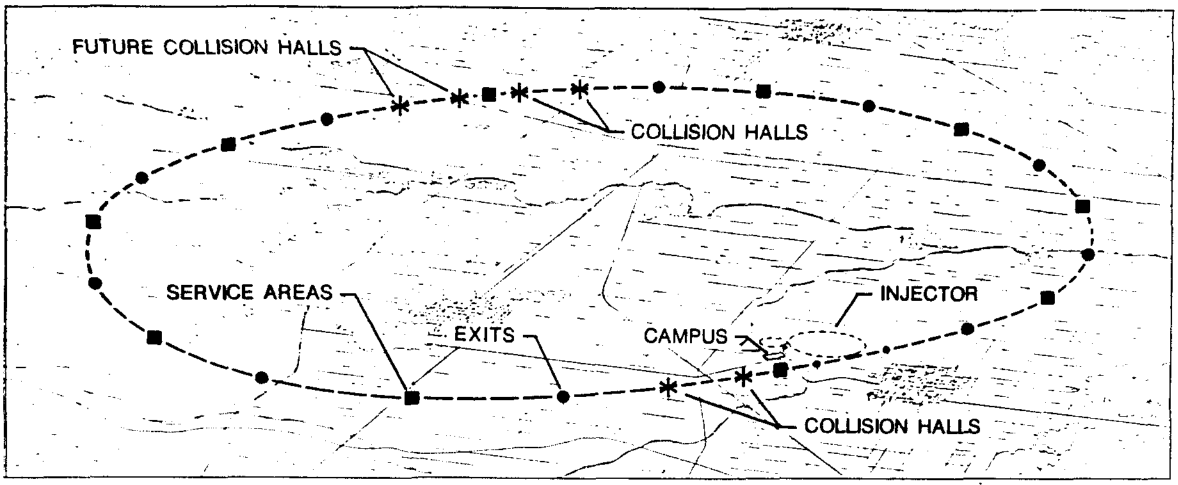

FIG. 1-1. Conceptual view of the SSC.

1.3 THE SAFETY REVIEW DOCUMENT

Properly designed facilities provide a much higher degree of safety than can be achieved by imposition of administrative controls and procedures on less adequate facilities. Attention to elimination or control of potential hazards in the design stage can also minimize operating difficulties resulting from safety problems and potential exposure to hazards. So, safety considerations must enter into the design of a project from the very earliest stage. This SSC Design Safety Review is intended to analyze in a non-site-specific fashion the potential safety concerns associated with the operations of the SSC, to describe ways to eliminate or mitigate the hazards, and to display the design concepts incorporated to meet these concerns. In this way it can serve as a basis for discussion among those with safety responsibilities for the project, thereby facilitating the later review process. Guidance in preparing this document is derived from relevant DOE Orders.[2]

REFERENCES

[1] DOE Order 5481.1B Chg 1 (5/19/87).

[2] DOE Order 5481.1B (9/23/86), DOE Order 5481.1B Chg 1 (5/19/87), and DOE Chicago Operations Office Order CH5481.1A (3/26/82).

2 IDENTIFICATION OF POTENTIAL HAZARDS

2.1 DESCRIPTION OF THE PROJECT

The SSC is a high-luminosity, proton-proton, colliding-beam accelerator designed to provide collision energies at least an order of magnitude greater than those presently available at existing high-energy physics facilities. The SSC facility is designed for a center-of-mass energy of 40 TeV. This potential will allow exploration of the fundamental constituents of matter in a hitherto inaccessible realm where new, fundamental phenomena are expected to appear.

As described in the CDR, the heart of the SSC is a pair of counter-rotating proton beams, each of which is constrained within a 3.7-cm-diameter vacuum pipe around the circumference of the accelerator.[1] The two beams are vertically separated from one another except in the collision regions. Each vacuum pipe is contained within a ring of magnets that constrain the protons to be within the pipe and to follow the circumference of the machine. The two beam systems are contained in an underground tunnel, which roughly describes an oval, 53 miles in circumference. The cross section of the tunnel has a diameter of ten ft. Access to the tunnel housing the magnet rings is provided at ten service areas spaced around the ring. Ventilation shafts with emergency exit provisions are located approximately midway between the service areas.

The magnet rings consist of periodic arrays of dipole (bending) magnets and quadrupole (focusing) magnets. The dipoles establish the curvature of the orbit of the protons around the ring, while the quadrupoles confine the particles to a narrow region about the ideal orbit. For the dipoles specified in the CDR, the maximum magnetic field is 6.6 tesla (66,000 gauss). For the design energy of 20 TeV, the circumference of the rings is determined by this maximum bending field to be 53 miles. To achieve this field, the magnets of the collider make use of superconducting technology, which uses cryogenic fluids to establish and maintain the superconducting state.

In the layout as presented in the CDR, the areas where the beams are brought into collision for experiments, the interaction regions (IRs), are clustered along the sides of the oval. The near cluster contains the main laboratory campus, the injector complex, and two of the experimental areas; the far cluster contains the two remaining experimental areas and the potential for future experimental areas. This arrangement tends to enhance operational efficiency and reduce costs for infrastructure and support requirements.

The experimental areas consist of large underground halls within which the two proton beams are deflected vertically to collide head on. In these collisions, large numbers of subnuclear particles are produced, the numbers, types and behavior of which provide insight into the processes that give rise to them. Experimental apparatus, the detectors, are deployed around each collision point to gather for later analysis relevant data on the particles from selected collisions. These detectors consist of very large arrays of electronic sensors and circuits, energy-absorbing materials, and magnetic fields: the largest detector can weigh as much as 40 kilotons.

Since the probability of a proton-proton collision is comparatively small, the two beams in collision are depleted at a slow rate and can continue to circulate for many hours without need of replenishment. A normal machine cycle is expected to be one filling per 24 hours.

The injector system, which provides the protons for the two collider rings, consists of a proton source coupled to a linear accelerator, followed by a cascade of booster synchrotrons. The final booster, which accelerates the protons to 1 TeV, is substantially the same as the Tevatron at Fermilab or the new HERA facility at Hamburg in Germany. Each of the accelerators that constitute the injector (i.e., the linac and booster synchrotrons) is housed in a separate tunnel with a radius (or length in the case of the linac) appropriate to its energy. In addition to providing protons for the collider rings, the injector also provides 1 TeV protons for the test beam facility where components of the detectors may be tested and calibrated before being assembled into the detector.

A minimum depth for the various tunnels and the collision halls in the IRs is set, as will be discussed below, by requirements for radiation shielding. In determining these depths, the designers have chosen to add a safety factor corresponding to a factor of three times the design intensity and a factor of ten times the design luminosity. With this provision, the minimum depth above the tunnel for the collider ring is 30 ft (9 m) for a nominal soil density of 1.8 g/cm^2. The actual depths of the various enclosures will be determined by the geology and topology of the final site chosen and may vary by as much as several hundred ft.

2.2 DESCRIPTION OF POTENTIAL HAZARDS

2.2.1 Types of Hazards

The SSC, as a major operating facility encompassing a large land area, will present potential hazards in the full range of safety concerns such as health physics, industrial safety and hygiene, fire protection, and environmental protection. The relevance of these concerns varies among the three types of facilities making up the laboratory. The first type includes those facilities related to the infrastructure (including the roads and utilities) and the campus with its administrative and support facilities. The second includes those related to the operation of the accelerator proper, that is, to the technical facilities of the collider and injector systems. The third includes those facilities with the operation of the experimental facilities; experimental facilities here means both the experimental detectors with their associated technical equipment and the structures and utilities that house and support the detector operations. As will be discussed in detail in Chapter 8, all of these potential hazards have been previously encountered and successfully mitigated at other accelerator facilities either operating or under construction. The SSC differs from these primarily in the matter of scale, so mitigative measures must take this into account.

2.2.2 Conventional Hazards

The first grouping of potential hazards, those related principally to the campus and the infrastructure of the entire site, include fire in any of the various campus buildings such as the central laboratory or works buildings; machine tool hazards in the works buildings; hazards associated with the use of chemicals in electronics production and magnet facilities; and electrical hazards, particularly with respect to the high voltages in the Near and Far Master Substations and the 13.8-kV switchgear for local site distributions. Primary power distribution around the site will be within the collider ring tunnel, so it does not affect the safety of the general public. However, the road network linking the various facilities will consist primarily of the existing public road network. Potential traffic hazards are collisions, road damage, and weather-related conditions on roads under the jurisdiction of the laboratory. Other traffic hazards are those associated with laboratory equipment and personnel operating on the public road network in the course of laboratory operations. These hazards, such as traffic and operation of machine tools, are of a type and magnitude routinely encountered by the general public and standard methods exist for mitigation of such hazards. In accordance with DOE guidelines, they will not be treated further in this document.[2]

2.2.3 Accelerator Hazards

The second category of hazards involves the technical components of the SSC facility exclusive of the experimental areas, which are treated separately as noted above. Most of the technical components of the SSC will be located in the collider and injector tunnels and enclosures and in the associated above and below ground structures and service areas.

Like all major accelerator facilities the SSC will operate continuously, 24 hours per day and 7 days per week, except for scheduled maintenance periods and equipment failures. The projected operating schedule for the SSC is based on 14-day cycles, of which two days would be for maintenance when the machine is not accelerating beam. To maintain a high degree of operational reliability, as much as possible of the equipment requiring regular maintenance is located outside of the accelerator enclosures in the service areas and related buildings. Development of a robot inspector will reduce the number of personnel accesses required for routine inspection and maintenance.[3]

The main component requiring regular tunnel access for maintenance is the shielded electronics modules located at each cell, or approximately 400 for the collider ring. The expected failure rate in initial operation is approximately 50 per week, or 100 per operating cycle. Including travel and replacement times, this involves approximately 40 manhours of access over the two maintenance days, or 10 two-man crews in the tunnel for eight hours each day. On the average, there would be one two-man crew in each 5-mile (8-km) tunnel sector on maintenance days with the tunnel unoccupied during the remaining 12 days of the cycle.

Failure of a magnet or similar accelerator component would require unscheduled access into the tunnel. A detailed analysis of the personnel levels and times required for magnet replacement was carried out in connection with the choice of a magnet design for the SSC.[4] Because of the sequential nature of the tasks involved in the replacement, it was estimated that the maximum level of tunnel occupancy in the course of the replacement would be up to seven people. Personnel would be in the tunnel for a total of six shifts to complete the replacement. On the average a total of ten such unscheduled events per year is anticipated, requiring 480 hours of tunnel occupancy out of a total of 6000 scheduled operating hours.

Access to the underground enclosures during these maintenance and repair periods will be strictly controlled and limited to trained, qualified personnel and escorted visitors who have been briefed by safety personnel and issued all required safety equipment. Safety procedures during access will be based on applicable sections of MSHA codes and regulations[5] as verified at similar research facilities.

2.2.3.1 Underground Spaces

Fundamental requirements for worker safety in the tunnel and underground enclosures are[6]

- A continuous supply of fresh air
- An unobstructed path to a point of safety from any local hazard
- An emergency warning system

Therefore, potential hazards associated with the tunnels and underground enclosures involve failure to meet these requirements in design or operation. The ventilation systems for the tunnel and underground enclosures are sized to provide one air change per hour; the tunnel aisles are unobstructed between exit points, so an alternate escape route is always available if a given exit is unavailable; finally, an alarm system that warns of oxygen deficiency, fire, and potential radiation and provides indications of exit directions is provided in the tunnels and enclosures.[7] These provisions, as expressed in the CDR, answer the requirements of worker safety. Potential hazards in operations arise from the loss of any one, or several, of these provisions.

2.2.3.1.1 Loss of Fresh Air Supply. Loss of an adequate fresh air supply can occur by failure of the ventilation fans, blockage of passages, or reduction of the oxygen content by fire or cryogen release. For each of these occurrences, provision must be made to restore the fresh air supply and evacuate personnel. Also, the potential for exposure to reduced oxygen levels will be reflected in health requirements for certification of personnel for access to the underground spaces.

2.2.3.1.2 Obstruction of Normal Exit Path. Alternate routes from any point in the tunnels or underground enclosures are included in the design. In case of an emergency inhibiting the use of a normal exit, such as a blockage or fire or cryogen release, personnel must be able to reach an alternate exit safely. Considerations here must include transport availability, indication of escape direction, and the distance an individual might be required to travel on foot. This also will be reflected in requirements of physical fitness for access to the underground space.

2.2.3.1.3 Emergency Warning Systems. Potential hazards associated with the Emergency Warning Systems are loss of system power, failure of detectors and of warning devices, and cutting off of a portion of a system from the central monitoring point. Provision must be made for redundancy, routine monitoring of the system status, and alternate power sources.

2.2.3.2 Tunnel Transport

For normal operations, the distances from the access point to a work point translate into lost time for personnel. To minimize this lost time and facilitate operations and safety, a transport system of the "people mover" type will be installed in the tunnel (see Fig. 4-7). The system will be capable of speeds up to 15 mph for personnel carriers, somewhat less for equipment transporters. The presence of these vehicles travelling at such speeds in the restricted space of the tunnel introduces the possibility of collisions between vehicles and personnel, between vehicles and equipment, and between personnel riding on the vehicles with equipment in the tunnel. The motors and battery packs constitute a potential fire hazard. The experience of the LEP project at CERN with operating its monorail system in the tunnel, as well as the considerable experience of Fermilab with golf carts in the Tevatron tunnel and of industry in the design and operation of people movers, will provide guidance for mitigating these hazards.[8]

2.2.3.3 Electrical Hazards

During those periods when personnel are allowed into the tunnel for installation and, later, maintenance, hazards arising from the presence of the various electrical distribution and subdistribution systems must be taken into account. In the collider ring tunnel the dual 35 kV distribution from the master substations is carried in the tunnel using armored cable attached to the tunnel wall. From the service areas, the power for use in the tunnel is redistributed within the tunnel at 13.8 kV with substations in power alcoves at approximately 0.6-mile (1 km) intervals to provide the 480 V used in the tunnel. The DC bus for the magnet excitation is carried for the most part within the magnet cryostats and is not accessible. In addition, personnel are normally not allowed in the tunnel when the magnets are energized. In a less severe form, all of these potential electrical hazards are also found in the above-ground service areas from which the cryogenics and electrical power are distributed. In the less restricted circumstances at the surface, normal industrial practice is sufficient to mitigate the problems associated with the electrical distribution. Applicable sections of relevant codes will be used in design and operations.[9]

2.2.3.4 Cryogenic Hazards

The presence of large quantities of cryogenic fluids in the restricted underground spaces of the collider ring and High-Energy Booster (HEB) can contribute to the interruption of the fresh air supply, as noted previously. In addition, it brings in the possibility of personnel in the near vicinity of a spill being incapacitated by the extremely low temperatures of the escaping fluids. Design considerations and operations procedures for mitigating these hazards have already been developed for existing research facilities; for the SSC, detailed analysis and design and operations considerations for their mitigation are given in Chapter 8 of this document.

2.2.3.5 Radiation

The very high intensity beams of the SSC would constitute a radiation hazard if they were accessible to personnel. However, personnel are excluded from the accelerator enclosures during operation.[10] In addition, the accelerators are buried sufficiently deep that, even under the worst assumptions, insufficient radiation, less than 10 mrem/y, is present outside of controlled areas to constitute a hazard. As a result of the operation of the machines, there will be a build-up of residual radioactivity leading to potential levels of exposure as high as several hundred millirems per hour at certain locations, principally in the regions of beam transfer from one accelerator to the next. These would constitute a minor hazard for personnel working around them for an extended period, if not mitigated in the standard manner for such operations.

In spite of the much higher (per particle) energy of the SSC, the radiation hazard will be similar to that of existing, much lower energy accelerator facilities such as Fermilab or CERN, both of which operate as facilities accessible to the general public. In fact, the cumulative amount of radiation would be less than that experienced at Fermilab or CERN, because of the longer average cycle time of the SSC, which results in a much lower total number of protons and integrated energy being accelerated per day than at Fermilab or CERN.

2.2.3.5.1 Radon Emission. Radon atoms are formed in rock or soil from the decay of naturally-occurring radium in the earth.[11] The radon is generally trapped within the solid where it is produced, since the diffusion rate in solids is slow compared with radioactive decay. If radium is present in the rock of an SSC site, the presence of the SSC tunnel cut through the rock makes it possible for the radon produced near the tunnel wall to escape into the tunnel and mix with the tunnel atmosphere. This would then constitute a potential hazard for personnel accessing the tunnel.[12]

2.2.3.6 Flooding

For those sites where the accelerator tunnels and enclosures are below the local water table, a possibility may exist of water intrusion into the tunnels. The severity of this problem would depend on the amount of water available for flooding, as well as whether the flooded tunnel is in a plane or tilted. With the small cross section of the tunnel, intrusion of water into a tunnel tilted with respect to the local gravitational field could fill up the low point or points on the ring. Monitoring systems and appropriate sump pumps will be used to mitigate this problem.

2.2.3.7 Service Areas and Magnet Quality Assurance Facility

Each service area houses the refrigeration and power supply systems for the sector of the collider ring that extends for 2.5 miles on either side of it. In the case of the HEB, the service area serves the same function for the entire ring. In each service area there is a compressor building, housing the large compressors for the helium system, and a service building, housing elements of the helium cold box, the high-current dc main magnet power supply, and a controls area. The compressor building and those areas of the service building in which elements of the helium service are housed have a potential for oxygen deficiency due to leakage of cryogens. The compressor building, in addition, presents a noise hazard. The large screw compressors generate noise levels up to 110 db under load. The service building encompasses the top of the access shaft to the underground spaces, and so provides a potential for personnel falling down the shaft. Each of these areas, with their heavy electrical power loads, presents a potential for fire.

Except for the cryogenic hazards, all of the other buildings for technical systems around the collider and injector rings present potential hazards similar to those of the collider service areas.

An early project requirement will be a facility for performing acceptance tests on completed magnets for Quality Assurance (QA) and for magnet development. As part of the QA program, it is planned to test 10 percent of the magnets produced in industry at the operating temperature of 4.35° K. This facility may be designed as an extension of the Near Service Area adjacent to the campus, or be a separate facility at or near the campus. In either case, from a safety viewpoint it will mirror the potential hazards of the service areas, such as potential oxygen deficiency and precipitous temperature drops due to loss of cryogens, potential electrical hazards due to the 7000-A dc magnet power supply and to the 4160-V supply to the helium and nitrogen compressors, potential noise hazards from the screw compressors of the cryogenic systems, and mechanical hazards due to handling of the 11.5-ton magnets. These potential hazards are aggravated in the case of the QA facility, because this is a continuously occupied facility in contrast with the remotely-operated service areas. Experience with comparable facilities at BNL and Fermilab provides guidance for successfully mitigating these hazards.

2.2.3.7.1 Exit Areas. The exit areas, located midway between the service areas at a distance of 2.5 miles from them, are fenced, 1-acre (200 ft by 200 ft) facilities containing the intake shaft and equipment for the tunnel ventilation system. The ventilation shaft also serves as an emergency egress from the tunnel with a positive-pressure enclosure located at the base of the shaft. For a shallow site, a stairway will be incorporated in the shaft. For a very deep site, provision will be made in the design of the shaft head for emplacement of portable, self-contained hoisting equipment by the laboratory emergency response brigade to access the tunnel and to remove personnel in an emergency. Laboratory personnel would only visit these areas for occasional service and maintenance of ventilation equipment. Potential hazards arise from penetration of the small, isolated areas by intruders. There would then be potential for electrical hazards, for a fall down the ventilation shaft, or for disruption of machine operation.

2.2.4 Experimental Area Hazards

The third category of safety hazards comprises those in the experimental areas. There is at present no approved experimental program for the SSC. Therefore, the analysis of potential hazards associated with the experimental areas must rely on general inference from several sources: existing experiments at operating collider facilities, chiefly the UA1 and UA2 experiments at CERN and the CDF and D0 experiments at Fermilab; new experimental facilities under construction, notably LEP at CERN, HERA in Germany, SLD at SLAC, and UNK in the USSR; and conceptual designs evolved by several task forces, workshops, and summer studies devoted to the experimental program at the SSC.

The SSC project includes six or more experimental areas, of which four are to be implemented initially. In the CDR, as noted above, two of these are grouped with the injection straight sections in the near cluster while the two remaining initial areas and the two future areas constitute the far cluster. The ISP allowed for the inclusion of additional future areas and increased flexibility for machine operations through provision for parallel sections in the lattice around the experimental areas. Various versions of this bypass design could accommodate up to ten future halls within the parameters of the ISP.

For the purposes of the CDR, two types of collision halls were used, one suitable for experiments requiring very high luminosity and the second suitable for experiments at lower luminosity. An examination of the possible detector configurations for SSC energies in the studies cited above indicates that the collision halls to house the detectors must be somewhat larger than those indicated in the CDR. Both types will have a span of approximately 82 ft (25 m) and a height of approximately 115 ft (35 m). The high luminosity (also called low β) halls will have a length along the beam of approximately 265 ft (80 m), while the lower luminosity (medium β) halls will have a length of approximately 165 ft (50 m). The detector will be symmetric around the collision point to capture all of the particles from an interaction (4π detector). These detectors can weigh up to 40 kilotons.

Although the halls, like the tunnels, are underground enclosures, the potential hazards involved are quite different. The halls themselves are such large volumes and the environmental control systems required for operation of the detectors are such that the oxygen deficiency hazard inherent in the tunnels does not occur here. The principal concerns here are problems of falling objects; personnel falling from ladders, scissor lifts, or detectors; flooding; fire; and use of hazardous materials.

Radiation problems associated with the experimental halls are similar to those in the tunnel. That is, there are radiation problems in the enclosure, but the enclosures are heavily shielded and interlocked to the operation of the accelerator. The residual activation hazards are of the same magnitude as for the accelerators, up to about 100 mrem/h locally.

As noted above, there is as yet no detailed experimental program designed for the SSC. However, it is possible to discern some hazards generic to classes of experiments from conceptual designs and to make a few observations about hazards that may be encountered with some of the special devices that will be involved in certain experiments.

In general, the major detectors for the SSC are very large devices, up to 66 ft × 66 ft × 165 ft (20 m × 20 m × 50 m) and may involve up to a million channels of electronics. Various gases, some flammable, will be used. Detectors will have a magnetic field to determine the charge and momentum of particles. Some of these will involve superconducting magnets. Most detectors will involve calorimeters of one sort or another to measure the energy of particles; some of these will involve heavy metals and cryogenic fluids like argon. Each of these characteristics may involve potential hazards.

The sheer size of the major detectors, some four stories high, coupled with the need to service electronics and detectors over much of their surface, involves hazards of falling objects and of personnel falling from these heights. With an order of a megawatt of power required for the detection devices and electronics of the detector, some of it at quite high voltages, there is a potential for electric shock and for fire.[13] The use of flammable liquids and gases in some of the detectors aggravates this potential for fire. Both the detector gases and the cryogenic fluids used in superconducting magnets and in calorimeters reintroduce the problem of oxygen deficiency, particularly where the gases or evaporated fluids are heavier than air and collect at the floor of the detector hall. In cases where magnetic fields in the kilogauss range are not wholly contained, ferromagnetic objects like tools can be captured by the field; for lesser fields medical implants or pacemakers can be affected. The use of beryllium for vacuum vessels and lead or depleted uranium for calorimetry raise questions of toxicity and, in the case of the depleted uranium, flammability and radioactivity. Some combination of all of these potential hazards have been encountered and successfully mitigated at existing laboratories; the measures adopted for mitigating them in the design and operation of the SSC are discussed in Chapter 8.

REFERENCES

[1] *Conceptual Design of the Superconducting Super Collider, Attachment A,* SSC-SR-2020A, Chap. 10, edited by J. D. Jackson (March 1986).

[2] DOE 5481.1B, Chapter II, Section 4b.

[3] Work in progress, FNAL.

[4] *Report of the Task Force on SSC Commissioning and Operations,* SSC-SR-1005 (1 July 1985).

[5] Safety and Health Standards for Metal and Non-Metal Underground Mines, 30 CFR, Chapter 1, Part 57 (July 1, 1987 edition).

[6] *SSC Reference Designs Study: Conventional Facilities* (8 May 1984).

[7] "Radiation Alarms and Access Control Systems," NCRP Report No. 88 (30 Dec. 1986).

[8] "Superconducting Super Collider Transport System," Univ. Mobility, Inc. (11 Oct. 1985).

[9] e.g. NFPA70, NFPA70E.

[10] "Operational Radiation Safety Program," NCRP Report No. 59, Sec. 4.2 (15 Dec. 1978).

[11] *Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States.* NCRP Report No. 78 (31 May 1984).

[12] D. Goss, "Radon and Tunnels," SSC-N-480 (8 March 1988).

[13] "Investigation Report of the Fire in the Wide-Band Laboratory at FNAL, 3 Oct. 87," U.S. DOE Chicago Operations Office.

3 SITE DESCRIPTION

As noted in Chapter 1, the DOE has not yet selected a site for the SSC. For the CDR, site criteria were derived from the technical systems' requirements and these criteria were then incorporated into the *Invitation for Site Proposals* (ISP). Those generic site criteria are reflected in the site description that follows here. Following site selection, this description and accompanying safety analyses will be narrowed to reflect the selected site.

3.1 SITE AND LOCATION

The scale of the SSC is its most notable physical feature. An area of approximately 16 by 20 miles (26 by 32 km) will be influenced by its presence. The 53-mile (85 km) perimeter, oval collider ring will be sited to allow it to be configured in a plane (or close to one) with a slope not exceeding 0.5 degrees.[1,2] Exclusive use of a subsurface area of 70 ft by 1000 ft (21 m by 305 m) will be required to maintain the integrity of the arcs of the collider ring tunnel (Fig. 3-1) and provide protection during operation. The required land area is shown in Fig. 3-2. If the collider ring is near the surface, the upper and lower collider arcs require a 1000-ft-wide (305 m) land zone totalling approximately 3800 acres, as determined by construction and operational requirements and by the need for flexibility in final adjustments in positioning of the collider circumference. The beam-absorber/buried-beam areas must be located outside the main ring and require approximately 4600 acres. The injector complex covers approximately 1700 acres. It is presently assumed to be located on the inside of the main ring, to avoid interference with the buried beams and beam absorbers and to facilitate access during operations. This location is preferable, but is not a strictly necessary arrangement if the available site characteristics favor an alternative solution. Another 1700 acres is provided symmetric to the injector area for a possible electron-proton option. If the ring is sufficiently deep, the laboratory may need to acquire, for the upper and lower arc regions and the beam absorber/buried beam areas, only a stratified fee estate to the subsurface areas.

In the CDR, the two experimental clusters provide space for up to ten experimental halls, of which four will be built initially and the remainder reserved for future development. The clusters also provide space for possible beam-bypass options and for the injection and extraction points of the collider ring. Approximately 4000 acres are required for the two clusters combined. Finally, the campus area—facility headquarters—covers about 350 acres. It is most conveniently located adjacent to the injector complex but, here again, other arrangements are possible.

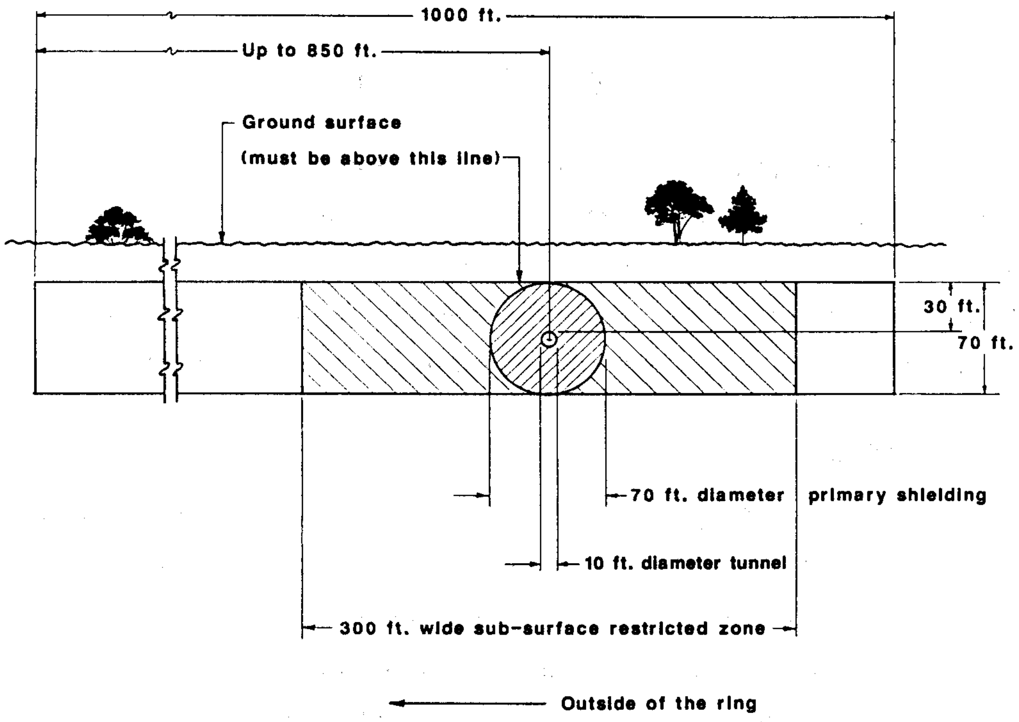

FIG. 3-1. Subsurface area required for the collider ring tunnel (assuming a tunnel that is at least 30 ft below the ground surface).

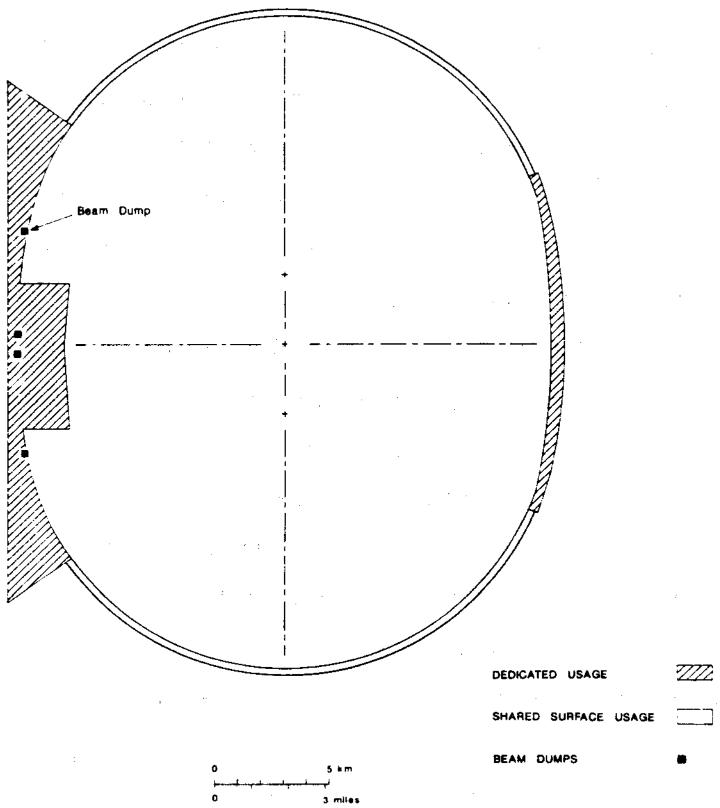

FIG. 3-2. Land required for the SSC.

The band of land defining the boundaries of the SSC facility will encircle an area of approximately 200 sq. miles that remains unaffected by its presence. Continued use and habitation of this area, as well as unimpeded transit across the ring, will be permissible. Not shown in Fig. 3-2 are easements for roads and utilities, including the existing road network. This network would have to be supplemented to connect the cluster regions and to provide access to the various service and exit areas located along the ring circumference.

The depth of the collider tunnel is largely dependent on topographical and geological factors. The minimum depth is 30 ft (9 m) of soil above the tunnel, assuming a nominal soil density of 1.8 g/cm^3. For deeper sites, experimental halls will be accessed through large-diameter vertical shafts.

It is assumed that the SSC site will be readily accessible to residential communities that will provide housing and services for the laboratory staff and their families (about 10,000 people total). Rural residences, agricultural activities, and highways will lie close to or over the (buried) accelerator ring. The impact of the SSC operation on these communities and individuals places requirements on the design of the facility. Thus radiation, noxious gaseous and liquid emissions, and noise to which the public is exposed will be maintained within acceptable limits as set by federal and state standards. The presence of those communities significantly augments the laboratory's resources for fire safety, emergency services, and security.

Electric power at up to 250 MW peak, 2200 gpm (gallons per minute) of industrial water and 250 gpm (average) of potable water will be available to the site. Of the industrial (cooling) water, 1500 gpm is available for fire protection. The electric power will be brought to the site from two preferably separate grids, or at least by two separately routed feeder lines, each connected to different points on the grid(s) so that essential loads are maintained in the event either line is out of service.[3,4]

3.2 SITE CONDITIONS

3.2.1 Geology

The SSC tunnel and experimental halls will be constructed either by underground tunnelling and excavation or by cut-and-fill from the surface. In either case, appropriate measures will be taken to ensure safe construction. In the case of underground tunneling in unconsolidated material, an initial liner may be required in advance of the installation and setting of a final concrete liner. For cut-and-fill trenching from the surface, the banks of the cut would be appropriately sloped or otherwise constrained by pilings and tie-backs as appropriate to avoid slumping or collapse.

Bearing capacity for the foundations of the experimental halls must be sufficient to support loads of up to 9 tons/ft^2 without serious differential settling.[5] Differential movement must be minimal between the halls and the adjacent tunnels.

3.2.2 Hydrology

Groundwater could pose significant construction problems in permeable soils or where tunnels in rock traverse water-bearing faults or shear zones. In some cases dewatering of the immediate area of active construction may be necessary; the procedures for discharging this water and the quality of the water discharged will be required to conform to local water quality standards.

Similarly, in sites where the industrial water supply has significant mineral content, the quality of the water discharged from cooling towers in the blowdown process will be required to conform to local water quality standards.

3.2.3 Seismology

Seismic disturbance of the SSC may affect the facility in two ways: the acceleration of the earth during earthquakes would stress supports of the accelerator magnets, experimental detectors, and other components; and the seismic displacement amplitude of the accelerator quadrupoles could perturb the beam orbits, causing the beams to be ejected from the machine into the primary beam absorbers.

In a seismically active area, special considerations are required in the design of surface structures and of underground experimental halls to ensure stability. Horizontal restraints and stronger supports may also be necessary for equipment such as magnets, cryogenics components, and experimental detectors.

To avoid these problems, limits are placed on the acceptable amplitude of seismic vibrations at the site, due not only to earthquakes but also to railroads, highway traffic, and other man-made sources. These limits are set forth in the CDR and in the ISP.

3.2.4 Meteorology

Weather and climate may have an influence on SSC cost and the efficiency of its operation. Temperature and humidity levels will affect heating and cooling system capacities and operating costs. Adverse and extreme conditions will affect construction, operations, and research productivity.

3.2.5 Ecology

The SSC will comply with the requirements of the National Environmental Policy Act (NEPA). An Environmental Impact Statement (EIS) including an analysis of the impact of construction and operation of the facility at the proposed site will be prepared. The project will also comply with applicable federal, state, and local environmental regulations.

For a summary of the SSC NEPA compliance plan and data needs at the Best Qualified List (BQL) stage, see Appendix D of the ISP. There is further discussion of the SSC environmental monitoring programs in Chapter 5 of this report.

3.2.6 Background Radiation

Since issues of radiation and radioactivation are important to the SSC, baseline information on the existing background levels of radioactivity in the soil and groundwater in the area of the SSC site will be gathered when the site is known.[6]

3.3 MATERIAL AND SCIENTIFIC RESOURCES

It is expected that the selected SSC site will be accessible to a significant university or institute that will work with the laboratory to provide graduate programs, adjunct and paid faculty positions, and other programs of mutual benefit to the laboratory and to the university or institute. Safety programs, including radiation safety, are generally in place in such research establishments, so no conflict is to be expected on safety issues. In possible instances of overlapping jurisdiction it is expected that the responsible safety officers of the laboratory and the local institution will establish mutually acceptable guidelines to meet the standards of both.

3.4 LOCAL DEMOGRAPHY AND REGIONAL RESOURCES

Each state has its own codes and standards for safety; in many cases these are a paraphrase of federal standards. Many states also have an office of occupational health and safety. Proposed SSC sites vary from those remote from population centers to those close to major cities. As state and local authorities have been closely involved in developing site proposals, there is every reason to expect strong cooperation with laboratory staff in safety and environmental matters. For example, the laboratory might contract with surrounding governmental units for services such as sewage treatment, water supply, and (non-radioactive) waste disposal. As the proposed sites could be very different from one another in this respect, further generalizations are avoided.

3.5 SPECIAL FEATURES OF SITE

Proposed SSC sites vary in almost every characteristic: Some are several hundred feet deep; others are near the surface (consistent with the ISP requirements). Some are in bed-rock; others are in clay or soils. Some are in arid regions; others are in regions of annual rainfall typical of the Eastern United States. Discussion of special features of the SSC site is therefore deferred until site selection is accomplished.

3.6 NEARBY (OFF-SITE) FACILITIES

The tight seismicity requirements for holding the proton beams in collision over a long period of time places limits on seismic disturbances from off-site facilities. In particular, quarrying operations or heavy road or railroad activity in the vicinity of the experimental areas would not be expected at the preferred site. Other than the requirements set forth in the ISP, it is not expected that the normal pattern of roads, pipelines, railroads, farms, and manufacturing or residential facilities will be disturbed in the vicinity of the SSC site.

3.7 CONFIGURATION, LAYOUT, MAPS, AND NOMENCLATURE

Figures 3.1 and 3.2, derived from the ISP, detail the land requirements for the SSC, the constraints on depth, and other key dimensions. The layout of the SSC and its injector complex are shown in Figs. 4-3 and 4-4. Beyond these descriptions, further details will depend on a particular site.

REFERENCES

[1] *Superconducting Super Collider Siting Parameters Document: A Technical Advisory on SSC Site Criteria and Catalog of Site Information Needs*, SSC-15 (June 15, 1985).

[2] *Invitation for Site Proposals for the Superconducting Super Collider* (ISP) DOE/ER-0315 (April 1987).

[3] ISP.

[4] *Report of the Independent Technical Review Committee Evaluation of the Los Angeles Metro Rail Project* (January 3, 1985).

[5] ISP.

[6] A. Bonifas, *et al.*, "Environmental Monitoring for LEP: Measuring Results of Preoperational Background Parameters During 1987," LEP Note 602, TIS-RP/IR/88-12 (7 March 1988).

4 DESCRIPTION OF TECHNICAL FACILITIES

The CDR and its four Attachments present a self-consistent design for the SSC.[1] For the construction project this design will be adapted to the selected site and modified as needed. As described in the CDR, the SSC consists of five basic components: (1) the campus/laboratory areas; (2) the site infrastructure, comprising roads and utilities; (3) the injector complex of cascaded accelerators in which protons are accelerated from rest to about 1 TeV (trillion electron volts); (4) the collider ring, where dual beams of protons are accelerated to 20 TeV and then stored; and (5) the experimental areas, which contain the particle detectors to record the debris emanating from the proton-proton collisions where the counter-circulating beams cross.

4.1 SITE FACILITIES

Adjacent to the campus is a main electrical substation, consisting of incoming high-voltage electrical service, transformers, switch gear, and distribution systems. A second main substation is located on the far side of the ring. Water treatment facilities are provided for processing the water used for the SSC, as are easements for utilities, including fuel and waste systems. A road network in the campus and injector areas connects to the cluster regions and the network that provides access to the service areas and the access points around the 53-mile (85 km) ring. Existing roads will be utilized as much as is practicable.

4.2 CAMPUS FACILITIES

The campus complex consists of approximately fifteen buildings clustered in four major groups: central laboratory building and auditorium, industrial buildings, warehouses, and auxiliary support buildings. A diagram of a possible campus plan, and the relationship of the campus to the injector facilities, is shown in Fig. 4-1. The campus occupies approximately 350 acres and accommodates about 2000 people. Design of these buildings will take into account appropriate requirements of life safety codes.[2]

The central laboratory building provides office and laboratory space for administrative and technical personnel. It contains all of the major offices of the facility and light laboratories for the development and testing of electronic components. It also includes the main control room for the accelerator, an auditorium, libraries, computing facilities, a main cafeteria, a series of conference rooms, and a small infirmary for emergency medical needs. Figure 4-2 is a conceptual rendering of such a building.

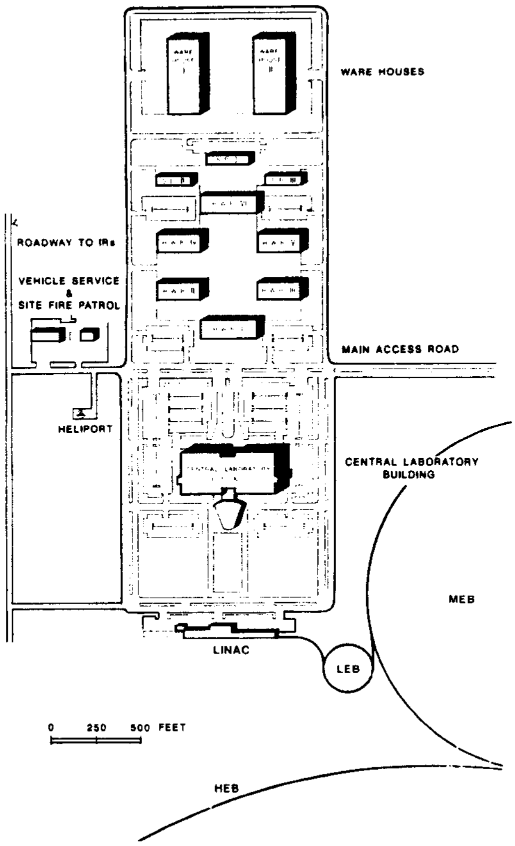

FIG. 4-1. Aerial view of a possible layout of the campus, illustrating its arrangement and its proximity to the injector facility.

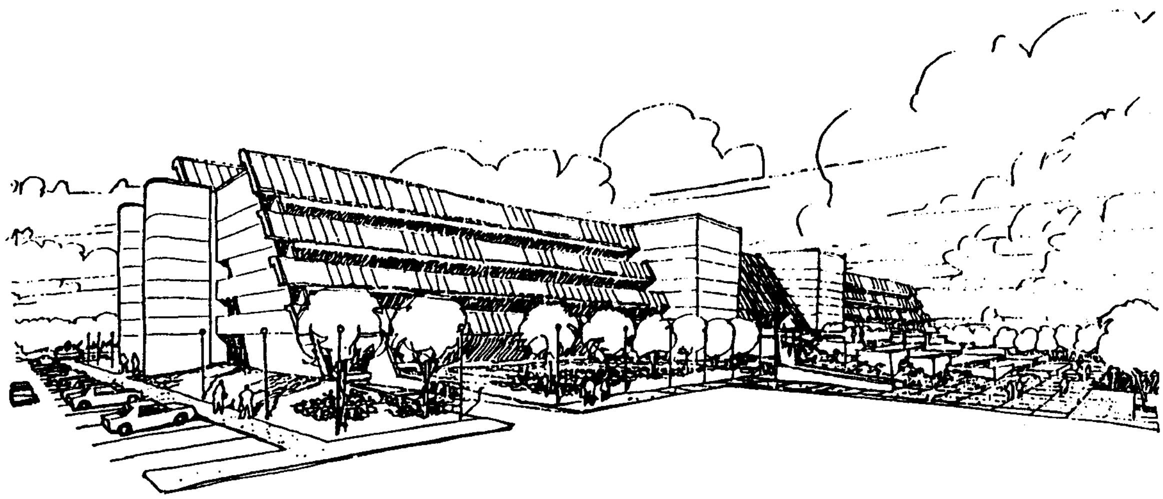

FIG. 4-2. An artist's conception of the facade of the central laboratory building.

Industrial buildings, as noted in the following section, house limited component assembly activities, various workshops, and associated offices. Warehouses serve as receiving and storage facilities. The auxiliary support buildings—fire, rescue, site patrol, visitor services, and vehicle service and storage buildings—provide services to the entire complex.

4.2.1 Work Areas

4.2.1.1 Heavy Works Buildings

Each of six heavy works buildings is designed for fabrication and assembly of such objects as components of experimental detectors. The largest buildings feature single high-bay work areas with large-capacity bridge cranes. Adjoining mezzanine areas contain office and work space; the ground floor is devoted to machine shops, supply rooms, a tool crib, and building services. Four smaller, but otherwise similar, heavy works buildings are sized for smaller and lighter work, such as conventional beam transport magnets or detector subassemblies.

4.2.1.2 Shop Buildings

There are three single-story shop buildings. One of these houses a main machine shop, with the largest machine tools belonging to the SSC facility. A second is given over to carpenter shops, a sheet metal shop, and a welding shop. Both buildings include limited office areas, tool cribs, and supply areas. The third shop is for cryogenic systems components. This type of activity suggests a single large work bay interrupted only by a small office area and a tool crib.

4.2.2 Ancillary Buildings

The first of the ancillary buildings is the emergency services building, located in a central area to ensure rapid access of emergency vehicles to all areas of the facility. It has full-depth vehicle bays for housing the fire and rescue equipment, small office and communications areas, a ready room and a domestic area for the fire crew. The site patrol and security operations occupy offices and communications areas at one end of the building.

The vehicle and site maintenance facility is centered in a building with vehicle bays and supply areas. The bays are capable of servicing the laboratory's fleet of trucks, vans and passenger cars. Site maintenance operations are conducted from one end of the building. Outside the building is a set of fuel dispensing pumps.

Two other buildings contain a water treatment facility and a sewage treatment plant, the former with the various circulating pumps and an adjacent large water storage tank, and the latter with settling, digester, and waste water purification tanks.

Special buildings or areas are provided as required for handling hazardous materials. These areas have a controlled and monitored environment and are accessible only to qualified personnel carrying appropriate monitoring equipment.

4.3 INJECTOR FACILITIES

The cascade of accelerators, starting with the linac and ending with the High-Eenergy Booster (HEB), are all variants of existing accelerator designs and systems; their design profits from knowledge gained in the construction and operation of their predecessors. The near-surface location of the injector makes it appropriate for the accelerators to be housed in shallow, concrete enclosures with earthen berms where appropriate to maintain correct shielding thicknesses around the various accelerators. Two prime performance objectives apply to the injector system: (1) its final energy must match the lowest energy permitted by the magnetic field of the collider ring, and (2) its beam must have a concentrated high flux of protons sufficient to achieve the specified full-energy interaction rates in the collider ring.

The CDR layout of the injector complex adjacent to the collider ring is shown in Fig. 4-3. Note that the geometry is so arranged that the HEB carries bi-directional beams. This is not a design requirement but facilitates the provision of protons to the main ring.

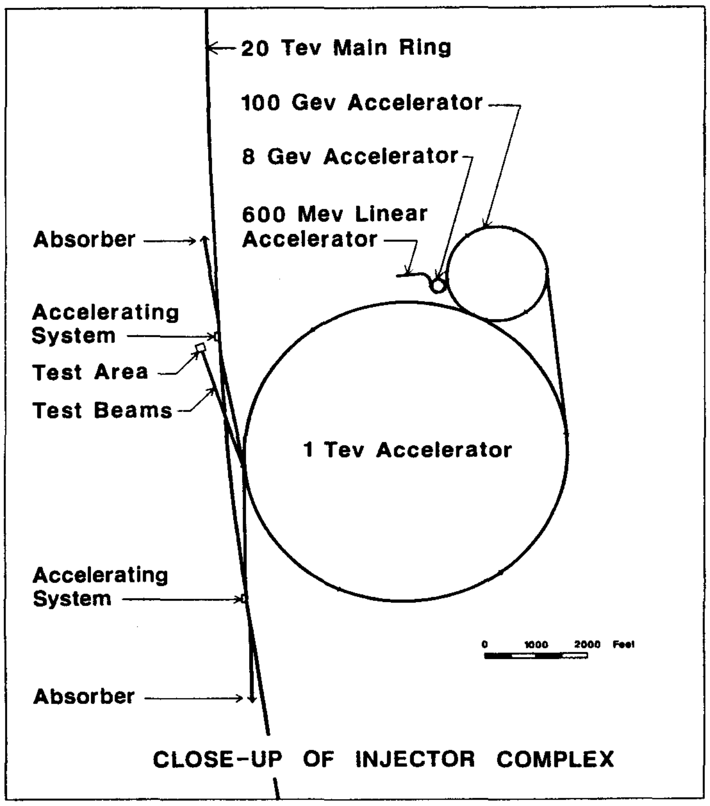

FIG. 4-3. Arrangement of the injector complex adjacent to the collider ring.

4.3.1 Linac

The first section of the injector chain is the linear accelerator or linac, in which the protons are generated in a hydrogen ion source and accelerated to an energy of 600 MeV. The linac is 410 ft (125 m) long, and consists of a succession of in-line rf cavities, each longer than the last to accommodate the gradually increasing proton velocity. It is housed in a conventional concrete structure below grade. Above and appropriately shielded from radiation is the service gallery, housing the klystrons that supply rf power to the linac cavities.

4.3.2 Low Energy Booster

From the linac, the protons are transported through a beam pipe into the Low Energy Booster (LEB). The LEB is a fast-cycling (10 Hz) proton synchrotron—the first circular accelerator in the sequence. The accelerator magnets that guide the protons are arranged around a ring of circumference of approximately 1000 ft (300 m). The final energy of the LEB is 7 GeV (billion electron volts).

4.3.3 Medium Energy Booster

The next step in the injection process is the Medium Energy Booster (MEB), which raises the proton energy from 7 GeV to 100 GeV. It, too, is a synchrotron utilizing conventional, iron/copper magnets. Its circumference is 1.2 miles (1.9 km).

4.3.4 High Energy Booster

The High-Energy Booster (HEB), the last stage in the injection sequence, raises the proton energy to 1000 GeV (or 1 TeV), the minimum energy necessary for injection into the collider ring. It is a slow-cycling (60 second) synchrotron 3.7 miles (6 km) in circumference. The HEB utilizes superconducting magnets. An additional function of the HEB is that of supplying test beams for the SSC, needed for testing detector components and subassemblies of the high-energy physics detectors. In the CDR design the beam absorbers for the collider rings are used in tuning the HEB.

4.4 COLLIDER FACILITIES

4.4.1 Tunnel Configuration

The collider ring tunnel is approximately 53 miles (85 km) in circumference, a length determined by the maximum beam energy of 20 TeV and maximum operating magnetic field of 6.6 T. A plan view of the ring is shown in Fig. 4-4, indicating its major features: the two diametrically opposed clusters containing the injector complex and six experimental "straight sections" or interaction regions (IRs); ten service areas comprising the facilities for cooling and energizing the superconducting magnet system of the collider; and ten exits that subdivide the ring into four sectors in the upper and lower arcs, each approximately 5 miles (8 km) long, and two special 6.8-mile-long (11 km) sectors comprising the near and far clusters. Figure 4-5 depicts a regular arc sector and its subdivision into sections and (half) cells. In addition to housing refrigerators, compressors, and power supplies, the service areas (see Fig. 4-6) are access points for people, vehicles, equipment, cryogens, and utilities. Thus, major access is possible every 5 miles (8 km), while emergency egress is possible every 2.5 miles (4.1 km) in the regular arcs.

A cross section of the tunnel, 10 ft in diameter, is shown in Fig. 4-7. Most notable are the two rings of superconducting magnets, one above the other, with a beam separation of 70 cm. Except for a warm gas return line, the cryogenic fluids are circulated within the magnet cryostats. Cryogenic isolation points are found approximately every 3300 ft (1000 m) (Fig. 4-5), where individual sections of magnets can be isolated and warmed up in case of need for maintenance or replacement.

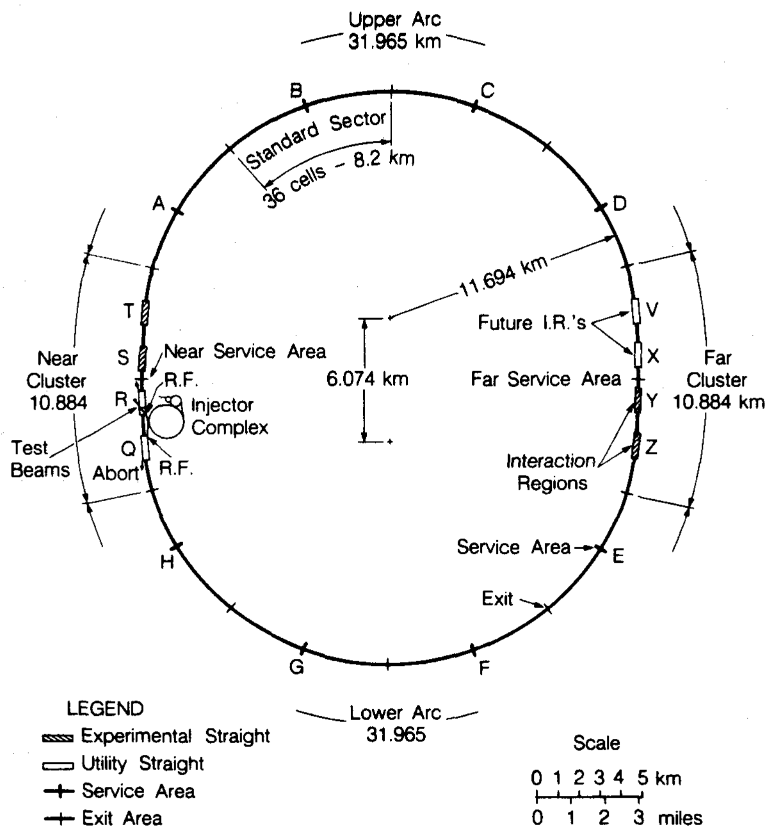

FIG. 4-4. Collider ring plan, showing major features of the conventional facilities and services.

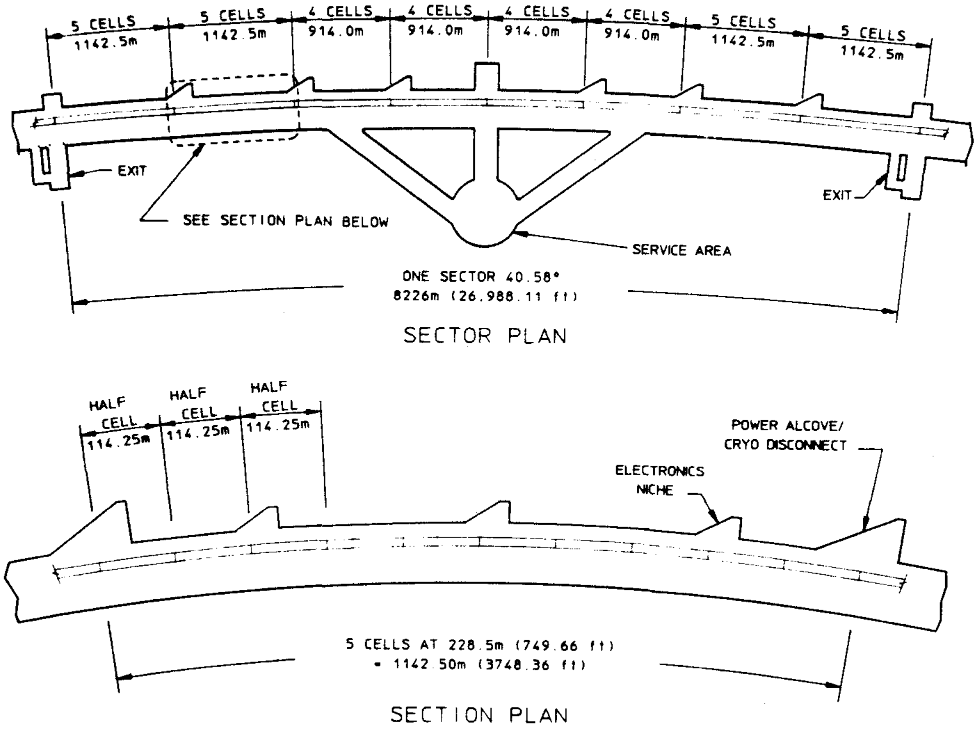

FIG. 4-5. Plan of a sector of the collider circumference, showing its subdivision into sections and (half) cells.

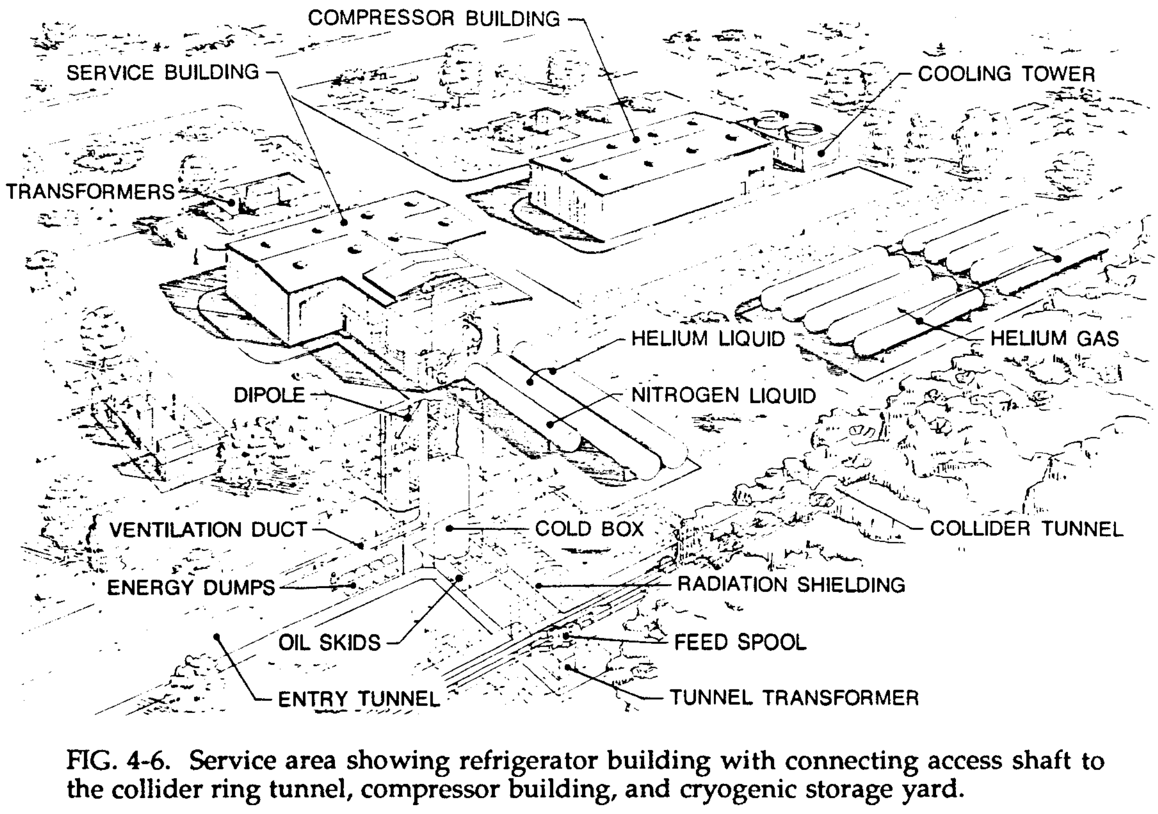

FIG. 4-6. Service area showing refrigerator building with connecting access shaft to the collider ring tunnel, compressor building, and cryogenic storage yard.

4.4.2 Magnet System

The superconducting magnet system for the SSC consists of 7664 superconducting dipoles for bending the two proton beams around the circumference of the lattice, 1576 quadrupoles for focusing the beams, and approximately 1600 "spool pieces" housing correction windings and instrumentation. In addition, special magnets are required to bring the two counter-rotating beams into collision in the IRs of the experimental areas. The most critical magnets, due to their demanding operating specifications and sheer number, are the regular dipoles; in this section their design is reviewed in moderate detail.

A cross section of a dipole ("cold mass") mounted in its cryostat, is shown in Fig. 4-8, and Fig. 4-9 depicts the cold mass in greater detail. The dipole is broadly classified as a "cold-iron, cold-bore" dipole incorporating excitation coils of a cosine-theta configuration. The magnet length, approximately 57 ft (17.35 m), is constrained by road transportation requirements. The peak magnetic field is specified as 6.6 T at an operating temperature of 4.35 K. The coils are formed from a flat cable fabricated from 23 (inner coil) or 30 (outer coil) strands of superconducting wire—each strand containing thousands of fine, twisted NbTi (niobium-titanium) filaments embedded in a high-conductivity copper matrix. The cable is insulated with a spiral wrap of Kapton and fiberglass-epoxy tape. The molded coils are clamped tightly around a cylindrical bore tube of 1.28 in. (3.25 cm) inner diameter with the aid of non-magnetic, interlocking stainless-steel collars. Final assembly of a magnet cold mass involves insertion of the collared coil assembly into a split, circular, laminated yoke of low-carbon steel, and closure of the yoke support vessel by welding together two half-shells of stainless steel. This support shell is also the outer wall of the helium containment vessel—hence the term cold mass. The weight of the cold mass assembly, roughly 8 tons per magnet, is borne by five cylindrical, reinforced plastic posts extending to the wall of the cryostat. In addition, the cryostat contains two aluminum heat shields (maintained at 20 K and 80 K, respectively), intervening layers of thermal insulation, and four cryogenic pipes, all housed in a steel vacuum vessel approximately 24 in. (61 cm) in diameter, as shown in Fig. 4-8.

Except for the IRs, the two rings of magnets are magnetically, electrically, and cryogenically independent of each other for operational reasons and in the interest of machine flexibility. They are arranged one above the other in the collider tunnel (Fig. 4-7), an arrangement that simplifies beam injection and extraction and magnet installation and generally results in a more efficient use of tunnel space. The vertical separation between the beams is 27.6 in. (70 cm), but the cryostats are separated by only approximately 3.6 in. (9 cm).

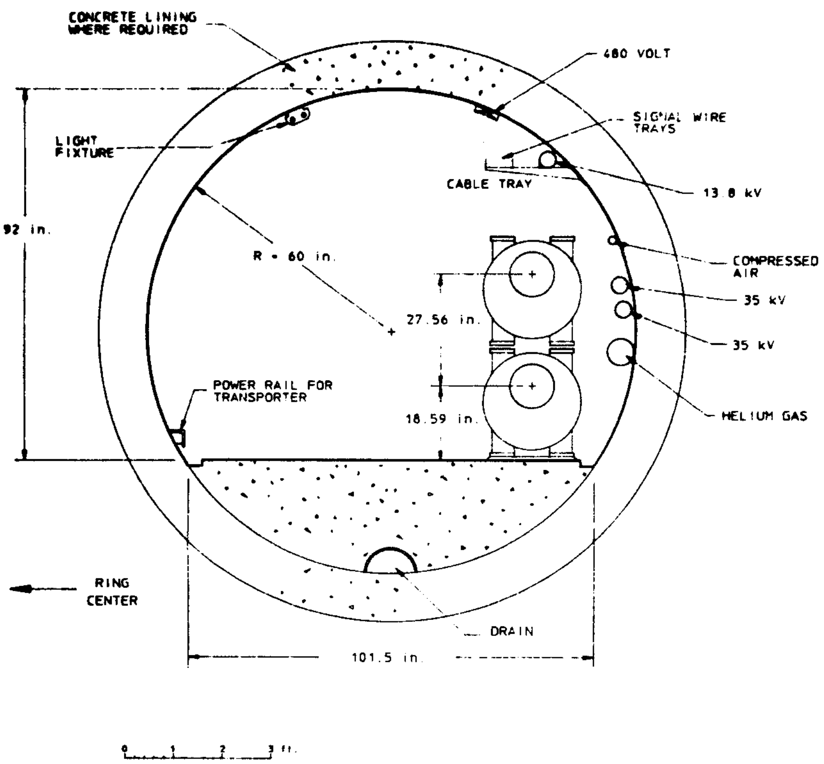

FIG. 4-7. Collider tunnel cross section. Beam separation is 70 cm.

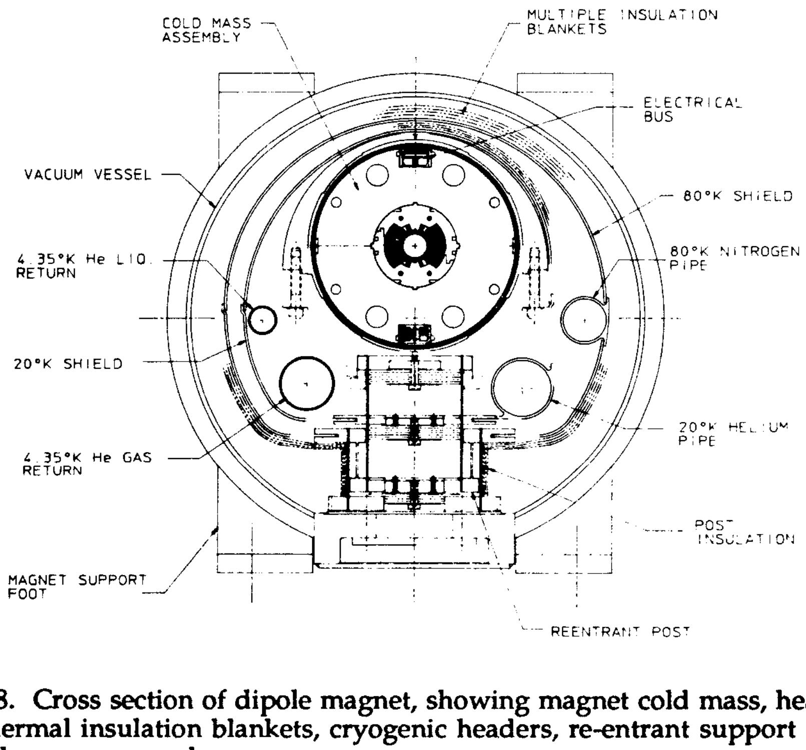

FIG. 4-8. Cross section of dipole magnet, showing magnet cold mass, heat shields with thermal insulation blankets, cryogenic headers, re-entrant support post, and external vacuum vessel.

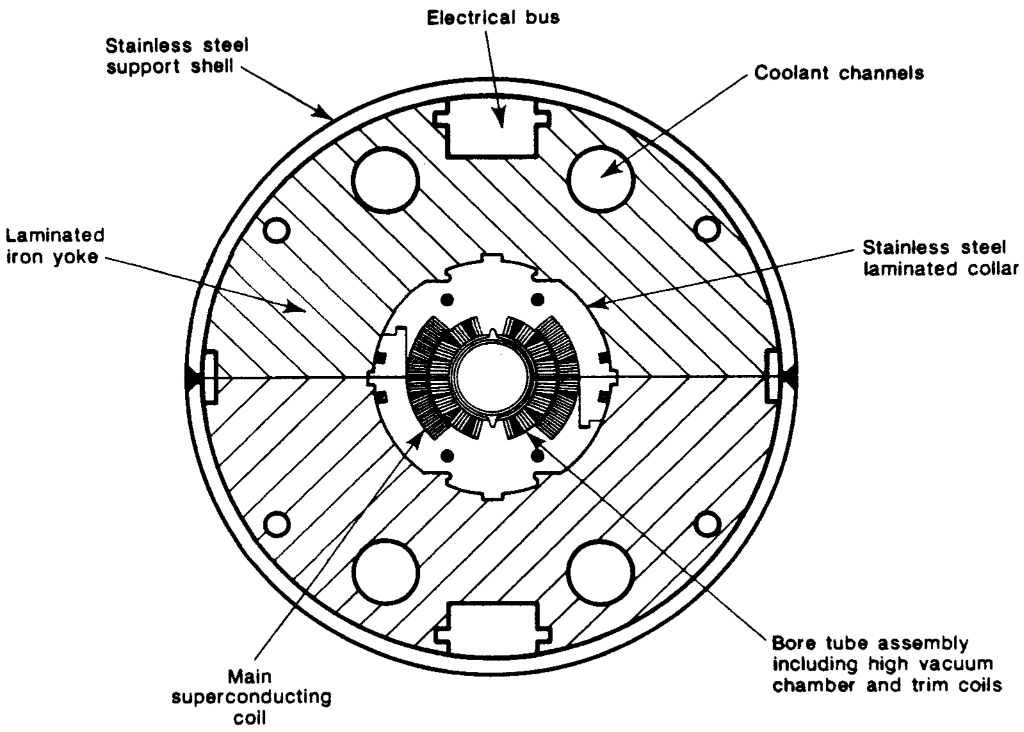

FIG. 4-9. Cross section of dipole magnet cold mass, including beam tube, coil winding, collars, iron yoke, and yoke support shell.

The quadrupoles have the same bore-tube diameter and inner coil diameter as the dipoles. Their two-layer coils are wound from cable identical to that used in the dipole coils. The operating gradient is 212 T m^{-1}, and the normal quadrupole length is about 16 ft (4.96 m). The mechanical and cryogenic details are very similar to those of the dipoles; quadrupoles and dipoles operate in series electrically. A half cell, the smallest repetitive unit in the magnet system (Fig. 4-5), consists of a quadrupole, spool piece, and six dipoles coupled together. In the drift spaces adjacent to each quadrupole is a spool piece that comes in a variety of types, which are enumerated in the CDR.

4.4.3 Refrigeration and Cryogenic Distribution System

The refrigeration requirement for the SSC, though large in aggregate, is well within the scope of current technology. Machinery and techniques that are part of current cryogenic practice are adequate to support SSC operation. The individual plants proposed for the SSC are smaller than those currently in service elsewhere. The experience gained in the operation of these systems gives confidence that the SSC cryogenics will meet expectations for performance and availability. New ground will be broken primarily in the extent of the system and in the low levels of heat leak for which it is designed.

The basic concept of magnet cooling and refrigeration distribution is illustrated in Fig. 4-10. A refrigeration plant is on the left, providing and accepting flow. Single-phase helium at 4.15 K and 4 atm is forced out into the magnet string of each ring upstream and downstream from the refrigerator, for a distance of 2.5 miles (4 km). It flows through the magnets in series and is recooled periodically at every cell by circulating through a heat exchanger, to maintain the superconducting windings at or below the specified 4.35 K. At the end of the 4-km string, the flow is returned toward the refrigerator. Since this fluid is flowing at a pressure above its critical pressure, in all parts of the circuit only a single phase is possible. Along this line, small amounts are withdrawn and expanded into pool-boiling recoolers spaced at intervals of one half-cell, 376 ft (115 m). The saturated gas from the recoolers is collected and returned to the refrigerator in a third line.

These low-temperature parts of each ring are enclosed in the vacuum-insulated magnet cryostats already mentioned. The helium gas cooling the 20-K shield flows from the refrigerator through one magnet string to the end of the sector and returns in the other string. Heat is removed from the 80-K shield by subcooled liquid nitrogen that is produced at two central air separation plants. Liquid helium can also be passed around the ring from one refrigerator to the next through the cryostat piping. Except for a single external header for the return of warm helium gas from the power leads (see Fig. 4-7), all the system piping is contained within the magnet cryostats, as shown in Fig. 4-8.

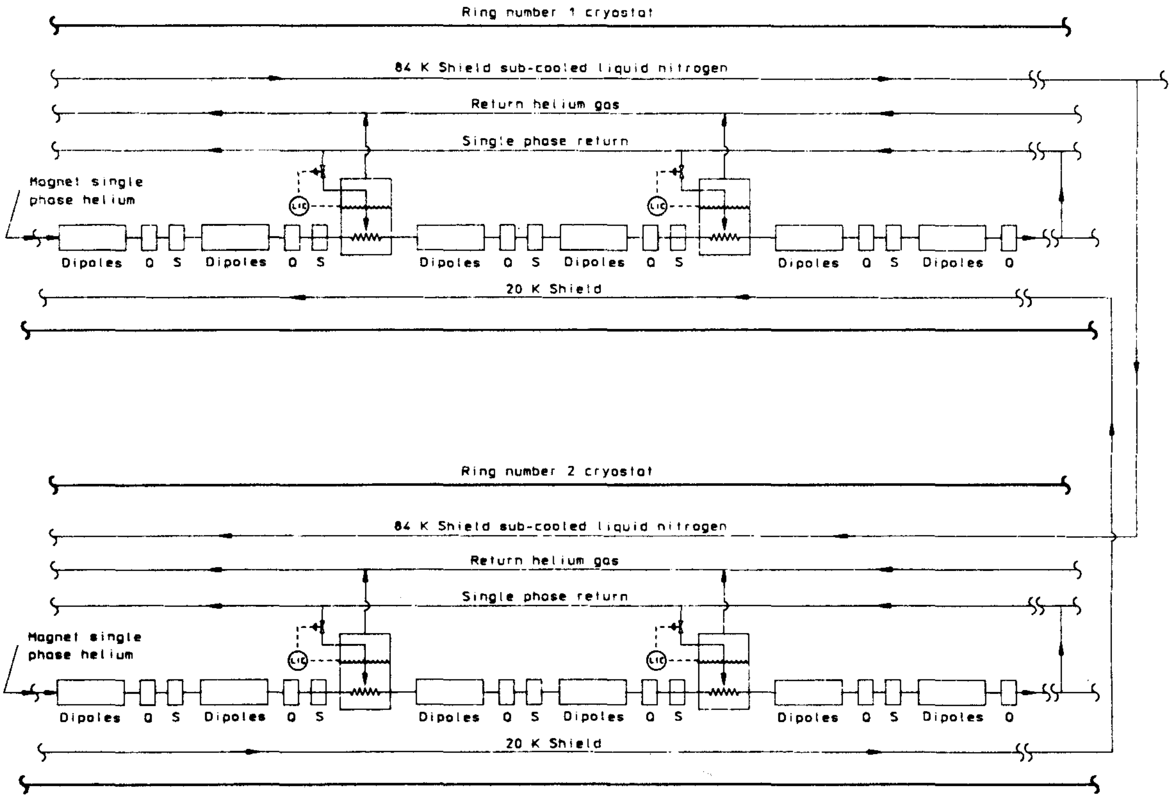

FIG. 4-10. Conceptual representation of cryogenic system for the SSC collider rings.

As noted in Section 4.4.1, the collider is divided into ten sectors of more or less equal length (Fig. 4-5): four 5-mile (8 km) long sectors in each of two arcs, joined by two 7-mile (11 km) clusters. The principal components of each of the ten cryogenic systems are a set of compressors for high pressure helium supply, a cold box containing a heat exchanger and expansion engines, and the associated magnet systems. The refrigerator plant is centrally located in the sector, and feeds two cryogenic strings, one for each ring, in each direction. Each 2.5-mile (4 km) string is subdivided into four 3300 ft (1 km) sections. A section is the smallest length of the machine that can be isolated and warmed up for service. Warm-up is accomplished by isolating the section through the use of U-tube disconnects and energizing electrical heaters within the cryostat. If a magnet has to be replaced, warming up a section, replacing the unit, and cooling down again is estimated to require nine days.

Except for the liquid nitrogen supply, each of the sectors is capable of independent operation at the rated heat loads. Neighboring refrigerators can share loads during cool-down or substitute for a malfunctioning refrigerator. For this purpose, each refrigerator is sized at 1.5 times the expected heat load, assuming the 1.3×10^{14} protons in each beam. In addition to the ten sectors of the main ring, the HEB represents an eleventh interconnected cryogenic unit with a similar refrigeration plant.

4.4.4 Magnet Power Supply and Quench Protection

Within a sector the dipoles and quadrupoles of each ring are connected in series to a single 6500-A, 300-V power bus. Except for the crossing regions, the two rings are powered independently from power supplies in the ten service areas, providing ten isolated circuits per ring congruent with the cryogenic circuits. The 300-V specification permits ramping a ring to full current in eight minutes. Since the dipole magnets are in series with the quadrupole magnets, the tracking within a sector (approximately 80 half-cells) is taken care of automatically, except for iron saturation effects in the dipoles. This saturation effect is about 2 percent at peak field and is compensated by the correction quadrupoles. The regulation from one sector to the next is done by differential transducers. The power supply arrangement in the clusters is more complicated, because of the need to independently vary some of the quadrupoles used in the IRs. The details are contained in the CDR.

4.4.5 Vacuum Systems

There are two vacuum systems of importance in the SSC. A very low residual gas pressure, about 10^{-12} atm, is required within the beam tube to permit long beam life. A rather modest vacuum, about 10^{-7} atm, is required within the radial space of the cryostat between the magnet cold mass outer dimension and vacuum vessel inner dimension to prevent significant heat transfer by convection. The primary pumping for both of these systems is provided by cryopumping. The gas molecules in the space will eventually strike a surface at a temperature of 4 K and be frozen there. For both systems the initial pump-down is accomplished with the use of portable carts that contain turbo-molecular pumps and diagnostic instruments. These are connected to the cryostat or beam tube through hand-operated valves, and are monitored through the control system. Once pump-out and cooldown are complete, the hand-operated valves are closed, and the carts are taken away.

The vacuum system has no permanently installed pumps or automatic valves. Vacuum gauges are permanently installed at each spool piece, and read out through the control system. Ion pumps are used for pressure monitoring, for valve interlocks, and to stop the progress of helium in case of a slow leak. There will be one ion pump per cell for each ring. This is indicated in Fig. 4-11, which shows the valves, pumps, instrumentation, and piping for the cold beam vacuum system at a full cell boundary. The cryostat for each spool piece has a vacuum barrier to facilitate leak-checking and to limit the damage in case of a catastrophic failure, such as a rupture in the vacuum or cryogenic systems.

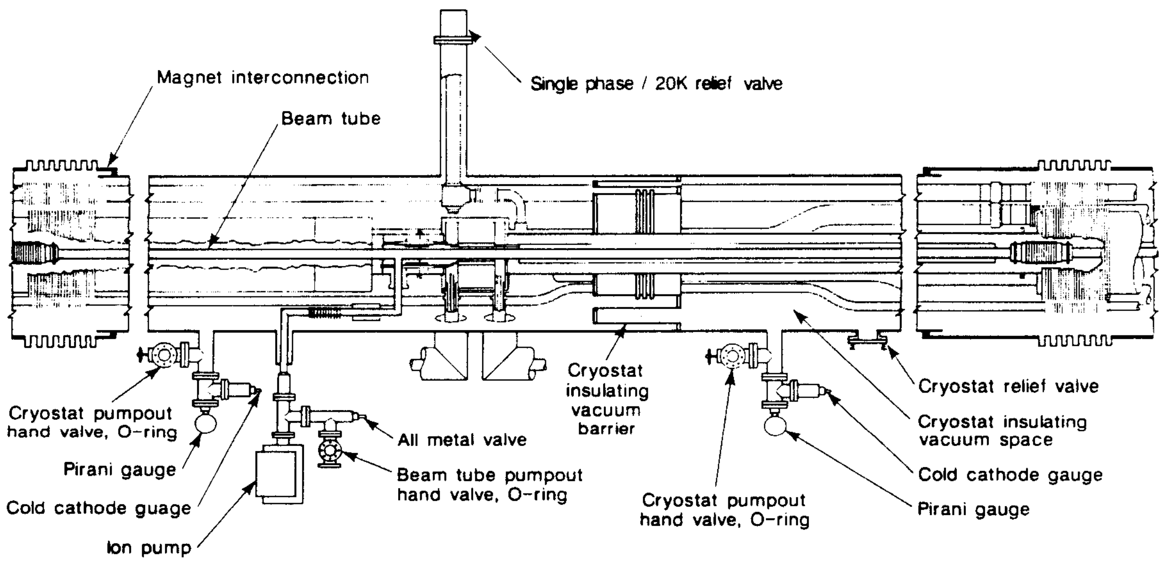

FIG. 4-11. The valves, instrumentation, and piping for the vacuum at a full cell boundary.

The beam tube vacuum system of the SSC is different from other proton accelerators in that synchrotron radiation emitted by the circulating beam desorbs gas molecules from the walls of the tube. The design of the vacuum system must take this into account.

Beam-tube gate valves will occur at each cryogenic section boundary, at 0.6-mile (1031 m) intervals within a sector, and at the sector boundary, i.e., at the end of each cryogenic loop. There are a total of 160 beam-tube gate valves in the cold system. Beam gate valves are also located in the room-temperature sections of the beam tube. These are regions near the IRs and utility straight sections, in particular at every warm-to-cold transition. In addition, a rupture disk is installed at the pump-out port closest to each beam valve to guard against over-pressurizing the beam tube if accumulated frozen gases in the beam tube are warmed. Each beam extraction line has a fast-acting valve to seal the line in case of rupture of a beam absorber window.

4.4.6 Beam Absorbers

As noted above, the main accelerator has a regular cycle of operation: injection, acceleration to 20 TeV, and storage of colliding beams. At the end of a cycle, when collisions over many hours have degraded the beam appreciably, the cycle is terminated by ejecting the beams, that is, dumping each beam via an extraction system into a specially designed facility called a beam absorber. The absorber consists of heavy shielding and stopping material sufficient to completely contain the heat and induced radioactivity of the full 20-TeV beam. In normal operation, the ejection of the beam occurs infrequently, once or twice a day. During accelerator studies and machine improvement periods, however, the beams may be ejected more frequently. Generally, the radiation from such ejections is insignificant, because the beams ejected during these periods are almost always at less than full energy and intensity. The beam will also be ejected when the beam sensors detect a potential orbit distortion. The beam absorber and beam ejection systems are described in Section 8.3.2, below, and in Sections 5.10 and 6.6 of the CDR.

4.4.7 Other Technical Systems

The collider facilities require a number of additional support systems similar in purpose, nature, and function to the corresponding support systems in existing accelerator complexes. These include: rf accelerating system of the main ring, required to raise the beam energy from 1 TeV to 20 TeV, maintain the tight bunching of the beams during collisions, and compensate for energy loss by synchrotron radiation; control system with computers, consoles, terminals, processors, and networks; beam instrumentation, radiation monitoring, and other instrumentation systems; water cooling systems; electrical power distribution, fire protection, heating and lighting systems; personnel safety interlock systems; and communication systems.

4.5 EXPERIMENTAL FACILITIES

A striking feature of high-energy colliding beam experiments is the size of the experimental detectors. For the important subclass of detectors seeking to capture a large fraction of the total 4π center-of-mass solid angle, that growth scales with collider beam energy. Beam energies have grown from 30-GeV–on–30-GeV at the CERN ISR Machine through 340-GeV–on–340-GeV at CERN Sp$\bar{p}$s and 900-GeV–on–900-GeV at the Fermilab Tevatron to 20-TeV–on–20-TeV at the SSC, a rise of more than a factor of 600 since 1971.

The experimental halls for the SSC (described in this section), are larger in size than existing ones at other accelerators, but only by a factor of about 1.5 in linear dimensions. The size scales roughly as the logarithm of the ratio of beam energies, a result that comes from fundamental characteristics of elementary particle interactions, most notably the exponential absorption of hadrons in bulk matter.

4.5.1 Experimental Area Configuration

Like experimental areas in earlier colliding beams machines, the SSC has a small number of IRs where experiments can be done. In the conceptual design presented in this report, four IRs are fully developed for experiments. Provisions have been made for more IRs to be developed later as circumstances demand. To complete the symmetry of the collider ring, there are two more straight sections in the machine, for a total of eight. The last two are used for injection of beams from the HEB and for the collider beam ejection systems. These eight "straight sections" of the accelerator are concentrated in clusters of four each, one cluster on the far side of the SSC and one on the near side contiguous to the campus/ injector complex. This section describes the initially developed experimental areas that occupy four of the eight straight sections.

Clustering the straight sections together rather than spacing them uniformly around the machine results in a number of design and operational advantages, some obvious and others less so. An obvious advantage is that of proximity. The clustering allows the central laboratory campus, the injector facilities and two of the four experimental areas all to lie within a few kilometers of one another and therefore within a few minutes vehicle travel time, a scale very similar to that of the experimental facilities at Fermilab. This is helpful both in terms of saving time and of increasing productivity for laboratory and scientific staff; it is very important in terms of response times for emergency services such as ambulance and fire calls.

Another benefit of clustering is the concentration of surface land acquisition and use. Less obvious benefits are the elimination of electric power and water piping runs that would otherwise have to be extended over tens of kilometers, either in the collider tunnel or in near-surface duct banks. Clustering of IRs also benefits property protection and site security.

One aspect of IR placement has a direct impact on the high-energy physics experiments. Since the collision points are a sizable source of radiation within the shielded enclosure during normal operations, the particles born at one IR collision point can, in principle, reach other collision points and detectors either through the collider tunnels (diffracted protons and fast neutrons) or through the earth (high-energy muons). Preliminary studies of these effects have shown that interference could be a concern at the highest luminosities if successive IRs were strung very close together with no intermediate bending of the circulating beam. Therefore, in the CDR the successive IRs are separated by 1.5 miles (2.4 km) of distance and 106 mrad (milliradians) of bending in the accelerator. With this distance and magnetic decoupling, the successive IRs do not interfere with one another. Four of the straight sections of the collider will be developed initially as experimental halls for high-energy physics experiments; each type of hall is optimized for a certain subset of experiments.

4.5.1.1 High Luminosity Collision Halls

An arrangement of a high luminosity (low-β) collision hall as given in the CDR is shown in Fig. 4-12. The central detector region in this model is 70 ft long by 75 ft wide by 70 ft high. Immediately adjacent to it, along the beamline, are smaller regions connecting the collision halls and the regular tunnel sections. These connectors are of similar transverse dimensions to the regular collider tunnel, but they incorporate the transition areas that allow for a vehicle bypass tunnel circling around the collision hall. The bypass tunnel carries utilities and cryogens and provides passage for magnet vehicles around the IRs.

4.5.1.2 Medium Luminosity Collision Halls

Medium-luminosity (medium-β) collision halls have smaller dimensions in the central detector area, but along the beam direction they may be longer than the low-β halls. Forward bays are used for small-angle detectors characteristic of a large class of experiments. The vehicle bypass is continued around the central collision area in the same way as in the low-β halls. The near-surface collision halls are constructed of reinforced concrete and have a radiation shield cover of earth and concrete, with a minimum thickness 30 ft (9 m). For the deeper halls, excavated out of rock, the requirements for the integrity of the cavern arch exceed the those for radiation containment, so no additional environmental shielding is required. A possible medium-luminosity collision hall is shown in Fig. 4-13.

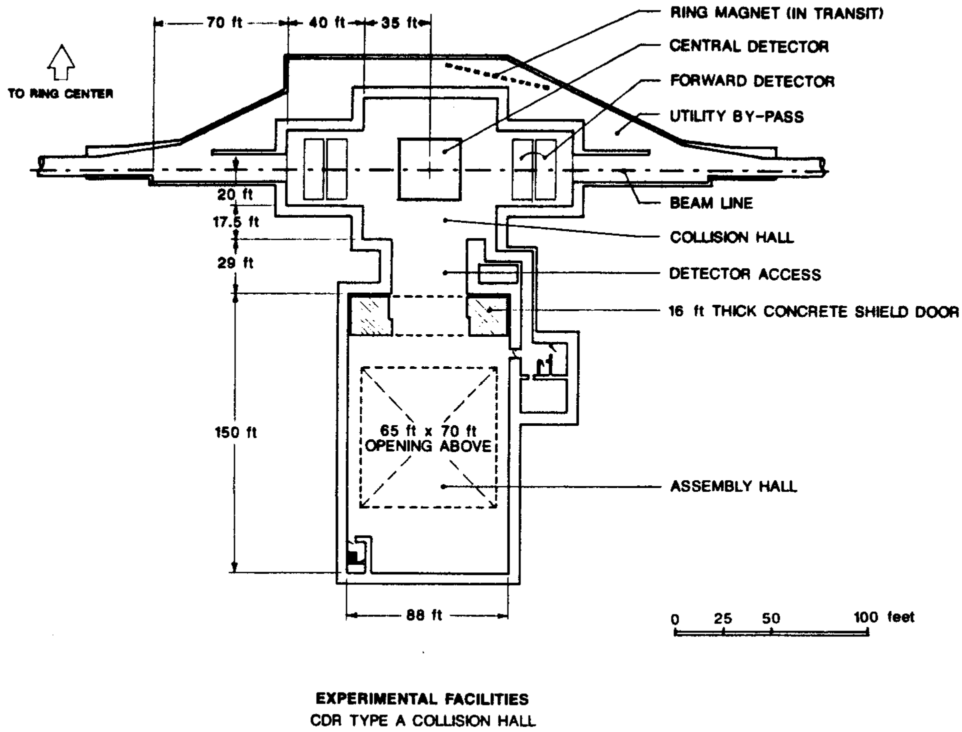

FIG. 4-12. Plan view of possible low-β collision hall with assembly area, showing collision hall, access way, shield doors, and staging building.

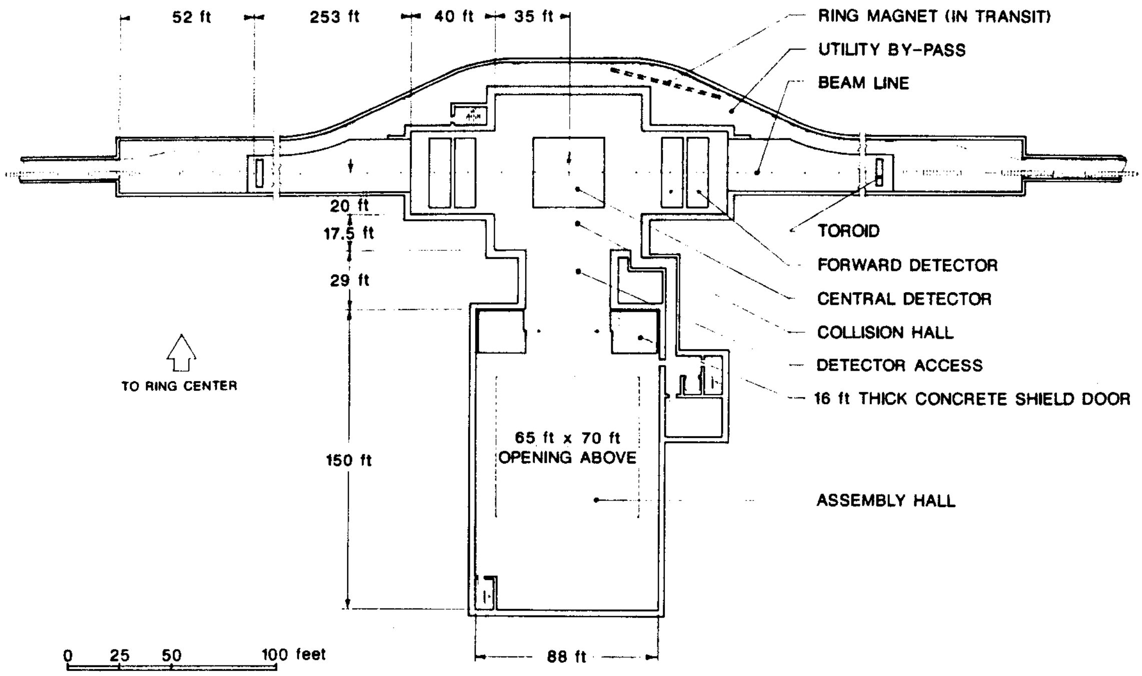

FIG. 4-13. Plan view of possible medium-β collision hall with assembly area, showing collision hall, access way, shield doors, and staging building.

4.5.1.3 Access Halls and Assembly Areas

Some of the experimental areas may have a detector assembly area at the same elevation as the collision hall for the experimental detectors to be prepared and serviced. The assembly areas are inside the ring and isolated from the collision halls by movable concrete shielding walls that permit the collider to operate while unrestricted personnel access is allowed in the assembly areas. Above the assembly areas are conventional industrial-type buildings that contain data-acquisition and detector-monitoring areas, shops, offices, electronics areas, and other support facilities that are required. Some of these are illustrated in Fig. 4-12.

According to one scenario, movable portions of the central detector would be moved on tracks between the central bay of the collision hall and the assembly area on a rolling support structure that passes through the access way. The access way is the relatively narrow passage that connects the two larger areas. It is sealed against radiation by the concrete shielding doors. The shield doors provide a minimum of 16 ft of concrete between the collision hall and the assembly area. This thickness is adequate to allow unrestricted personnel access to the assembly area even with the machine running and to allow portions of the detector to be constructed and power-tested while the machine is being commissioned. In the same way, repairs or upgrades on portions of the detector can be carried out while operating detectors run for high-energy physics research.

The experimental areas that do not include an assembly hall require that the detector be assembled within the collision hall when the accelerator is not operating. This is the approach being used for the large L3 detector at CERN. This arrangement simplifies assembly and eliminates the need to move components weighing upwards of ten kilotons; it also complicates scheduling and access.

4.5.1.4 Detector Staging Buildings

The detector staging buildings are located at the surface above the underground assembly areas. These buildings are similar in concept for all four IRs: they contain all the support services and facilities for assembling, testing, and running their associated detectors. A cross section of a typical staging building is shown in Fig. 4-14. Detector subassemblies may be put together in the surface-level workspace and then lowered by crane into the pit area where they are incorporated piece-by-piece into the final detector.

In this example, there are two mezzanine floors incorporating electronic counting rooms, offices, and shops in the full-length side bay of the staging buildings. These bays are 30 ft

(9 m) wide. Typical relationships between the elements of a staging building, an assembly area, and an access tunnel can be seen in Fig. 4-15.

In terms of building construction and building services, the staging buildings resemble the heavy works buildings in the central laboratory campus. They are steel-framed structures with insulated metal panel outer walls and a steel-decked, insulated single-ply membrane roofs. Internal partitions are metal-studded drywall or cinder block as appropriate. The buildings are heated and supplied with water for drinking, cooling, and fire protection. A local sewage system is sized to the building occupancy. Fire protection is accomplished by a combination of sprinklers, halon tanks and local extinguishers, as appropriate. There are smoke detectors and alarms in each of the areas.

Each staging building is surrounded by a parking lot plus various utility elements. Among the latter are power transformers, cooling towers, and flammable-gas storage sheds as required. For detectors that incorporate low-temperature or superconducting systems, there is room to accommodate storage tanks for liquid cryogens. The electrical power distribution at 480 V is sized to the installation of specific experimental apparatus.

Utilities for the IRs in the near cluster are supplied from the campus area. Those for the far cluster are provided from a satellite campus on that side of the ring. Communications between the IRs and the central control room follow the normal collider tunnel routing for the near cluster, but are routed across the ring from the far cluster. Most of the signal transfer and processing associated with HEP experimentation is local and involves only connections between the detector and the electronic counting rooms in its associated staging building, except for large data transfers to the central computing facility at the campus.

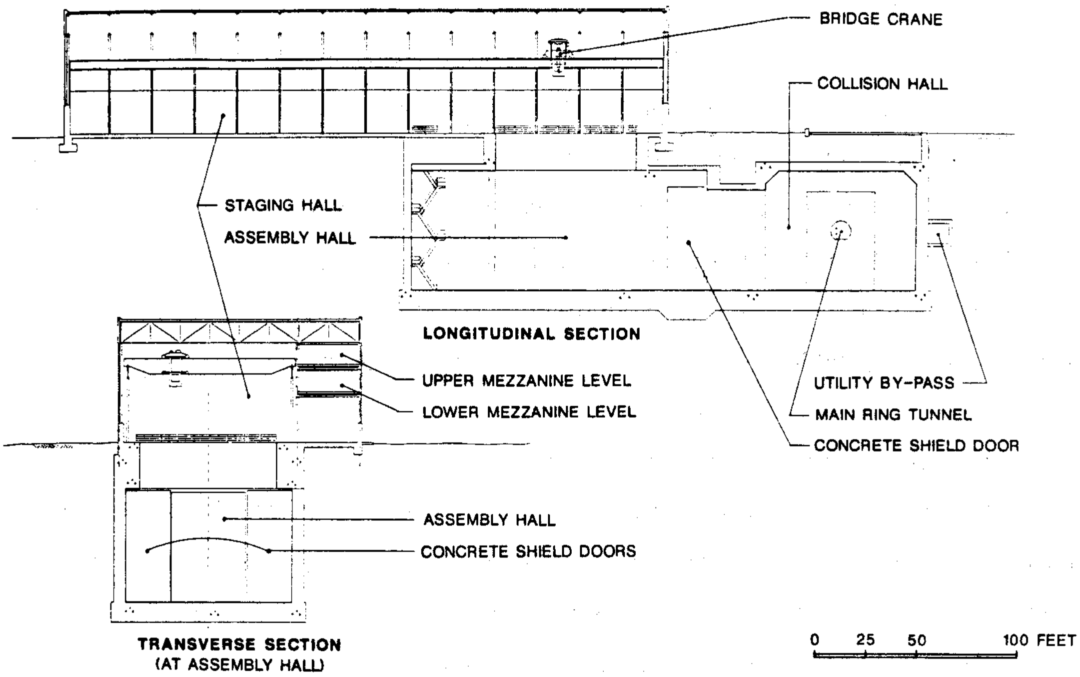

FIG. 4-14. Cross section view of typical staging building, showing building elements, high-bay area and assembly area.

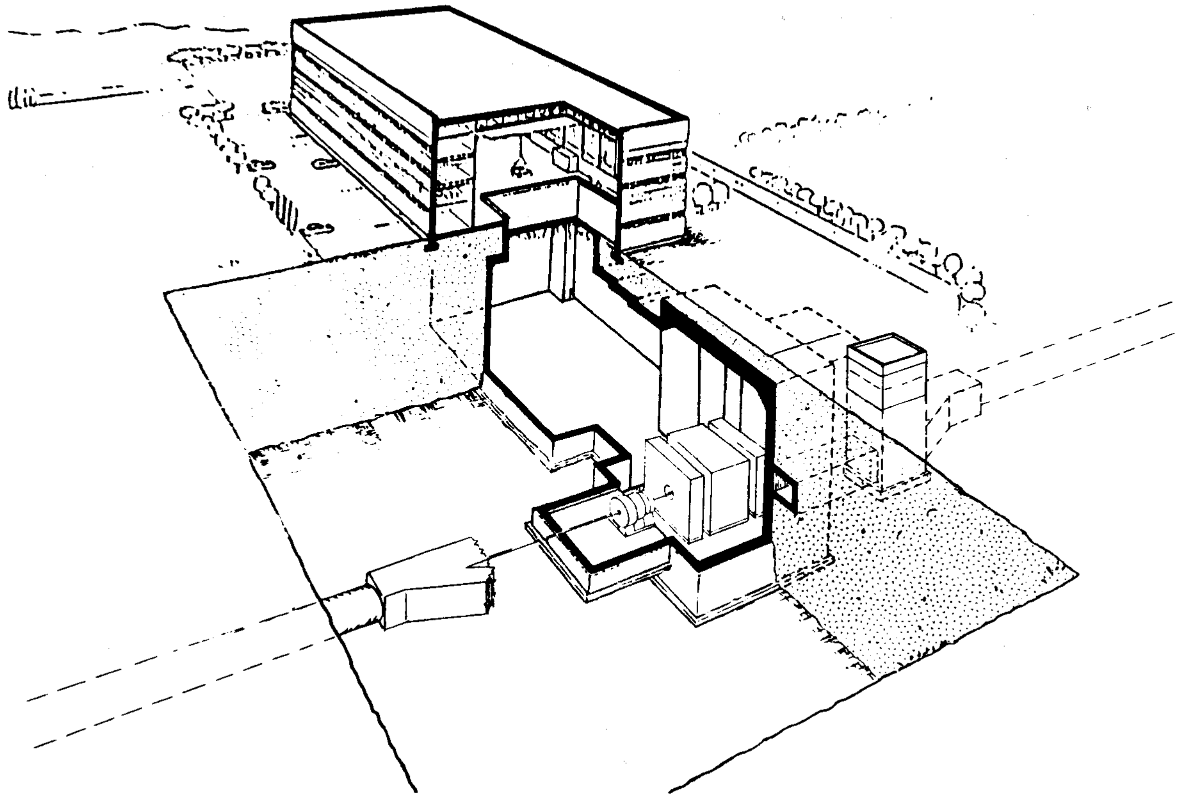

FIG. 4-15. Perspective view of experimental hall.

4.6 DETECTORS

The description of a detector to fit in any one of the IRs is subject to uncertainty, as there is no mechanism for receiving proposals yet, much less any approved proposals. However, as the recent workshop on detectors for the SSC illustrates,[3] there are some general features common to most detector concepts. Starting with the beam pipe that contains the circulating protons and proceeding outwards, the first piece of experimental apparatus to be encountered is some kind of micro vertex detector. This is made of silicon microstrips or pixels. Next follows a central tracking chamber, a proportional wire chamber, or a chamber made from "straws"—single wires each enclosed by its own thin tube, or more silicon microstrips and/or scintillating fibers. In some detector designs, next comes a hadron calorimeter. The passive materials considered for the calorimeter are either lead or depleted uranium; the detector materials may be liquid argon, warm liquids such as TMP or TMS, silicon, or plastic scintillator. In many designs, all of the detector layers through the hadron calorimeter are contained within a solenoidal magnetic field for momentum and charge determination. This field is produced by a superconducting coil contained within a helium cryostat concentric with the beam axis. Finally, there is lepton identification: electrons, possibly from calorimetry alone or with the addition of transition radiation detectors (TRD) and muons, with momentum measurement accomplished by chambers sandwiched between large magnetized iron toroids.

More specialized detectors may be proposed, such as those designed to search for fractionally charged particles, magnetic monopoles, or heavy stable particles, or to look for violation of CP (charge & parity) invariance in the B-meson system.

REFERENCES

[1] *Conceptual Design of the Superconducting Super Collider*, SSC-SR-2020; *Attachment A, SSC Conceptual Design: Parameter List*, SSC-SR-2020A; *Attachment B, SSC Conceptual Design: Magnet Design Details*, SSC-SR-2020B; *Attachment C, SSC Conceptual Design: Conventional Facilities*, SSC-SR-2020C; *Attachment D, SSC Conceptual Design: Cost Estimate Details*, SSC-SR-2020D. ed. by J. D. Jackson (March 1986).

[2] e.g. NFPA 101.

[3] *Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the SSC*, ed. by R. Donaldson and M. Gilchriese, World Scientific Publishing, Singapore (1988).

5 SAFETY AND MONITORING PROGRAMS

5.1 RESPONSIBILITY

In accordance with the Safety and Health Policy of the DOE,[1] the SSC contractor has a primary responsibility to meet DOE safety and health requirements in all of the design, construction, and operations activities undertaken on behalf of the DOE. The DOE will vigorously oversee the contractor's activities to assure compliance with this policy. Operationally, this primary responsibility for safety rests with the laboratory director, who is chosen by the contractor with the approval of the DOE.

5.2 ORGANIZATION OF RESPONSIBILITY

The SSC will be an operating facility, requiring closely regulated procedures for its safe operation.[2] To ensure the safety of personnel and equipment, the laboratory will have a safety organization similar to that successfully employed at other facilities. Safety in an operating environment must be a line responsibility; each line supervisor is directly responsible for the safety of those under him. As noted in paragraph 5.1, primary responsibility for meeting DOE safety and health requirements in the design, construction, and operation of the laboratory rests with the director. This responsibility will be delegated by the director to the heads of the various line organizations and through them to operations supervisors. An SSC Management Plan will detail the safety organization and responsibility. Operations supervisors are held directly accountable through line authority to the director for the safety of their operations. An organization chart for the SSC Laboratory as given in the draft Management Plan is shown in Fig. 5-1. Line responsibility would be vested in Accelerator Division for the safety of accelerator operations, technical systems and associated structures, and in Conventional Systems Division for safety in the design of buildings, for operational safety of the utility systems, for traffic safety, and for site security. The Technical Support Division would have line responsibility for safety of mechanical design and fabrication, as well as operational safety for shops and material handling facilities and equipment.

An oversight responsibility will be vested in an environment, health, and safety section, which will be responsible for monitoring the various safety functions and conducting periodic safety audits. The safety section will also be charged with maintaining safety records and preparing the safety reports required by the DOE or other oversight bodies, in addition to *ad hoc* reports as required by the director. The safety organization will be responsible for developing the technical basis for setting safety standards in areas for which appropriate standards have not been established. The head of this safety organization will report directly to the laboratory director and will have the authority as the director's representative to summarily halt any activity at the laboratory that he perceives to be imminently hazardous.

The laboratory safety organization will include a safety committee to advise the director regarding all elements of the laboratory safety program.[3] This committee will include subcommittees for specialized areas such as industrial hygiene, health and environment, radiation, cryogenics, electrical installations, fire, mechanical devices, and emergency preparedness. Appropriate safety manuals and handbooks will be developed and periodically updated through the safety committee its subcommittees.

For an accelerator facility such as the SSC, areas of special importance to safety are radiation safety, cryogenic safety, and operational safety. A radiation physics group in the safety section will be responsible for providing technical support, special services, and consultation to other laboratory divisions/sections and for auditing the activities of those groups as they bear on radiation safety. Radiation safety personnel in the operational areas will be responsible for day-to-day radiation safety matters within their areas.

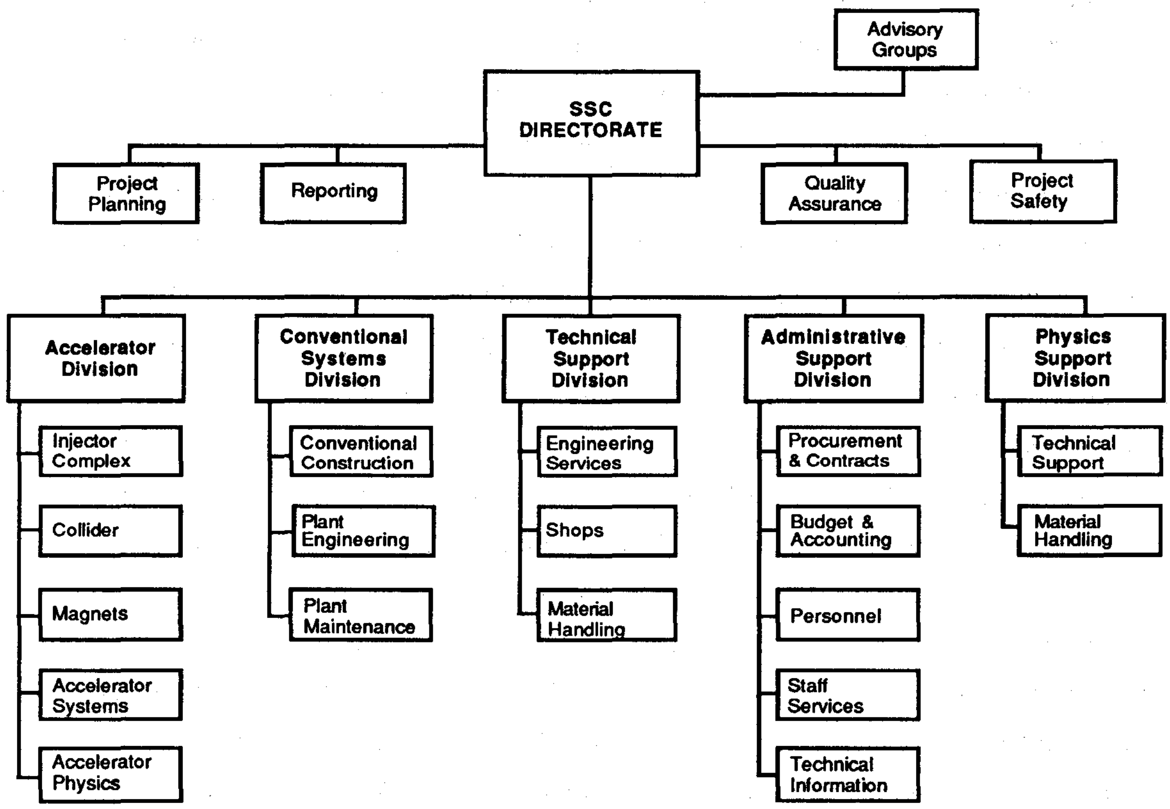

FIG. 5-1. SSC Project organization.

The cryogenic safety subcommittee will work closely with safety review panels, which may include external experts and consultants at the discretion of the director. The panels will be responsible for reviewing safety analyses of the various cryogenic systems of the SSC and for periodically reviewing the safety of their operations.

5.3 PROCEDURES

5.3.1 Safety Audits

The safety section will conduct safety audits on a regular basis to assess and document laboratory compliance with defined safety policies. Besides their direct administrative function, these audits will serve to increase safety consciousness within the laboratory. They will also provide guidance for the evolution of safety procedures and systems for the laboratory. Such an audit program will involve:

1. Operational Coverage
There will be an internal safety auditing organization to improve safety in all operations. The head of the safety section will direct this program and provide to all levels of personnel the safety information relevant to their areas of responsibility.

2. Corrective actions and appraisal follow-ups
The safety section will audit the expeditious completion by division/section heads of corrective actions and appraisal follow-ups.

5.3.2 Safety Reviews

Safety reviews will be carried out for all new facilities and major modifications to existing facilities; these reviews will verify compliance with all relevant codes and standards. The laboratory safety section will include in its staff the requisite level of expertise to conduct those reviews, especially in the cases of electrical, mechanical, and cryogenic safety. In particular, all construction projects will be reviewed early in the planning stage to ensure adequate fire detection and suppression and to limit possible consequences of a fire within appropriate DOE criteria. Likewise, the radiation physics group will review the adequacy of shielding within laboratory guidelines, in order to minimize the exposure of the general public and of laboratory personnel. The mechanical devices safety subcommittee will set standards and review designs of pressure vessels and potentially hazardous mechanical devices. Special committees will be appointed to review the design of each of the experimental detectors. Because of the complexity of these systems, in addition to safety section staff, such committees will include members from each of the specialized committees such as fire, mechanical, and radiation.

5.3.3 DOE Safety Appraisals

Management appraisals of contractor activities will be conducted at reasonable intervals, in keeping with DOE policy. Also, in keeping with DOE policy, functional appraisals of contractor activities will be conducted with sufficient scope and frequency to ensure the effectiveness of the contractor's environmental, safety, and health activities.

5.4 MONITORING PROGRAMS

Monitoring the safety of a facility like the SSC has several aspects. The audit and review functions described above are one aspect. A second aspect is the day-by-day inspection of facilities and observation of operations by safety staff. Still another, which might be called passive monitoring, involves the use of detectors of various types placed strategically to provide and record information on the safety of operations.

5.4.1 Inspection and Observation

The safety group within each operating division will be responsible for ensuring the safety of personnel and operations within the area of that division's responsibility. This responsibility will be exercised through oral instructions to staff on safety precautions, through preparation of appropriate manuals, and by a program of inspections to ensure safe conditions and observations to ensure safe procedures in operating the facilities. In addition the laboratory fire department will have site-wide responsibility for observation of fire safety and inspection and testing of fire alarm and fire suppression systems.

5.4.2 Monitoring Systems

The radiation exposure of each employee classified as a radiation worker will be monitored by personal radiation monitors such as film badges, dosimeters, and TLDs. The monthly doses, as well as the cumulative lifetime doses, will be recorded and be available for the safety audits noted above. In addition, any individual or group of individuals entering a potential radiation zone will be required to carry personal radiation monitors whose readings will be recorded and made available for audit.

Besides these personal radiation monitors, a general environmental and monitoring system (EMC) will be installed over the site.[4,5,6] This will monitor fire, radiation,[7] and facility safety with appropriate sensors and transducers throughout the site. All of the sensors will report to the main operations center, where personnel will be on duty around the clock. In addition, fire and security signals will be monitored at the emergency operations center. Radiation and environmental sensors will be monitored by the laboratory safety as part of their oversight function. Access to radiation areas will be monitored and controlled through the accelerator control system. [8,9]

An additional monitoring function incumbent on the environment, health, and safety section of the laboratory will be that of monitoring compliance with environmental regulations. This will involve off-site sampling of water and air as well as on-site sampling of effluent, soil, etc., where transducers and remote readouts into the EMCs are not appropriate.

REFERENCES

[1] DOE N5480.1 (8-21-86).

[2] "Operational Radiation Safety Program", NCRP Report No. 59 (1 Nov. 1980).

[3] Ibid., Sec. 2.2.

[4] National Fire Codes 1987, NFPA Section 72D.

[5] DOE/EP-0023, "A Guide for Environmental Radiological Surveillance at U.S. DOE Installations" (July 1981).

[6] C. Briegel, *et al.*, "FIRUS; The FNAL Site-Wide Fire & Utility Monitoring System", Nucl. Inst. & Methods in Physics Research, **A 247** 85–88 (1985).

[7] "Radiation Alarm and Access Control Systems", NCRP Report No. 88 (30 Dec. 1986).

[8] D. Neet, "Access Control for LEP," LEP Note 478 (14 Dec. 83).

[9] Rapporte Provisoire de Sureté du LEP, Chap. III, 3.6.1 Controle d'accèss et verroilages de sécurité, CERN (1987).

6 CONDUCT OF OPERATIONS

6.1 ORGANIZATION OF OPERATIONS

The conduct of SSC operations shall conform to relevant portions of DOE orders, such as DOE Order 5480.11 (Draft 3, August 1987). As with the safety and monitoring programs, the precedents established by Fermilab[1,2] and CERN[3] can serve as useful guides for the SSC. Under this model, the organization of operations would be the responsibility of the laboratory director. The overall responsibility for the operation of the SSC will rest with the accelerator section head. The responsibility for the around-the-clock running of the accelerator complex will rest with the head of an operations group to whom the crew chiefs will report. There would be five operation crews for the three-shift operation, each headed by an operations chief. Each shift crew will have operators and trainees. The crew on shift will be backed up by operations specialists on-call around the clock for specialized systems. For the first years of operation many or most of these specialists would be involved in installing and in some cases building SSC components.

Prior to operating any major system, an Operational Readiness Review (ORR) will be conducted. In particular, operations at each of the service areas will be phased to permit acceptance testing of each refrigeration plant, then cool down the associated magnet system in the tunnel as they are certified. Finally, when cryogenic systems tests are completed, the magnet system will be tested under power.

During operations, all tasks that affect the accelerator complex will be authorized and scheduled by the crew chief on duty. For certain defined tasks, the crew chief will need explicit permission from the division head. Others will require the authorization of the safety officer of the accelerator section. A small number of tasks will require authorization of both the division head and the safety officer.

The experiments at the SSC will be designed, constructed, and operated by staff responsible to and paid by universities and other external laboratories and institutes, as well as staff of the SSC laboratory. A senior physicist, who may or may not be a member of the laboratory staff, will act as spokesman for each experiment. A staff physicist will be assigned to each experiment to provide liaison between the experimenters and the accelerator. While it is expected that a professional physicist will be present and responsible for each experiment on each shift, the laboratory liaison staff will be consulted in all matters affecting either safety or SSC operations. In these matters, the accelerator crew chief on duty will have local temporal authority.

6.2 TRAINING PROGRAMS FOR LABORATORY PERSONNEL AND VISITORS

The safe operation of any facility requires that personnel receive adequate training for their tasks with provision for periodicly updating that training. An important part of that training must be an awareness of safety aspects of their tasks including proper response to hazards to which they might be exposed.[4]

6.2.1 Training Program for Operators

At the beginning of operation of the SSC, the first operating crews will require considerable education in the nature of the accelerator complex and its component systems. This can be done through lectures, video presentations, and reading assignments followed by written and oral examinations. It can be expected that most if not all of the first crews of operators will have participated in at least the latter stages of SSC component construction and installation. The physicists and engineers who design and build the SSC will also be involved in its initial operation and will work closely with the operating crews.

After the initial operation of the SSC, new operators will be trained in the course of normal staff turnover. They will be assigned to the operations crews as trainees for a period of on-the-job training. During this period they will be assigned reading material and attend lectures related to SSC operations. At the end of the training period the trainee will be given comprehensive examinations under the supervision of the operations group's training coordinator.

Regular operators will be kept at optimum proficiency through a program of retraining and of education concerning new systems and components. The system's specialists who will be responsible for bringing new or modified accelerator systems into operation will provide appropriate training for the operators concerning these systems.

6.2.2 Training Program for Maintenance

The regularly scheduled maintenance will be directed by the operations crew chief. The maintenance tasks will be carried out by scientists, engineers, and technicians knowledgeable in the tasks required. In addition, the regular operations crew will also be expected to be involved in such routine maintenance. This will enable them to stay current on the hardware with which they must be familiar. In addition, they will assist the maintenance staff and will facilitate regular visual inspection of the accelerator systems.

The training of the maintenance crews will include specific in-depth instruction in industrial hygiene,[5] cryogenics, and radiation safety. Maintenance of particular systems will require the direct supervision of a particular system specialist.

6.2.3 Training in Safety Procedures

The training of all laboratory employees and resident visitors will include instruction concerning safety issues and procedures. In the case of the staff of the accelerator section, this training will be particularly intensive and will include specific in-depth instruction fire protection, electrical safety, and cryogenics and radiation safety.

An important group for training in safety will be the experimentalists from institutions participating in experiments on the SSC, who will be resident at the laboratory for periods ranging from a few days to several years. It will be necessary to develop training programs to inform these visitors of the hazards, precautions, and procedures as discussed elsewhere in this report.

6.2.4 Qualification

A systematic procedure for qualification of operators, accelerator maintenance personnel, and experimental-area staff and visitors will be instituted in the accelerator section. Qualification of personnel authorized to work in the tunnels of the accelerator complex will include physical fitness and training in escape and rescue techniques.

6.3 EMERGENCY PLANNING

Plans and procedures will be established in accordance with appropriate guidelines for dealing with possible emergencies[6] such as a rupture in a cryogenic line, a destructive loss of beam, or a fire; in experimental areas, leaks of flammable gas and personal injury due to falls or electric shocks represent other possibilities. Notification procedures and responsibility for rescue and securing of areas will be part of the training noted above. Similarly, plans for orderly evacuation will be posted and known.

Special procedures will be developed for operations and installation activities with significantly greater than average risk. These might include such activities as replacing a component with a high level of radioactivity or repairing a break in a flammable gas system. These examples all have precedents at existing high-energy laboratories, and successful procedures adopted at these laboratories will be adapted at the SSC.

6.4 ACCIDENT PREVENTION

A laboratory-wide program of safety awareness will be important in reducing accidents. Crucial in this program will be the proper training and education of each employee and visitor. In addition, enforcement of safety measures such as the wearing of hard hats in certain areas and access requirements for controlled areas will be established and approved.

As far as safety is concerned the only unique feature of the SSC is the extent of the facility compared with other particle physics research facilities currently in operation, though the LEP facility of CERN approaches this scale. The extent of the facility, requiring the use of public roads between laboratory installations, adds a new dimension to traffic safety.

REFERENCES

[1] *Energy Saver Safety Analysis Report,* Fermilab (1983).

[2] *TeVatron I Safety Analysis Report,* Fermilab (1986).

[3] *Rapport Provisoire de Surete du LEP,* CERN (1987).

[4] "Operational Radiation Safety-Training," NCRP No. 71 (15 March 1983).

[5] DOE Order 5480.10, "Contractor Industrial Hygiene Program" (6/85).

[6] DOE Order 5500.2, "Emergency Planning, Preparedness, and Response for Operation" (8/81).

7 QUALITY ASSURANCE

It will be the policy of the SSC laboratory to assure that the required standards of quality, inherent reliability, and reproducibility consistent with the scope and nature of each activity are achieved in all laboratory programs. Formulation of the particular procedures for quality assurance, quality control, configuration control, etc. will be the responsibility of the laboratory director and will be incorporated in the Project Management Plan. The SSC Quality Assurance (QA) program will include the elements of DOE Order 5700.6B applicable to Energy Research Programs.[1]

7.1 QUALITY ASSURANCE — QUALITY CONTROL PROGRAM

The objective of the laboratory Quality Assurance–Quality Control (QA-QC) Program as it pertains to operational safety is to achieve the following results:

a) Obtain the level of quality of components, systems, and performance considered necessary for successful operation of the SSC and related experiments commensurate with the laboratory's responsibilities for health and safety of personnel, the protection of the environment, and the reliability and continuity of operations, with appropriate consideration of cost and timeliness

b) Ensure that facilities, systems, components, and equipment procured, fabricated, constructed, or modified by and for the laboratory conform to contract requirements, specifications, and drawings

c) Prevent or minimize delays and increased costs in the SSC program due to rejections or failure of vendor or in-house-supplied material and equipment

Using appropriate elements of national standards,[2] QA procedures will be developed and implemented in such critical areas as design services, machine shop operations, magnet fabrication operations, and procurement practices. The following steps will be undertaken in establishing the QA program:

a) Preparation of a *Project QA Program Plan* that specifies how the QA program will operate

b) Specification of the procedures and instructions that detail how the QA program is implemented

c) Definition of an audit that verifies compliance with the plan and procedures, and measures the effectiveness of the QA program

The SSC QA program will be consistent with basic DOE-ER policy, which states that the quality of components, systems, and experimental data should be adequate to support the research program and that the QA actions, in furtherance of this objective, should be commensurate with the nature, costs, safety, and programmatic significance of the activity. The QA procedures will encompass the following:

a) Research and development will be performed where appropriate to define critical items in advance of and/or concurrent with the development of specifications. For example, where appropriate, research and development on subsystems will be undertaken to assure that the design is fundamentally safe and sound and to resolve design and fabrication problems.

b) Where appropriate, prototype equipment will be tested to prove performance and reliability under conditions simulating those in the ultimate system, before production is initiated.

c) The specifications for the production components will incorporate results from the above tests. This process will help to identify components to be controlled and the level to which the controls should be established. These controls will then be included in the specifications.

d) Within the scope of each equipment procurement package will be requirements for vendor procedures and processes to meet the established controls. In some cases, vendors will be required to establish appropriate quality control programs as part of their contractual obligations.

e) Qualified personnel will monitor the vendors' Quality Control (QC) programs for compliance with specifications. Resident inspectors will be utilized for major items where appropriate. Specialists will be used for particularly critical operations. Visiting inspectors will monitor minor items on a selected basis to ensure compliance where critical fabrication or testing is involved.

f) After equipment delivery and prior to installation the laboratory might again perform certain field tests on the equipment. During the installation phase, the laboratory will test the equipment when operable segments are available.

7.2 CONFIGURATION CONTROL

An SSC configuration management plan will define procedures for approval of drawings and plans. A laboratory systems integration function will review the mutual compatibility of elements of the accelerator complex.

7.3 CHANGE CONTROL PROCEDURE

Change control procedures will be addressed in an SSC configuration management plan. Changes will be appropriately documented and classified according to their impact on project objectives, costs, schedules, and safety. Minor changes will normally be handled at the level of the concerned units. Major proposed changes will be reviewed at the directorate level.

7.4 TESTING AND INSPECTION PROGRAM

The division head who has approved a particular job will be responsible for the inspection of work in progress and of completed work to assure achievement of the objectives of the task. This will include specification and oversight of such tests as may be appropriate; pressure tests, vacuum tests, thermal leak tests, and high-voltage breakdown tests are examples of acceptance tests that may be required for certain systems.

Testing procedures will be in accordance with appropriate codes and standards[3] adopted by the laboratory. Where standards and specifications do not exist, the laboratory will adapt appropriate sections of related standards, taking cognizance of procedures at similar facilities and of draft standards that might exist.[4]

Published standards and specifications do not exist for many of the technical components of particle accelerators, since the number of such machines is small and each tends to be unique. For the SSC Project, drawings or specifications will be prepared for every such technical component so that it meets the performance parameters outlined in the CDR and subsequent approved revisions thereof.

REFERENCES

[1] DOE Order 5700.6B (9/23/86).

[2] e.g., ANSI/ASME NQA-1 (1986).

[3] Code of Federal Regulations 40CFR61 (1/1/86).

[4] e.g., ANSI B31.10 for cryogenic fluids.

8 ANALYSIS AND MITIGATION OF POTENTIAL HAZARDS

8.1 INTRODUCTION

Hazard identification and elimination or control must be initiated during the earliest phases of any project. This has been assured for the SSC project by drawing from the beginning on the services of people with long and successful experience in building and operating accelerators and in underground construction.

In Chapter 2, above, the potential hazards associated with the operation of the SSC facility have been identified under three categories: campus and infrastructure, accelerator, and experimental areas. In the present chapter, those hazards will be analyzed in light of the specific design of the SSC as presented in the CDR, and the preventative or mitigative design features and administrative controls provided to limit the risk from them will be described. Applicable guides, codes, and standards will be identified.

8.2 CAMPUS AND INFRASTRUCTURE

As noted in Chapter 2, above, the hazards potentially associated with the campus and infrastructure are no different from those found at a university or light industrial facility: these might include hazards related to fire, vehicular traffic, electrical wiring, and falling objects. All of the potential hazards in this category are of a type and magnitude routinely encountered and accepted by the public. Following the guidance of DOE Order 5481.1B, Chap. 2, Sec. 4b, these will not be treated further in this document. Relevant portions of DOE orders, such as DOE 6430.1 (12 Dec. 1983) and DOE 5480.7 (16 Nov. 1987) will be implemented in the design of these facilities.

8.3 ACCELERATOR

8.3.1 General Tunnel Safety

In the absence of specific regulations for the safety of operations in an accelerator tunnel guidance may be sought on the one hand in the practice at existing accelerator installations and on the other hand in regulations for underground enclosures which are functionally similar to an accelerator tunnel. Table 8-1 gives some examples of recent tunnels with their functions.[1] Accelerators that have been built in underground tunnels are the Tevatron at Fermilab, the SPS and LEP at CERN, SLC at SLAC, U70 and UNK in the USSR, and HERA in Germany. Operations in these accelerator tunnels are characterized by their occasional nature and by the restriction of access to the tunnels to authorized and trained personnel.

Maintenance operations in water conveyance tunnels and utility tunnels share with accelerator tunnels the occasional nature of access and the need for restricting access to authorized trained personnel. Test tunnels at the Nevada Test Site may also share these characteristics. Water conveyance tunnels of substantial length are relatively common in the American west for both power generation and water supply. For example, the upper tunnel on the Calaveras combined water and power project, which has a diameter of 5.5 m, is 13 km in length with access at each end and an intermediate access at approximately 7 km from the upper end. Periodically the tunnel will be taken out of service and emptied to permit personnel access for inspection and maintenance.

Mining operations differ from accelerator tunnels in that they involveg continuous occupancy, relatively large numbers of personnel, intensive and continuous materials handling activity, and possibly noxious or explosive atmospheres. They share with accelerator tunnels the requirement for limiting access to authorized, trained and properly equipped personnel.

Access to the SSC tunnel will be controlled at all times. Normal access to the tunnel will be restricted to personnel who have been medically certified for good physical and respiratory health. Personnel will be logged in and out of the tunnel from the central control room. Access requirements will include personnel pairing (the "buddy" system), radio communications, oxygen monitors, and specific safety equipment as noted below. Transporters will be assigned to each group entering the tunnel, so their locations will be monitored by the transporter block signaling system.

As noted in Sec. 2.2.3.7.1, above, emergency egress from the tunnel and access to the tunnel for the laboratory emergency response teams is provided at the exit locations midway between the service areas.

In preparing the Conceptual Design Report, construction industry and other codes and regulations were reviewed and studied with respect to tunnel safety, including the new Federal OSHA tunnel construction regulations currently under consideration. As noted in Chapter 2, the requirements for safety in an underground work space are:

- A continuous supply of fresh air
- An unobstructed path to a point of safety from any local hazard
- An emergency warning system

Table 8-1. Comparison of degree of hazard and corresponding safety considerations for occupancy of tunnels.

					Population					Hazards: Fire			Hazards								
Tunnel	Function	Length	Distance between Exits	Cross Section or Diameter	Number	Occupancy	Type	Training & Procedures	Ventilation	Source of Combustion	Volume of Inflam	Type Fire	Loss of Air	Exit Blockage (Max. distance to escape)	Monitor or Sensors & Alarms	Access Control	Safety Provisions for Occupants	Applicable Code(s) for maint. & ops.	Determining Criteria for Exit Interval	Maximum Exit Distance (for Safety Analysis)	Remarks
Rogers Pass	Railroad, single track	9.2 mi	9.2 mi	Ø = 18 ft + Nominal – (18 x 29)	6 to 8 10 to 20	·Normal (train in tunnel) ·Maintenance	Train crew Maintenance crew	Briefed on walking out	Forced, longitudinal	Cargo & rail cars; Diesel fuel; Toxics	10^7 gal	Accident, fuel fed	Gas; Smoke; Loss of ventilation	9.2 mi	None	Uncontrolled but remote from population	Radio on train	Canadian & BC Province Safety Code	Ridge crossing, tunnel portals	9.2 mi	Shaft at tunnel mid-point has special elevator (shaft is 1350 ft). Throughout winter, exit house is snow bound. Owner: Canadian Pacific RR
Downtown Seattle Transit	Bus transit	1.3 mi	1100 ft +	Twin, Ø = 17 ft	8000 to 10,000 per hour	Continual	General public	None	Forced, at stations	Diesel fuel, Rubber tires	300 gal	Accident, fuel fed	Smoke	1100 ft*	TV surveillance; Sensors & alarms (Central control & monitoring)	Controlled at stations	Radio on buses, Surveillance TV at stations	NFPA 130 Fed OSHA; Local Fire & Safety	Station spacing	1100 ft	* Jackknife articulated coach could block tunnel and escape passageway Owner: Metro Seattle
Glenwood Canyon Highway Tunnel I-70	Highway	3900 ft	2500 ft	Twin Ø - 40 ft Roadway is 15 x 40	200 to 1000/hr.	Continual	General public	None	Forced, semi-transverse (reversible)	Cargo materials, Gasoline fuel, Diesel fuel; Toxics, Vehicles	e.g., 6000 gal fuel tanker truck	Accident, fuel fed	Smoke, Loss of oxygen, Loss of ventilation	650 ft (to cross passage)	TV surveillance, Alarm to nearby town Fire Dept.	Uncontrolled	Broad Band AM/FM radio antennae*	Fed. OSHA; AASHTO; Colorado OSHA	Portals; Ventilation; Cross passages	650 ft	* Operations center can broadcast instructions to radios of autos in tunnel on all frequencies. Owner: Colorado Dept. of Highways
Calaveras Water & Power Tunnel	Water transmission	8 mi	4.3 mi	Ø = 18 ft	4 to 6	Occasional (annual inspection & maintenance)	Maintenance workers	Briefing; Buddy system; Log in/log out	Natural (Open manholes at adits)	None	None	None	Lack of oxygen, Lack of ventilation	8 mi	ODH Monitors	Locked access; Log in/log out	Radio with teams; Person stationed outside	Cal. OSHA	Lake to power house distance; Construction convenience	4.0 mi	Owner: Calaveras Water & Power Authority
Govalle Sewer Tunnel	Sewer interceptor & diversion	43,000 ft (8.1 mi)	1.0 mi to 2.5 mi	Ø = 8 ft	2 to 3	Occasional (maintenance & inspection)	Trained maintenance personnel	Safety lectures & briefing	Forced, longitudinal	Gasoline	Fumes	Explosion	Gas (H_2S); Loss of oxygen	2.5 mi	Gas monitor	Log in/log out	Vehicles; Radio with team	WPCF-MP9 Des. & Constr. of San. Sew.; State Dept. of Health	Sewer connections	2.5 mi	Owner: City of Austin
San Antonio Flood Diversion Tunnels	Flood water diversion	4.0 mi	4300 ft	Ø = 24 ft	4 to 6	Occasional (maintenance & inspection)	Trained maintenance personnel	Safety lectures & briefing	Temporary fans for maintenance cycle	Natural methane	Small, airborne	Explosion	Gas (Methane & CO_2)	4300 ft	None	Log in/log out	Vehicles, ODH monitors	Fed. OSHA; COE Safety & Health Requirements Manual	Ventilation during maintenance	4300 ft	Require max. HP engine of diesel truck used for maintenance and no. of occupants to be limited by operating spec Owner: U.S. Army, COE
Chicago TARP	Flood and CSO collection & transport	28 mi, (110 mi total)	4000 ft	Ø = 22-35 ft	4 to 6 per 5 miles	Occasional (maintenance & inspection)	Trained maintenance personnel	Safety lectures & briefing	Natural, (open manhole)	Gasoline, Methane	Small, airborne	Explosion	Gas (H_2S, Methane, CO), Loss of oxygen	4000 ft	None	Log in/log out	Vehicles, ODH monitors	OSHA, MSD Safety; Chicago Fire Dept.	Chicago Fire Dept. rescue for constr. period	4000 ft	Owner: Metro Sewer District
Second Hampton Roads Tunnel	Highway	7280 ft	1.4 mi	Ø = 28 ft roadway is 15' x 28'	200 to 3000/hr.	Continual	General public	None	Fully transverse	Carried materials; Gasoline fuel, Diesel fuel, Toxics	e.g., 6000 gal fuel tank truck	Accident, fuel fed	Loss of oxygen; Smoke	1.4 mi	TV surveillance; Air quality sensors	None	Broad Band AM/FM radio antennae*	AASHTO; Fed. OSHA, Virginia DOT safety criteria	Estuary width	7280 ft	* Operations center can broadcast instructions to radios of autos in tunnel on all frequencies. Owner: Virginia Dept. of Highways
SSC	Research equipment enclosure	53 mi	2.5 mi	Ø = 10 ft	2 to 4 per 5 miles, 10 to 12 total – all in buddied pairs	Occasional (biweekly inspection & maintenance)	Maintenance staff with medical certification	Safety lectures & briefing, Buddy system, Personal safety equipment, Log in/log out	Forced, longitudinal	Dry transformers; Electric carts; Circuit breakers	Non-flammable materials by spec.	Electrical	Smoke, Local loss of oxygen;* Loss of ventilation	2.5 mi	ODH, radiation, fire & flooding monitors; Vehicle location monitoring (Central control & monitoring)	Interlocked gates; Cardkey-type log in/log out	Radios with teams; Power backup on fans & transport; Refuges; Personal radiation monitors	Fed. OSHA	Length of technical sector	2.5 mi	* Hazards are potential smokey electrical fire (low combustibles) or a helium or nitrogen gas release Owner: U.S. Dept. of Energy

8.3.1.1 Fresh Air Supply

Normally, the accelerator tunnels are not occupied; access is only required for installation, modification, or repair. The ventilation system is designed for operation only during these times. At normal operating speeds the ventilation fans provide 10,000 cfm to the tunnel, injecting at the exit points and exhausting at the service area shafts. This amounts to 1400 cfm per person for the seven-person crew that would be required for replacing a magnet. Mine safety codes and the proposed federal OSHA rules for underground construction specify 30 to 200 cfm per person, so the design provides for an adequate supply of fresh air.

8.3.1.1.1 Loss of power. In operations this continuous supply of fresh air could be interrupted in several ways. First, and most obvious, would be loss of power to the ventilation fans. Backup power is provided in several ways. Alternate service areas around the collider ring are connected to separate points on the primary electrical grid, so that even if one primary grid went down, there would still be some ventilation in the tunnel, and the alternate fans could be put on high rate to enhance this. Additionally, 13.8-kV remotely-operated transfer switches are located at the sector ends and the exit locations, to back feed power along the 13.8-kV subdistribution network to power emergency systems, including the ventilation fans, in the sector that has lost power. A third level of backup is provided by emergency generators at each of the service areas.

8.3.1.1.2 Fire, smoke, or cryogen spill. A second way that the supply of fresh air might be interrupted would be by a reduction of the oxygen levels by fire or a cryogen spill, or introduction of toxic gases from burning materials. Possible sources of fire are the power and signal cables, transformers, and electric cars. To mitigate this hazard, cables to be installed in the tunnel will follow specifications adopted for similar installation requiring that they be nonflammable, low-smoke, zero-halogen, jacketed cables.[2] In addition, tests on cables in traps in the Proto-collider tunnel at Fermilab indicate that, under the conditions of those tests, fires initiated in the cable tray containing standard cables were self-quenching.

With the ventilation fans operating at normal speed, the air movement in the tunnel will be 100 fpm. Since normal walking speed is 3 mph, or 264 fpm, occupants would be able to walk away from any potential hazard at about three times the speed of the moving air. As noted, personnel in the tunnel will have assigned transport, so that they can evacuate the tunnel at speeds up to 15 mph, if required. The tunnel evacuation warning system will indicate the direction for evacuation. The normal procedure for fire, smoke, or cryogen alarms in the tunnel will be to evacuate personnel until the condition clears.[3] Personnel isolation zones under positive pressure of fresh air will be provided in the stairwells at the service areas and exits.

8.3.1.1.3 Blockage of ventilation. A third way for the fresh air supply in the underground spaces to be interrupted would be for the tunnel to be physically blocked in some way. This will be treated with the second requirement, an unobstructed path to a point of safety from any local hazard, discussed in the following sections.

8.3.1.2 Obstruction of a Safe Means of Egress

Various codes deal with the requirements for egress from workplaces.[4] These codes generally set a requirement for at least two separate escapeways from a work area.[5] In addition, for mines there is a requirement for egress within a time limit of one hour using normal exit methods As noted, the normal mode of exiting the tunnel is by transporter operating in a speed range of 5–10 mph with a capability of 15 mph. The maximum distance to a tunnel escapeway specified in the CDR is half the distance between exits, 1.25 miles. This amounts to 8–15 minutes in the operating range of the transporters, or 5 minutes at maximum speed. Operationally, the designed egress conditions can be changed in several ways. Power might be lost in the transporter bus, or a blockage might occur cutting off one of the escapeways.

8.3.1.2.1 Loss of transport power. The transporters are powered from a 480-V bus housed in the guide rail. Backup power for the bus is provided as for the ventilation fans as described above. To provide limited locomotion in the tunnel for vehicle passing and parking the transporters are provided with a battery pack which is continuously charged from the bus. The capacity of the battery pack is specified by the maximum distance between escapeways. If the transporter must be detached from the bus, personnel can travel to an escapeway under battery power. For safety the transporter is geared down to a maximum speed of 5 mph when not attached to the guide rail, i.e., when operating on battery power.

8.3.1.2.2 Tunnel blockage at escapeway. There may be circumstances under which the tunnel is blocked at an escapeway, for example by fire in a shaft. Since the tunnel is continuous, at least one other escapeway is available within the limits specified by applicable federal regulations.[6] If there is a physical blockage of the tunnel such that ventilation is impeded, an evacuation alarm will sound, and personnel will have been trained to leave the tunnel immediately. The volume of air in the tunnel is sufficient to sustain the oxygen level above ODH levels during exit by working crews.

The volume of air in the 2.5 mile length of tunnel between exits is approximately 10^6 cu ft. On a vehicle moving at 5 mph, this amounts to approximately 35,000 cfm/minute encountered, or 5,000 cfm/person for a 7–person magnet installation crew, compared with OSHA requirements of 30–200 cfm/person.

8.3.1.3 Provision of an Alarm System

An alarm system conforming to Section 72D of the National Fire Codes will be installed throughout the SSC Complex. For the underground spaces, sensors and alarms will be provided for fire, smoke, oxygen deficiency, temperature and flooding.

8.3.2 Radiation

8.3.2.1 General

There are two separate concerns with regard to radiation levels and hazards in the SSC: protecting laboratory personnel against radiation exposure from the accelerator and research facilities and keeping the environmental radiation and radiation exposure of the general public, both on- and off-site, well below safe limits. The actual and potential sources of radiation are: (a) collisions of the proton beams with residual gas molecules, (b) collisions of protons with scrapers and collimators (particularly during beam transfer), (c) beam-beam collisions in the IRs, (d) beam absorption at the end of a cycle, (e) collision of beams with beam pipe walls, and (f) test beams from the HEB and the collider ring. Although the IRs, beam-gas scattering absorbers, and beam absorbers are the only regular sources of significant radiation from the SSC, allowance is made for the possibility of accidental loss of the full beam at some point along the machine circumference. Smaller regular sources of beam loss are the beam scrapers at various locations around the ring.[7] Environmental concerns associated with these losses are the possibilities of soil and groundwater activation, of airborne radioactivity, and of muon penetration downstream from the interaction and beam absorption regions. At some sites there may be radon naturally present in the tunnel.[8]

From a radiological perspective, the radiation of primary concern is the prompt radiation arising from the collision of beam protons with matter or from the decay of secondary particles arising from these collisions. Hadrons are one component of the secondary radiation. They typically travel some tens of centimeters in matter before interacting and are completely stopped in a few m to tens of m, depending on the energy, the type of radiation, and the character of the absorbing material. The hadrons are accompanied by high-energy photons and electrons, which are absorbed over typically shorter distances of at most a few m in solid matter. A different concern is the muons which, in contrast to the hadrons, photons, and electrons, interact very weakly with matter and are thus very penetrating; the most energetic travel several kilometers in earth. These are very strongly collimated along the direction of the primary proton beams, and so the needed shielding is confined to long, well-defined regions tangential to the circumference of the main ring at the IRs and downstream of the primary beam absorbers.

Also of concern is the residual radioactivity produced in the process of stopping the high-energy particle beams. Stopping these energetic particles gives rise to showers of lower-energy particles, including neutrons; some of these are absorbed by the nuclei of surrounding matter to produce radioactive isotopes. The resulting radioactivity is of low level: areas with activation levels of significant concern are confined primarily to the beam absorbers, which are specifically designed to contain the radioactivity[9] and dissipate the heat generated by the beam.

It should be noted that, in spite of the higher energy of the SSC, the cumulative amount of radiation will be less than that experienced at the Tevatron, due to the longer cycle time and resulting lower average beam intensity. The Tevatron accelerates 10^{13} protons to 1 TeV every 60 seconds; the SSC will accelerate 1.3×10^{14} protons in each beam, but only once per day. The integrated energy deposition, which is the primary determinant of radiation exposure, is, then, 14×10^{15} TeV/day for the Tevatron and 5×10^{15} TeV/day for the SSC.

The radiation safety of the site outside of beam enclosures will be provided by shielding and by the monitoring of compliance as described above. Approval of shielding designs and monitoring of compliance, as well as record-keeping and preparation of reports, will be the responsibility of the laboratory environment, health, and safety group.

Most of the radiation associated with accelerators occurs within the beam enclosures during operation of the beams. Except for some residual activation in regions of the beam where the beam is injected into or extracted from the machine, accelerator-related radiation disappears with the shutting down of the beam. For this reason the primary emphasis in accelerator radiation safety is on ensuring the exclusion of personnel from the beam enclosures during operation of the beams and the exclusion of beams from areas that may be occupied by personnel.

Exclusion of personnel during periods of scheduled operations is secured in the first instance by a programmed, sequential search of all affected beam enclosures before a beam can be introduced into any technical device. The scale of the SSC makes search and secure a qualitatively different problem from what is encountered at the older generation of accelerators. Approximately 60 miles of underground enclosures, including the injector tunnels, are involved. To cope with this, the collider tunnel and enclosures will be divided by the interlock logic into segments based on the service areas at the midpoint of each machine sector. Each of the ten sectors and each of the injector accelerators will be monitored and controlled by logic circuits. The interlock logic requires a positive signal from the search sequence before beam can be introduced into a facility; for the collider ring, a positive signal from all ten sectors is required.

Access control is based on coded ID badges issued to all operations personnel. The badge contains worker identification, health clearance, and other relevant access information. Access to an enclosure is recorded by the insertion of the badge into a badge reader at the gate under surveillance from Main Control. Each person entering an enclosure is thus logged in.[10] The sector beam permit signal requires the logging out of all personnel who have logged in. Furthermore, following any controlled access, a search team will do a physical surveillance of the accessed areas. The search team keys must be returned to the sector key tree in order to complete the beam permit signal.

Within the collider tunnel, each sector will be divided by interlocked gates into eight sections coinciding with the eight cryogenic sections constituting a sector. Each section constitutes a subloop of the interlock circuit for the sector. All eight subloops must be "made up" before the sector interlock loop is complete. When access to the ring is required for inspection or maintenance, only the necessary number of sections will be opened, i.e., the minimum number of interlock subloops will be dropped. This procedure minimizes the possibility of exposure to hazards and expedites the search and secure procedure.

The access system will consist of four levels of interlocks. The highest and most restrictive level, beam permit, excludes all personnel under all circumstances. The second level, access with magnet power supplies on, is extraordinary and requires explicit permission of the head of the accelerator division. Special keying procedures under control of the division safety officer and the accelerator crew chief on duty are provided for this eventuality. The third level is for inspection and maintenance. Magnet power must be off, but the magnet systems may be at operating temperature and charged with liquid cryogens. In this case, the higher-level permits are dropped, but the interlock loops remain intact to prevent unauthorized entry into enclosures. Access procedures are as noted above. The fourth and lowest level, open access, is only used during periods of major installations or emergencies. In this mode, the affected interlock loops are dropped and no physical login is required at the access; laboratory security personnel will monitor the access point to prevent casual entry. When security personnel are not present, access gates will remain physically locked, though not interlocked. In this way, positive control of access to enclosures is maintained at all times.

Once an enclosure is secured, any access will void the beam permit and prevent introduction of beam until the accessed sections have been searched and a positive clearance signal has been received at the main control room by return of the search team's keys to the sector key tree, as previously noted.

The highest level of interlock, which ensures that no beam is brought into beam enclosures with personnel present, requires for its effectiveness the disabling of at least two independent devices. These are the critical devices, either of which alone, when disarmed, is capable of preventing beam from entering an accessed enclosure. In the SSC this is accomplished by a combination of facility and system design. The orientation and separation of adjacent accelerator enclosures, e.g., between the HEB and collider tunnels, are chosen so that, with either or both critical devices off, beam from one facility cannot reach the following one. Furthermore, beam loss in one accelerator will not cause radiation exposure to personnel who might be present in the adjacent tunnel. The injection lines from one accelerator in the injector chain to the next are designed with a bend angle such that the beam is completely removed from its channel when the power supply for the magnet producing the bend is not energized; one of the two critical devices is this power supply. The beam channel is also designed with a long drift space where adequate shielding can be installed completely around the beam pipe. In the beam line upstream of this constriction is an iron block sufficiently massive to absorb the beam. When the beam is on, this "beam stop" is suspended above the beam by an energized solenoid. The second critical device is the power supply for this solenoid. These devices are both "fail-safe"—loss of power or of the permit signal from the control logic will prevent the beam from entering the downstream enclosure.

Access controls and critical device signals involve life safety, therefore the links between them and the Main Control Center will conform to life safety standards. The power supply for the system will be backed up by non-interruptible power sources (UPS) in conformity with relevant guidelines.[11]

All personnel entering the beam enclosures must be positively identified and equipped with personnel monitoring devices. These devices will be routinely monitored and logged by the environmental health and safety group, who will maintain detailed exposure records of each individual. Individuals will be allowed into the beam enclosures only after attending classes and receiving proper certification. Preparation and presentation of these courses will also be the responsibility of the health and safety group.

8.3.2.2 Injectors

The injector complex is a major accelerator facility in its own right, comparable in scope (energy, intensity) to existing, operating facilities at Fermilab and CERN; thus, the ample operating experience of both of those facilities is applicable. From the radiological standpoint, however, the SSC injectors are easier to deal with due to the absence of an experimental fixed-target program, which constitutes the major shielding and monitoring problem in accelerators not designed as colliders. The only external beams presently foreseen are test beams from the HEB with proton beam intensities less than one-tenth of what is required for high-energy physics experimentation.

For both the Linac and LEB the CDR calls for a cast-in-place concrete enclosure below ground. The necessary radiation shielding is provided by earth fill between the accelerator enclosure and the power supply gallery and technical areas above. The MEB ring is located in an underground tunnel constructed by the cut-and-cover method from precast concrete sections. The needed radiation shielding will be provided by an earth berm over the concrete tunnel, 11 ft (3.4 m) thick. The HEB tunnel is shielded with a 13 ft (4 m) thick earth berm. As in the MEB, the HEB service buildings are located at ground level and are sufficiently offset to the inside of the accelerator ring to clear the shielding berm.

8.3.2.3 Beam Transfer

The relative placement of the HEB and main collider rings is dictated by a requirement that allows personnel access to the HEB while the collider is operating, and vice versa. For this reason, the plane of the HEB in the CDR lies above and inside the collider rings, with the minimum separation between the HEB and collider rings being approximately 30 ft (9 m) horizontally and 23 ft (7 m) vertically. Proton beams are extracted tangentially from the same HEB straight section in opposite directions, and bent down to the plane of the collider. A full charge of protons is extracted from the HEB and injected into the collider fourteen times to fill one collider ring. With a HEB cycle lasting 60 seconds, approximately one hour is required to fill both rings of the collider.

The combination of earth shielding and redundant critical device protection is designed so that radiation cannot enter the collider from the HEB when the collider tunnel is occupied. Conversely, by placing rings at different elevations and locating the HEB inside the circumference of the collider, muons from the HEB are prevented from being a radiation safety hazard in the collider tunnel, and collider muons do not constitute a hazard in the HEB tunnel.

Scrapers require particular attention since they are directly exposed to the circulating beam and the induced radioactivity in their vicinity will be relatively high. Extra shielding will be provided as needed in these locations. The amount of scraping feasible in the utility straight sections, as well as in the arcs, for beam cleanup purposes is discussed in Section 8.3.2.5.

8.3.2.4 Collider, Prompt Radiation

In normal operation, the proton beams are confined in the vacuum chambers of the magnet rings. Radiation normally occurs only at the IRs, where the two beams cross one another, at the scrapers, and at the primary beam absorbers to which the beams are directed at the end of a physics run. A very small amount of radiation, which is absorbed within the walls of the tunnel, is produced as a uniform halo around the ring by the collision of beam protons with residual gas molecules in the evacuated beam tubes. The amount of such radiation is very small, since the vacuum required to sustain the circulating beams is very high, i.e., very few gas molecules remain in the beam tube. In the absence of collisions in the IRs, the beam lifetime due to the beam-gas collisions is greater than 300 hs, corresponding to a uniform loss around the entire ring of less than 10^8 protons/sec, or 1.5×10^3 protons/m/sec; the local loss rate at the IRs due to beam-beam collisions is an additional several times 10^8 protons/sec, leading to a useful lifetime for the beam of approximately a day. At this time, the 80 percent of the beam remaining will be ejected in a 300-μsec (microsecond) burst to the beam absorbers at the end of the 24-hour cycle.

As in all accelerators, protection will be provided against a beam straying from its designed orbit and impinging on accelerator structures like the magnets or beam tubes. A highly sophisticated system of beam-position monitors and beam-loss monitors is incorporated into the design of the facility. These are coupled with very fast beam-ejection systems to minimize the possibility of such beam loss in the accelerator structures. Such systems have been employed successfully at all existing high-intensity synchrotrons to protect the accelerators from damage by the beam.

In this design, the beam-position monitors sense the location of the beam within the vacuum pipe while beam-loss monitors detect secondary radiation from even small beam losses. These systems together will, within a small fraction of a second, sense a developing loss and trigger the system of special magnets which eject the beam into the beam absorber in a controlled manner. Controlled extraction of the beam in this way protects the accelerator components against damage. Operation of the accelerator is prevented if the ejection system is not primed, that is, ready to extract the beam.

This magnet protection system also serves to protect the environment and public by properly disposing of the beam in a primary beam absorber. However, there will also be sufficient earth shielding over the accelerator to protect the public even if the system were to fail completely.

For calculating the shielding required away from normal loss points (scrapers, absorbers, and IRs), it is hypothesized that a full loss of beam could occur anywhere on the periphery of the machine once per year and that this loss would occur at full energy and full intensity. A safety factor of three times the design intensity is assumed in designing this radiation shielding. Under this hypothesis the specified minimum radial shielding around the tunnel is, everywhere, 30 ft. This thickness is based on the hadron component of the radiation. The forward muon emission from such an event will extend along the tangent to the ring for a distance of up to one-and-one-quarter miles, using very conservative criteria. The sweeping of this cone around the entire periphery delineates a zone in the plane of the collider rings. Since muons are far less interactive than hadrons, this zone demands less restrictive personnel access than the narrower zone for the hadron component.

A test beam of energy greater than 1 TeV will be provided but it will be of very low intensity, as noted above. In the current design this beam is extracted from the injector in the vicinity of the injection channels for the collider. Instead of being directed to the primary beam absorbers, the beam is steered into a facility for testing experimental equipment. The design of the radiation protection features for this beam are similar to those for the primary beam absorber. That is, iron and concrete sufficiently thick to provide protection for the environment and the public will surround the target and the test beam absorbers.

One other type of radiation is present in the SSC collider itself: synchrotron radiation. The energy of the proton beam is sufficiently high and the radius of curvature of the ring sufficiently small that the circulating protons will emit substantial synchrotron radiation in the form of visible and ultraviolet light and soft x rays—enough to have a significant impact on both the cryogenic and vacuum systems, since the radiation constitutes a heat load and leads to desorption of gas molecules from the vacuum-tube surfaces. However, this radiation will be completely absorbed in the beam-tube wall inside the magnets. Its energy is less than a kilovolt, so its range is less than the magnet wall thickness. This radiation is thus of no concern for personnel radiation shielding.

8.3.2.5 Collider, Residual Activation

As remarked in Section 8.3.2.4, the collider magnets cannot tolerate a significant beam loss on the cryogenics components due to their very low heat capacity and the small energy deposition required to cause loss of superconductivity. Thus the activation of the SSC superconducting magnets and related components at tolerable levels of irradiation will not be significant. Experience at Fermilab supports this conclusion.

Interaction of the hadrons from the various beam-loss points with the liquid helium in the superconducting magnets will lead to the production of tritium. However, preliminary calculations with programs using known tritium production cross sections, such as CASIM, confirmed by operating experience at existing facilities, indicate that the amount produced will be negligible.[12]

As noted above, at a small number of points around the tunnel special beam scrapers will be placed to remove the unwanted diffuse halo of particles that surrounds the dense central core. Removal of the halo improves the quality of the beam at the interaction points. The scrapers will consist of barriers, placed very near the beam, of sufficient length to effectively remove these unwanted protons.

The totality of beam scraped off in the various beam cleanup regions can amount to several percent, but this will not be confined to the loss point. Downstream of a scraper, there will be scattered protons impinging for tens of m on the magnets and other accelerator components; these protons and their secondaries will constitute a source of heat. For scrapers located in the arcs, the presence of superconducting magnets sets a limit on the heat input and therefore on the amount of halo removal that can be done at such locations. A design upper limit is 0.2 percent of the beam over a storage cycle at 20 TeV. More robust beam cleanup stations will be located in the utility straight sections adjacent to the injector complex, where the rf, injection, and beam ejection units are located. Conventional magnets, which can handle a larger heat load, are used downstream of the scrapers.

The scrapers have been modeled by a CASIM simulation,[13] and dose equivalent calculations are available[14] for 0.2 percent beam loss (equivalent to 1.3×10^{14} protons per year at design intensity) from cleanup in the arcs and 1.0 percent beam loss (6.5×10^{14} protons per year) applicable to the main scrapers in the utility straight sections. Scaling to other values can be done from these results.

At the end of a machine cycle, when collisions over many hours have degraded the beam intensity sufficiently, the run is terminated by ejecting the beams from the machine with the aid of the fast extraction system described above and directing them to beam absorbers external to the ring. The absorbers, one for each ring, are designed to withstand an impact of three times the design value of stored beam energy in 300 μsec. The absorbers are designed so that induced activity and contamination levels are minimized and decontamination efforts and service life are optimized.[15] The central core of the absorbers will consist of graphite plates. Graphite is chosen for its refractory and mechanical properties and because it does not become as radioactive under proton-beam irradiation as metal. This core is cooled by contact with a surrounding water-cooled aluminum box. It, in turn, is surrounded by aluminum and steel blocks designed to prevent groundwater activation problems by absorbing neutrons from the hadron cascade initiated by the beam. The mass of the absorber is sufficient to absorb the heat from the beam even with loss of coolant. The whole assembly will be encased in a reinforced concrete vault, in order to exclude groundwater from the active core of the absorber. The integrity of the graphite core will be monitored by ionization detectors in the steel behind the graphite. Sampling tubes leading from the inside of the concrete box to the tunnel will be sampled periodically to determine whether there is any water inside the sealed concrete box. In addition, an underdrain running the length of the beam absorber will allow sampling of possible radionuclides outside of the sealed containment.

Since the absorber is effectively a target for the proton beam, it will be a source of intense prompt radiation consisting of secondary particles produced by the stopping of the primary protons. For estimating the radiation source strength and consequently the required shielding, certain assumptions about the annual number of protons ejected are necessary. This number will be subject to administrative oversight and control in a manner very similar to that in which radiation doses to personnel will be controlled. The design of the SSC beam absorbers in the CDR assumes 6000 hours of physics experimentation per year and routine cycling every 20 hours, amounting to 300 beam ejections per year at full energy. Ejection at the lower energy and intensity associated with accelerator studies is estimated to be the equivalent of 200 additional full-energy ejections. Therefore, 500 full-energy beam absorptions per year at three times the design intensity are taken as the equivalent source term for radiation from the beam absorbers. This amounts to a total of 2×10^{17} protons at 20 TeV per primary beam absorber per year for radiation calculations.

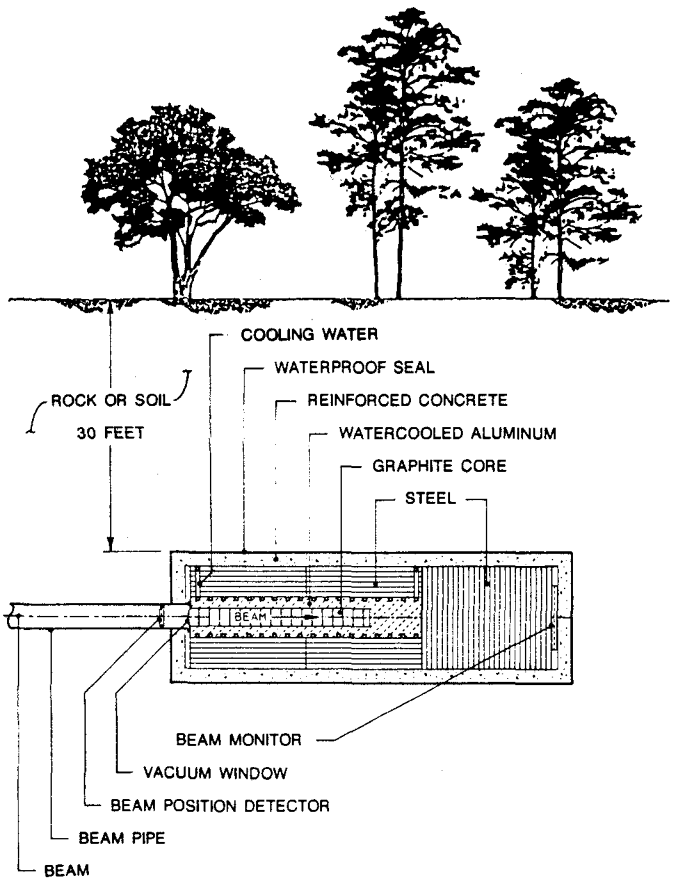

FIG. 8-1. SSC beam absorber example.

Based on these assumptions, absorption of the prompt muons in the forward direction will be provided by the shielding in a restricted zone at beam elevation—30 ft (9 m) in width and extending 3.25 miles (5.2 km) downstream from the absorbers. The shielding calculations on which these dimensions for the beam absorber are based assume soil with a density of 2.24 g/cm^3. A lower density at a specific site can be compensated by the addition of moderate amounts of high-density material (e.g., iron) in selected downstream locations. Since muons are far less interactive than hadrons, the muon zone, confined to the plane of the rings, demands less restrictive personnel access conditions than the 30 ft (9 m) radial hadron zone, as noted in Section 8.3.2.4.

8.3.3 Cryogenics

8.3.3.1 Cryogenic System

The SSC cryogenic system will include a large inventory of liquid and gaseous cryogens. The magnet system for the collider rings, which includes low-β quadrupoles and a many other special magnets in the IRs, contains 2.1×10^6 liters of liquid helium. Each of the ten refrigerators distributed around the collider ring will be equipped with two 32,000-gallon liquid-helium storage tanks and one 20,000-gallon liquid-nitrogen storage tank. Each refrigerator will have an ambient-temperature helium-gas storage facility of 600,000 ft^3 capacity at a pressure of 15 ata. In addition, liquid nitrogen will be furnished from two air-separation plants located near the IR clusters; each of these plants is equipped with two 55,000-gallon liquid-storage tanks. Single-phase pressurized helium will be forced through strings of magnets upstream and downstream from the refrigerators and returned with small amounts withdrawn *en route,* to be expanded into the pool-boiling recoolers. Helium gas will be used for cooling the 20-K heat shield in the ring magnet cryostats; liquid nitrogen provides the refrigeration for the second, 80-K, heat shield. Except for a room-temperature, 6-in.-diameter header, all the cryogenic piping for the collider rings is contained within the magnet cryostats.

8.3.3.2 Oxygen Deficiency Hazard

In case of leakage of cryogens (helium or nitrogen) from the superconducting magnet system, oxygen is displaced from portions of the collider tunnel, and there is a possibility of an oxygen deficiency. To protect personnel against this, oxygen sensors are installed at appropriate intervals in the tunnel and at each of the various access points to the tunnel around the circumference: at each of the ten service areas, at the ten exit areas located midway between service areas, and at accesses to IRs. For the same reason, oxygen sensors are placed appropriately in the tunnel and at the major equipment access points and service buildings of the HEB. Sensors for nitrogen leakage are to be installed at knee height above the floor, and sensors for helium leakage are to be located at head height.[16] Monitors are read out as alarms in the main control room as well as audible local alarms as described in section 5.4.2 above.

The normal partial pressure of oxygen at sea level is 158 mm Hg (millimeters of mercury).[17] Effects of lack of oxygen do not occur in healthy individuals until the partial pressure is less than approximately 135 mm Hg—an atmosphere defined as oxygen-deficient. In order of increasing severity, these effects include: reduced night vision (threshold 135 mm Hg); reduced judgement, memory, and motor movements (threshold 114 mm Hg); loss of consciousness (threshold 92 mm Hg); and coma. These effects are indicated in Table 8-1.

Table 8-1. Effects of exposure to reduced oxygen.

Oxygen Partial Pressure (mmHg)	Percent of Oxygen (at 760 mmHg total pressure)	Reduced Night Vision	Increased Ventilation Rate	Reduced Judgement, Memory, & Motor Movements	Time to Loss of Consciousness (minutes)	Time to Coma (minutes)
159	20.9					
135	17.8	Threshold				
131	17.3	23%				
117	15.4		Threshold			
114	15.0		↓	Threshold		
110	14.5	59%	↓	↓		
105	13.9		↓	20%		
92			↓		Threshold	
89	11.7	Required increase in illumination to see equal detail	↓	50%	↓	
86-73	11.4-9.6		1.65 x normal	80%	↓	
73	9.6				20	
64	8.4				5	
60	7.9		No further increase	Test results		10
56	7.4					5
52	6.9				1	
49	6.5					2
35	4.6					1
32	4.2				1/2	

Guyton A.C. (1971): Textbook of Medical Physiology, Fourth Edition, W.B. Saunder Co., Philadelphia, pp. 518-521.

8.3.3.3 Release of Cryogen in the Collider Tunnel

A potential cryogenic hazard associated with the SSC is an accidental release of cryogens in the collider tunnel or other confined spaces, which could lead to a precipitous drop in temperature over a small area and the local displacement of oxygen to less than life-supporting levels, if the release were large enough. Of particular concern is a large-volume, albeit highly unlikely, liquid-nitrogen spill in the collider tunnel—e.g., as a result of a failure of an outer magnet vacuum shell bellows or other bellows connecting nitrogen circuits between magnets. Liquid helium poses a similar hazard. Approximately 40 linear ft of tunnel would be involved in the oxygen deficiency.

Tests involving the release of liquid cryogens—liquid helium in particular—in an accelerator tunnel have been performed at Fermilab[18] and Brookhaven.[19] One experiment consisted of venting approximately 350 liters of liquid helium for a short period of time in the Fermilab main ring tunnel. The test was a simulation of a possible accident in which a cart or magnet transport vehicle strikes a spool piece of the Tevatron and tears off all the relief valves on that spool piece. The test in question was a realistic simulation of short-term effects of an accident in a superconducting magnet collider system.

A similar, complementary test was conducted in the colliding beam accelerator tunnel at BNL; its purpose was specifically to determine if a relatively small leak of helium could, over a long period of time, go undetected by oxygen deficiency monitors in a collider tunnel and create a pocket where a potentially dangerous deficiency of oxygen could exist.

These tests show that helium stratifies, moving quickly to the top of the enclosure rather than mixing with the tunnel air. Measured propagation characteristics indicate acceptable response times for oxygen-deficiency monitors (ODMs) and that individuals walking at a normal pace can evade the hazard. This is convenient from the standpoint of detecting oxygen deficiency, since a detector located at the tunnel ceiling will always indicate the lowest oxygen concentration. Similar conclusions can be drawn with respect to a liquid nitrogen (LN_2) spill.[20] Should a rupture occur in a liquid nitrogen line, LN_2 will spill onto the tunnel floor and flow from the point of spill along the pitch of the floor and into the gutter. From there it will flow into drains in the floor (see Fig. 8-1) to be collected in the underdrain. Cold nitrogen (N_2) gas vaporized in the spill area will flow away from the point of generation and along the tunnel, covering the floor area as it travels away from the spill. As the gas contacts the concrete floor, it will be warmed at a rate limited by the heat-transfer coefficient between the gas and the concrete. The liquid nitrogen trapped in the underdrains will be vaporized only slowly through the drains. Because of the density differences, the cold N_2 gas will stratify and not mix readily with the air in the tunnel. Studies indicate that distinct boundaries will be generated between oxygen-deficient and normal atmospheres.

8.3.3.4 ODH Monitoring and Ventilation

Permanently installed ODMs will continuously monitor the tunnel atmosphere: in the event of an ODH incident during access periods, the ventilation system will respond and an alarm will be set off.[21] Personnel will be trained to move ahead of gas from a break in the cryogenic system, toward fresh air.

The ventilation system for the collider ring tunnel consists of a push-pull arrangement with exhaust fans at each service building shaft and supply fans at each exit shaft halfway between the service areas at a distance of 2.5 miles (4 km). The fans are rated at 10,000 cfm, permitting an air flow in the tunnel of about 1 mph (1.5 km/h). The system has provisions for tempering the air during cold or humid weather. These fans are under local control with provision for remote control from the main control room. The system operates whenever the tunnel is occupied; access to the tunnel is precluded if the fans are not operating.

8.3.3.5 Cryogenic Systems Design

Policies pertaining to potential cryogenic hazards and accidents will be developed from those delineated in Chapter 5 of the *Fermilab Safety Manual*,[22] and similar documents describing safety procedures at other large cryogenic installations. The collider ring cryogenic system design and all cryogenic components and subsystems with unusual hazards will be subjected to a safety analysis and a safety review. The director of the laboratory can delegate responsibilities to division or section heads and appoint the necessary review panels and safety subcommittees. Cryogenic personnel will have sufficient education, training, and supervision to ensure that they can perform their work in a manner safe for themselves and for others. They will attend appropriate formal safety courses or receive direct instructions in working procedures and cryogenic safety considerations, depending on the degree of the hazards. The division or section heads controlling the various cryogenic facilities will be responsible for ensuring that the latter provisions are enforced.

Components and systems will be subjected to a Failure Mode and Effects Analysis (FMEA). Alternatively, consequences of system failures and upsets, as well as procedural errors, can be analyzed by what is known as a What-If Analysis, which analyzes subsystems rather than components and seeks to unearth hidden flaws in the design or procedure that could present a hazard to personnel and equipment. Particular hazards identified and multiple failures difficult to treat in a FMEA will be analyzed instead in a Hazard Analysis.

From the procedural standpoint, each active component of the system will be reviewed in each failure mode and documented. Hazards to be analyzed will be identified; in the subsequent analyses, care will be taken to include the effect of failures in adjoining systems and to clearly define the boundaries of the analyses.

Table 8-2. Oxygen Deficiency Hazard classification scheme (after Fermilab Safety Manual)[23]

(a) Determination of the Oxygen Deficiency Hazard class for an operation.

The Oxygen Deficiency Hazard (ODH) class depends on the probability of fatality to a lone and unequipped person engaged in the operation. This probability is roughly equal to the oxygen-deficiency hazard index:

$$\phi = \sum_{i=1}^{n} (P_i F_i)$$

where

ϕ = the oxygen deficiency hazard index (h^{-1})

P_i = the probability of the i^{th} event (h^{-1}) and = (experience MTBF*)$^{-1}$

F_i = the fatality factor of the i^{th} event (h^{-1}) = $10^{(6.5 - PO_2{}^{\dagger}/10)}$

It has been assumed that there are n independent events that may result in an oxygen deficiency.

(b) Oxygen Deficiency Hazard Class

ODH Class	ϕ (h^{-1})
0	$< 10^{-7}$
1	10^{-7} to 10^{-5}
2	10^{-5} to 10^{-3}
3	10^{-3} to 10^{-1}
4	$> 10^{-1}$

* Mean Time Between Failures
† Percent of Oxygen

Operations in potentially oxygen-deficient atmospheres will require: (1) that each operation be assigned an ODH class (see Table 8-2)[24] and (2) minimum protective measures be instituted for each operation based upon its ODH class. Protective measures include

- Posted warning signs (ODH class 1 or higher)
- Personal oxygen monitors (class 1 or higher)
- Medical approval for ODH work (class 1 or higher)
- Oxygen deficiency hazard training (class 1 or higher)
- Ventilation (class 1 or higher)
- Multiple personnel in communication (class 2 or higher)
- Communication with unexposed observer (class 3 or higher)

To avoid over-pressurization of cryogenic vessels, the design and use of all SSC pressure vessels will be in accordance with applicable American Society of Mechanical Engineers (ASME) Codes. To prevent unwanted build-up of pressure, all systems will be designed with adequately sized pressure-relief and vent systems to expel gases either into a recovery manifold or directly to the atmosphere in the tunnel.

8.3.3.5.1 Cryogenic equipment failure analysis. Among the most plausible types of equipment failure that could lead to large-scale spills of liquid helium (LHe) or liquid nitrogen are:

- Dumping of stored energy from a quenching string of magnets into one or a few magnets, possibly as a result of failure of the quench protection system (it should be noted that this does not constitute a personnel hazard, since personnel are excluded from the tunnel when magnets are powered)
- Rupture of the LN_2 magnet shield line into the insulating vacuum space
- Rupture of the LN_2 magnet shield line in magnet interconnection region
- Rupture (shearing) of bellows in outer vacuum jacket between magnets
- Rupture of outer vacuum wall of magnet cryostat
- Rupture of outer vacuum wall of spool piece cryostat
- Rupture of relief valves on spool pieces

A major break in the vacuum wall of the magnet cryostat coupled with a rupture in the 80-K-shield cooling line can be detected by flow measurements in the suction and discharge lines to and from the magnet shield. These will activate a system of alarms. Secondary information, aiding in locating the break, is provided by pressure and level gauge measurements. Analysis of such an event[25] shows that immediately after a rupture the pressure will drop to the local boiling point value, followed by boiling and a large expansion in volume. Initially, the liquid nitrogen will remain in the cryostat vacuum space, warming up magnet and cryostat. After a period of time, the liquid will start spilling into the tunnel where it vaporizes at a rate dependant upon the temperature of the liquid and its thermal contact with the environment. The tunnel ventilation system will mix air with vaporized nitrogen, producing a gas with lower-than-average temperature and oxygen concentration downstream of the spill for a period of roughly one minute. The flow rate of the venting gas will be reduced and the total amount limited by the inclusion of valves at approximately 1-km intervals in the shield line.

If a break in the vacuum shell and 80-K shield line should occur, it is possible that the 20-K helium-gas-cooled shield line could rupture as well, since both lines are located on the same side of the cryostat (Fig. 4-8). The consequences of such an event have also been analyzed and various measures identified for warning of such failure (pressure sensors) and for reducing the rate of flow of helium (valves, appropriate modifications of shield line sections).[26]

A break in either the 4-K-vapor or liquid-helium line has also been analyzed.[27] In this study, it was assumed that the 80-K and 20-K shield lines would not break in the same accident because they are located at the other side of the cryostat from the 4-K lines. A worst-case scenario leads to an oxygen-deficient atmosphere (10 percent oxygen) in the immediate vicinity of the break, helium gas separation from air in the tunnel downstream of the failure (but the lower half of the tunnel remaining free of helium), and tunnel conditions unaffected by the event immediately upstream of the failure. Venting of helium gas, rather than liquid helium, results in less oxygen deficiency (~17 percent). The cryostat design will be studied with a view to locating the 20-K and 80-K lines on the wall side of the tunnel and the 4-K lines closest to the tunnel traffic area.

8.3.3.5.2 Compressor noise. The ambient noise levels from the helium-gas compressors at the service areas will be up to 110 dba. The compressors will be installed in a building separate from the service building housing the refrigerator, magnet power supplies, and controls. Ear protection will be required for access to the compressor building.

8.3.4 Electrical Systems

8.3.4.1 Electrical Bus Bars and Power Supplies

Almost all of the bus-work in the electrical systems for the main ring as well as the injector synchrotrons and linac are contained inside the respective magnet systems and cannot be accidentally touched. Exposed electrical bus is either protected by physical barriers or de-energized by the electrical safety system prior to personnel access to an area. All power supplies that feed power to exposed conductors above a defined voltage or where the stored energy is greater than a defined minimum, except for tunnel vehicle power, will be connected into the safety interlock system. Standard lockout procedures will be followed prior to allowing general access to any area where there are potential high-voltage electrical hazards.

8.3.4.2 Electrical Power Distribution Safety

The electrical power distribution systems, including the substations and a variety of feeders, can constitute lethal hazards. Although the installation, maintenance, and repair of these systems at the SSC will be done by qualified electricians, it will be the responsibility of the SSC supervisor on any particular job to ensure that the work be done safely and according to the applicable codes. Procedures for safe work on electrical power distribution systems include[28]

- Use of approved disconnects or breakers to allow the safe isolation of subsystems
- De-energizing and tagging out electrical systems before a supervisor permits work to proceed, except under exceptional circumstances
- Authorization only by an SSC supervisor for work on an energized subsystem; at least two qualified workers assigned to such work
- Consultation with a technical expert in case of doubt by either the supervisor or the workers assigned to work on energized equipment
- Inspection of completed work by the supervisor before the system is re-energized

8.3.4.3 Microwave Radiation[29]

The microwave energy generated by the klystrons of the rf accelerating system of the collider will be completely enclosed within wave guides held under vacuum. Microwave leakage to the environment will be minimal, with permanent monitors to ensure that exposures are negligible.[30] However, the klystrons and cavities will be sources of x rays. Frequent radiation surveys will be carried out to ensure that shielding is in place. In addition, temporary lead shielding will be utilized to ensure that the x-ray levels remain low during cavity tests and operation. At the klystron gallery of the CERN LEP accelerator, the x-ray levels are specified to be less than 0.5 mrem/h in the passageway along the klystrons.[31] A similar administrative control level will be established at the SSC.

8.4 EXPERIMENTAL AREAS

8.4.1 Radiation

During beam operations, the IRs will be the most significant source of radiation in the SSC. The radiation in the transverse direction from beam interaction points is dominated by hadrons; the radiation in the forward direction beyond an IR consists primarily of muons, since forward hadrons are of necessity absorbed by special scrapers and absorbers designed to protect the superconducting magnets in the accelerator lattice.

At the low-β IRs, there will be 10^8 interactions per second. Each interaction will produce over 100 secondary particles, so over 10^{10} energetic secondaries will be produced per second and will be incident on the detector. In view of these large numbers, the potential for radiation damage and activation of detector components is of concern. A workshop in the fall of 1987 focused on the latter.[32] In general, it appears that radiation damage to many kinds of detectors (such as silicon devices and plastic scintillators) is of greater concern than component activation. Nevertheless, activation will constrain procedures in the repair and dismantling of detectors, especially in high-luminosity areas.

Personnel protection will depend on access labyrinths and strict access control, with the use of a fail-safe, redundant safety interlock system.[33] Models for such a system are already deployed at the collider Detector at Fermilab (CDF) experimental hall of the Tevatron and the SPS collision areas at CERN. Temporary local shielding will be used during work on the detectors and accelerator components in the hall where residual radioactivity warrants.

Some of the energy absorption in the radiation cascade will take place in the air of the IR halls, as well as in the air of the accelerator tunnel.[34] A fraction of the energy absorbed by the air results in activation of the air nuclei. Since the accelerated beams of the machines are contained in vacuum, the radiation will be produced in air only by secondaries and therefore will be very low. For the same reasons, the amounts of noxious gases such as ozone produced by radiation will also be negligibly small. Nevertheless, careful monitoring will be maintained to ensure by direct measurement that the laboratory operates well within safe guidelines.

A large 4π detector will provide much of its own shielding. Most detectors discussed in the various workshops will employ the equivalent of two or more m of iron perpendicular to the beam axis. However, for IRs in which a detector has not yet been installed, or which contains thinner detectors, two conditions will need to be considered: accidental loss of the full beam, and "normal" radiation from the collision point. For personnel protection in the event of an accidental full beam loss in the absence of a detector, a minimum of 16 ft of concrete shielding is specified. In practice, such a loss would most likely occur as the beam entered or exited from the focusing quadrupole in the final-focus triplet; in this case a beam pipe with a large enough diameter to contain the secondaries from the beam loss as they traverse the open region will be coupled with local shielding of the triplet magnets bounding the region. This shielding will be sufficient to limit exposure from normal radiation from the collision point to be within the established administrative limits. As at the Tevatron, additional personnel protection will be provided by interlocked radiation detectors that prevent beam operations until corrective action is taken.

Because the full-intensity beams do not encounter stationary targets in the IRs, problems involving soil activation and, for the most part, radioactivation of components, are minimized. Nevertheless, beam losses must be considered. One consequence of beam-beam collisions is energy deposition in IR magnets (in particular in the focusing triplets) by the hadronic cascade initiated by inelastic collisions in the IR. Since these elements will be superconducting, there will be heat removal and quench considerations, and the materials used will be chosen for radiation resistance. A further consequence of this energy deposition will be radioactivation of the same components, for which estimates exist.[35] Finally, radiation damage to detectors and electronics can be expected, particularly at forward angles.

Neutron skyshine, the re-scattering from air nuclei of neutrons penetrating the radiation shield, can present a hazard at a distance from the source; therefore, the thickness of the shielding for near-surface or surface collision halls and the structure of their access labyrinths will be carefully designed to eliminate this concern.[36] Shielding above the accelerator tunnel in the vicinity of the collision halls will be designed to absorb upwardly-directed muons from the vertical beam steering sections.

8.4.2 Cryogenic Systems

As noted in Section 4.6, the large colliding beam detectors will probably incorporate large-bore superconducting solenoids. The use of liquid or gaseous cryogenic sub-systems in connection with these magnets poses cryogenic hazards essentially identical to those associated with the main collider and HEB cryogenic systems and delineated in Section 2.2.3: cryogenic liquids or gases under pressure could produce high-velocity flows in the area of rupture; extremely cold liquids or gases could cause cryogenic burns, frostbite, or lung damage; under certain conditions liquid cryogen spills could cause oxygen-deficient atmospheres; with the release of liquid cryogens, the water vapor in the atmosphere might cause clouds or mists to form that could reduce visibility in a local area. Oxygen-deficiency, and measures to protect against it, have been discussed in Section 8.3.3. Policies, procedures, and standards pertaining to other potential cryogenic hazards associated with cryogenic systems for large-scale solenoid magnets and IR magnets are no different from those of the collider ring cryogenic system as outlined in Section 8.3.3.

The precautions applying to all enclosures containing substantial quantities of cryogenic liquids, e.g., the necessity for personnel to have escape devices available (see Section 8.3.3), will apply equally well to the environs of the housing for a liquid argon-uranium calorimeter.

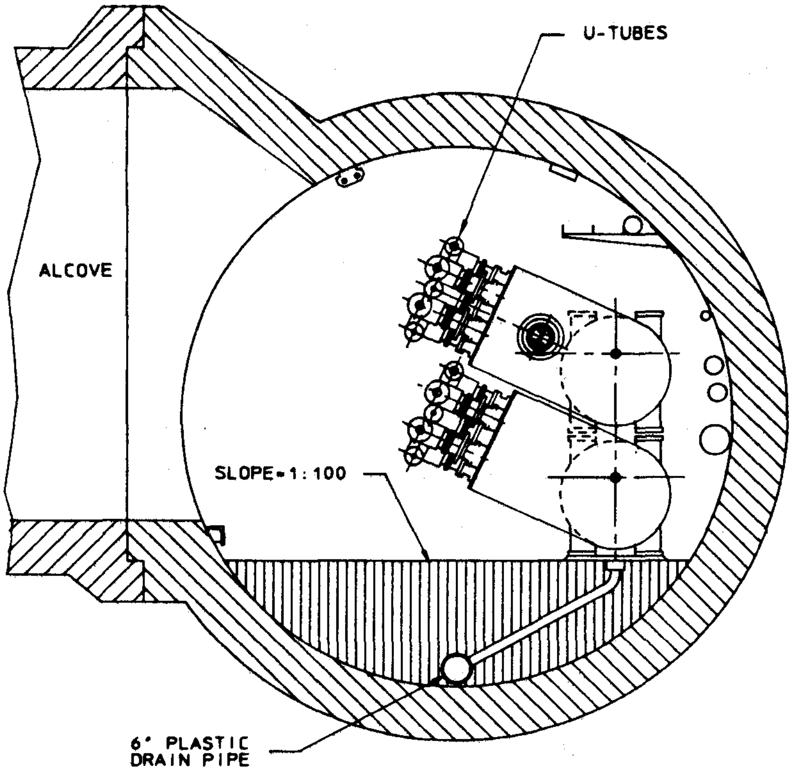

FIG. 8-2. Cross section of collider tunnel at cryogenic disconnect.

The collision hall with such a detector will require special ventilation to handle the very large inventory of LAr. Shafts and chases will be provided for a conventional air exchange and heating/cooling system. For the D0 detector at Fermilab, which has such a calorimeter, a deep sump is provided with an argon purge system to collect liquid/gaseous argon spills for controlled disposal.

8.4.3 Magnetic Fields

Because of the possible hazard to people with pacemakers, accessible areas with magnetic fields greater than 10 G will be posted. These fields will occur around the detector magnets in the experimental areas. Areas in the detector halls where personnel may be in fields greater than 100 G will also be posted to caution against the admission of ferrous tools and equipment. The SSC management will monitor the development of regulations and the progress of research that relate to other aspects of personnel exposure to static magnetic fields and will develop laboratory rules and guidelines accordingly. The precedents set at other high-energy laboratories such as Fermilab, BNL, and SLAC will be helpful in this regard.

8.5 DETECTORS

8.5.1 Detector Construction

For most detectors considered in design studies, large pieces will be a part of the iron yoke for the magnet, the hadron calorimeter, the muon identifier, and the support structure. With the total weight in a detector as much as 50,000 tons, individual pieces can be of the order of 100 tons, and special care must be taken in installing these pieces in the experimental areas. While lowering the modules, access to the regions where heavy equipment is being handled will be restricted to the necessary minimum of people. It is preferred that the equipment be designed so that no welding or cutting be required during assembly of the detector.

Pressure vessels will be required to conform to the appropriate codes. Standards are as stated above for accelerators.

Many of the gases used in detectors are flammable and/or toxic. Standard procedures for handling these gases include

- Bulk storage at the surface; reservoirs isolated from the local storage and detector volume to avoid unnecessary hydrostatic pressure levels
- Gas mixing, pumping, and monitoring at the surface in an isolated building
- Use of appropriate metallic plumbing
- Leak detection including flammable gas detectors in the experimental hall and monitoring of gas inventory by mass flow comparison of the supply and return lines
- Leak detectors interlocked with fail-safe gas-supply valves and power supplies
- Smoke and heat sensitive fire alarms in and on the detector. Possibly interlocked to the gas supply systems and connected to the SSC fire-alarm system
- Measurements of leakage rates by pressure decay times to ensure that systems are adequately tight

8.5.2 Calorimeters

An alternative to the cryogenic complications of a liquid argon system involves the use of the flammable organic liquid TMP. The flash point for this substance is 7°C, its boiling point is 122°C, and its lower flammable limit is at $\Delta V/V = 0.9\%$. The experiment UA1 at

CERN is in the process of constructing a calorimeter using TMP. If it proves successful, there may be proposals to use TMP at the SSC. At CERN it is planned to detect leaks using an infrared analyzer technique with three levels of alarms: the first level at $\Delta V/V = 0.05\%$, the second at $\Delta V/V = 0.1\%$, and the third at $\Delta V/V = 0.2\%$. Requirements at SSC will take cognizance of the CERN experience. Fire and smoke detectors will be mounted at relevant locations on the detectors and in the halls.

Calorimeters employing depleted uranium are used at both Fermilab and CERN and are under construction for HERA. The risk of contamination and fire from the pyrophoric nature of small uranium chips and the flammability of bulk uranium have dictated a policy at both laboratories of allowing no machining of uranium on the laboratory site. The experience of these laboratories, plus guidance from the industries handling this material, will be followed at the SSC, if such materials are used. Precautions proper to heavy metal contamination will be enforced.

High voltage circuits will be designed and constructed with materials and components as intrinsically safe as possible. Halogen-free cables, conforming to the low-toxicity, fire-retardant IEC specifications will be used. Cable trays will be shielded as far as possible from mechanical damage. The high-voltage supplies will have an external trip input which will be connected to an alarm. This external trip can be in addition to the automatic rundown initiated externally by the gas system in case of an emergency, or internally by an overcurrent detected on the current monitors. The high voltage can be tripped in less than 10 msec. Reset will require manual intervention.

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9 WASTE HANDLING, STORAGE, AND DISPOSAL

Like any community of approximately 3000 people, the SSC will generate a certain amount of waste materials. In order to estimate the volume and nature of such waste, the DOE has reviewed data on waste generation from other basic research facilities to use as a basis for projecting to the SSC.[1] In this chapter the results of the projection are summarized. Both liquid and solid waste are considered under the categories of conventional, radioactive, hazardous, and mixed waste.

9.1 CONVENTIONAL WASTE

The amount of conventional solid waste generated by the SSC facility is estimated to be 30,000 yd^3/yr—mostly in the form of waste paper, cafeteria wastes, etc. Such waste may be disposed of as solid waste in an on-site landfill, in an off-site landfill, or by other methods. Volume reduction techniques will be used where feasible to reduce the amount of waste to be handled.

Conventional liquid waste such as sewage or effluent from cooling systems will amount to approximately 150,000 gal/day. Almost all of the sewage will be generated in the campus/injector area, which is the normal work place for the majority of the staff. A sanitary network will be provided in this area, discharging into a central sewage treatment plant. The effluent from this plant will be treated to meet appropriate state and federal standards, and will be discharged in accordance with National Pollutant Discharge Elimination System (NPDES) permit requirements. The sanitary waste from the experimental areas away from the main site will be treated locally in small packaged sewage treatment systems or piped to a neighboring municipality that would contract with the laboratory for this service.

At most sites, cooling towers will be used to eject heat from the refrigeration systems. At an average site, approximately 300 gal/min of water will be required to compensate for evaporation from the cooling towers. Waste water from this process and from chemical treatment of the recirculating cooling water will be treated in an evaporation process with care taken to isolate evaporation ponds from the local ground water system.

9.2 RADIOACTIVE WASTE

The energy of the circulating beams is absorbed when the particles are stopped in the primary beam absorbers (Section 8.3.2) or by interaction with some components of the machine, usually at the positions where the particles are injected into or extracted from the machine (Section 8.2.2.3). A very small fraction of this absorbed energy results in the creation of radioactive nuclei—mostly with very short lifetimes (seconds or minutes). The longer-lived radionuclides constitute activity in the components where the beam is absorbed. The amount of this activity is proportional to the beam energy and the number of particles in the beam. When maintenance, modification, or repair is carried out on these activated machine components, material classified as low-level radioactive waste may result in the form of protective paper clothing or non-reusable material removed from the machine (e.g., cables and electronic parts).

Because of the extreme sensitivity of superconducting magnets to the heating caused by the absorption of energy from the beam, the tolerable number of protons striking the magnets is very low, as discussed in Section 8.3.2.4. Therefore, the amount of residual radioactivation resulting from the collider is significantly less than at a facility of similar size utilizing conventional magnets. Moreover, the SSC does not include a fixed-target facility. In a fixed-target facility, the beam energy is absorbed in a number of target locations external to the accelerator. Each of these locations is a potential source of low-level radioactive waste. Based on experience, half of the low-level waste produced at a fixed target facility is due to the accelerator and half to the fixed-target program.[2] So the amount of low-level waste from the SSC will be approximately half that from an accelerator with a fixed-target program that annually accelerates a comparable amount of total beam energy.

As noted previously, the SSC will accelerate two beams of 1.3×10^{14} protons each to 20 TeV once per day; by contrast, over most of the decade from 1976 to 1986 for which its waste history has been reviewed the Fermilab accelerator facility accelerated a single beam of 2×10^{13} protons to between 400 and 950 GeV every twenty seconds. Since the activation is proportional to the total number of protons accelerated per year times the proton beam energy, the total radioisotope production by the SSC should therefore be a few times less than the Fermilab facility in spite of its higher energy. Based on the Fermilab experience,[3] and allowing for the fact that the SSC will not have a high-intensity fixed target mode, the amount of low-level radioactive waste from the SSC is projected to be 8000 ft^3/yr (300 yd^3/yr) with an average activity of 0.001 Ci/ft^3. (This is similar to what is produced at a major university with a medical facility.)[4]

All of this low-level waste will be disposed of as solids in approved disposal sites. Any liquids produced,such as tritiated water from closed loop cooling systems or oil from vacuum pumps in an active area, will be solidified for shipment. Disposal is the responsibility of the DOE as provided for in the Low-level Waste Policy Amendments Act of 1985; additionally, disposal at a (NRC-licensed) state low-level waste facility remains a possible option, if that were acceptable to the states concerned.

Procedures instituted at Fermilab in 1987 for screening, sorting, and recycling materials have led to a twenty-fold reduction of radioactive waste relative to the basis used for the SSC projection. The SSC is monitoring this program, although such a reduction of the waste volume amount is not being projected at this time pending more extensive experience.

9.3 HAZARDOUS WASTE

Many of the support activities to be carried on at the SSC—from producing specialized electronics boards to vehicle and plant-maintenance activities—are typical of small industrial facilities. These support activities would result in an accumulation of hazardous wastes such as acetone, naptha, or freon. Extrapolating from Fermilab's experience in this area to the size of staff and the level of these activities expected at the SSC, the quantity of hazardous wastes is projected to be approximately 10,000 gal/yr. These wastes will be treated, stored, and disposed of in accordance with the Resource Conservation and Recovery Act 40 CRF 260 *et seq*.

9.4 MIXED WASTE

Mixed waste is waste that has a radioactive component as well as a hazardous component. At Fermilab in the past very small quantities of this have been generated, of the order of a few cubic ft per year. This has consisted of irradiated PCBs and irradiated lead/acid battery packs from emergency lights in the accelerator tunnel. At present, this mixed waste consists of aged capacitors from the booster accelerator and the lead/acid battery packs. The battery packs are being replaced at a rate of four per year, amounting to a volume of approximately 0.1 yd^3/yr. The newer model emergency lights that will be installed place the battery packs outside the radiation zone of the tunnel, so this source of mixed waste will be eliminated in the near future. Similarly, as funding allows, the booster capacitors are being phased out. The level of radioactivity in these materials is sufficiently low, and the half-life is sufficiently short that the activity dies away after a fairly short period, and procedures for hazardous waste are used in disposing of them. Based on this experience, the amount of mixed waste from the SSC is projected to be zero.

REFERENCES

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10 DECOMMISSIONING

10.1 INTRODUCTION

At the end of its useful life the facility will be decommissioned, that is, it will be removed from service and the site made available for other uses. The goal in decommissioning such a facility is the eventual restoration of the site to unrestricted use. To accomplish this, any radioactive or hazardous materials must be removed or effectively sealed off with safeguards to prevent access during the residual life of the activity or hazard. Any remaining structures must be removed or sealed off so they do not constitute a physical hazard.

10.2 CURRENT EXPERIENCE

A number of major accelerators have been decommissioned in the U.S. and Europe, most notably the Cambridge Electron Accelerator (CEA), Penn-Princeton Accelerator (PPA), Cosmotron, and Zero Gradient Synchrotron (ZGS) in the U.S. and the ISR in Europe. All of these machines were housed in buildings within laboratory sites. In each case the equipment was removed and the buildings used for other functions. The bulk shielding and much of the specialized equipment were salvaged and used at the laboratories, while cables, cable trays, and miscellaneous items were disposed of as scrap. A small amount was disposed of as low-level radioactive waste. Similar procedures will be followed for the SSC.

10.3 SSC DECOMMISSIONING

The above-ground facilities such as the service areas and staging buildings of the collider ring, the buildings of the injector complex, and the campus buildings will be stripped and dismantled, except, possibly, for some of the campus buildings that may find other uses. Since there is no residual radioactivity involved in the above-ground facilities, the procedures for decommissioning these facilities will be no different from normal industrial practice. In general, the refrigerators, power supplies, and associated equipment will be surplused following normal government procedures. Buildings will be demolished and the sites restored to their original states, as far as is practicable.

More complicated solutions are required for the underground facilities. There will be some low-level residual activation of accelerator components and possibly of the walls of enclosures in the interaction regions and at beam transfer points.[1] Potentially the greatest amount of activity will be in the beam absorbers. Since these are by reason of their function necessarily activated, the materials specified in their design will be selected to minimize residual activation, as noted in Chapter 8 of this document. As part of the decommissioning process, the absorbers will be removed and disposed of as low-level radioactive waste. The absorbers will be designed to minimize exposure to personnel in the dismantling process by the use of appropriate modular elements.

Data from Tevatron operations indicate that the superconducting magnets will not be measurably radioactive. However, since there is no foreseeable use for any but a small fraction of the accelerator magnets, these will probably be left in place, even though not radioactive, and the tunnels will be sealed at the bases of the access and exit shafts. Equipment in the shafts will be salvaged and the shafts scavenged. The shafts will then be sealed at grade-level as part of the surface restoration.

REFERENCES

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APPENDIX A

Pertinent DOE Safety-Related Orders

DOE Order	Title/Date
1540.2	Hazardous Material Packaging for Transport—Administrative Procedures (9/30/88)
3790.1A	Management Notification of Communicable Illnesses (4/22/86) (CH Notification expires 4/22/87)
5000.3	Unusual Occurrence Reporting System (11/84) (CH-6/85)
5400.2	Environmental Compliance Issue Coordination (8/87)
5440.1A	Implementation of National Environmental Policy Act (10/80)
5440.1B	Implementation of National Environmental Policy Act
5480.1	Environmental Protection, Safety, & Health Protection Program for DOE Operations (5/80)
5480.1-CH-III	Safety Requirements for Packaging of Fissile & Other Radioactive Materials (5/81)
5480.1-CH-VIII	Occupational Medical Program (5/81)
5480.1-CH-IX	Construction Safety & Health Program (5/80)
5480.1-CH-XII	Prevention, Control, & Abatement of Environmental Protection (12/80)
5480.1-CH-XV	Contractor Occupational Medical Program
5480.1A	Environmental Protection, Safety, & Health Protection Program for DOE Operations (8/81)
5480.3	Safety Requirements for the Packaging & Transportation of Hazardous Materials, Hazardous Substances, & Hazardous Wastes (7/85)
5480.4	Environmental, Safety, & Health Protection Standards
5480.7	Fire Protection (11/87)
5480.10	Contractor Industrial Hygiene Program (6/85)
5480.11 (draft)	Radiation Protection for Occupational Workers (8/87)
5480.15	DOE Laboratory Accreditation Program for Personnel Dosimetry (12/87)
5480.XX (draft)	Radiation Protection of the Public & the Environment (8/86)
5481.1B	Safety Analysis & Review System (6/86)
5482.1A	Environmental Protection, Safety & Health Protection Appraisal Program (CH-11/1/81)
5482.1B	Environment, Safety, & Health Appraisal Program (9/23/86)
5483.1A	Occupational Safety & Health Program for DOE Contractor Employees at Govt. Owned Contractor Operated Facilities (6/83)

5484.1 ....Environmental Protection, Safety, & Health Protection Information Reporting Requirements (2/81) (CH-3/84)

5500.1 ....Vital Records Protection Program (7/81) (CH-8/82)

5500.2 ....Emergency Planning, Preparedness, & Response for Operations (8/81)

5700.1 ....Major System Acquisition (9/78)

5700.6B................Quality Assurance (9/86)

5820.2 ....Radioactive Waste Management (2/84)

6430.1A................General Design Criteria Manual (12/87)

GLOSSARY OF TERMS AND ABBREVIATIONS

Abort Dump: See Beam Absorber.

Accelerator: Here, a device to increase the speed, and thus the energy, of charged particles such as electrons and protons.

ANSI: American National Standards Institute.

ASME: American Society of Mechanical Engineers.

B-zero: One of six long straight sections in the Fermilab Tevatron $p\bar{p}$ collider; the location of CDF.

Baseline: A reference set of data to be used as a measure of any changes to the environment caused by the construction and operation of the SSC.

Beam Absorber Window: A metal diaphragm separating the vacuum of the beam transport of the ejection line from the beam absorber. The ejected protons exit from the beam transport through this window.

Beam Absorber: Specially-engineered, water-cooled structures of graphite, aluminum, iron, and concrete into which the degraded circulating proton beams would be directed at the end of a period of colliding beam operation. The beam would also be directed to an absorber if, for any reason, normal operations were terminated earlier.

Beam Bypass: A possible alternate path for protons in the collider, which would permit continued operation of the collider during construction or servicing of detectors.

Beam Ejection Region: Region of the collider ring where a primary beam is extracted to be sent to the primary beam absorber.

Beta (β): A parameter of the accelerator magnet arrangement related to size of the beam at each part of the structure.

BNL: Brookhaven National Laboratory.

Bore Tube: Vacuum tube inside the magnets that contains the proton beam.

BQL: Best Qualified List of the proposed sites for the SSC; to be presented in January 1988.

Calorimeter: A detector component generally made up of sequential layers of absorber and detector elements that absorb virtually all of the energy of a hadron, electron, or gamma ray and produces an electronic signal proportional to that energy.

CASIM: A computer code developed at Fermilab for simulating hadron-nucleus interactions in shielding calculations.

CDF: Colliding Detector Facility, a major colliding beam detector at Fermilab.

CDR: *Conceptual Design of the Superconducting Super Collider*, SSC-SR-2020, edited by J. D. Jackson (March 1986).

Center-of-mass Energy: Total useful energy available for particle production in a particle accelerator or collider.

CERN: The European Laboratory for Particle Physics (Conseil Européen pour la Recherche Nuclèaire) in Geneva, Switzerland.

Cluster: Either of two approximately 5-mile-long portions of the SSC ring containing experimental halls and the beam injection and absorption areas (see Fig. 4-4).

Coil: Current-carrying winding in a conventional or superconducting magnet that produces (often with the aid of an iron yoke) the desired magnetic field strength.

Cold Box: A component of the helium refrigeration system in which high-pressure helium gas is expanded and cooled to liquid temperature.

Cold Mass: The magnet proper, or that portion of a superconducting magnet assembly that is maintained at helium temperatures.

Collar: Metallic structure used to support the coils in a superconducting accelerator magnet against the electromagnetic forces generated at high operating fields.

Collider Arcs: The curved portions of the roughly oval-shaped SSC main ring tunnel (see Fig. 4-4).

Collider: An accelerator in which two opposing beams of particles collide head-on.

Critical Devices: Elements of the safety system that are independently capable of shutting off the system. In accelerator systems these might be the ion source of the pre-injector, a beam shutter capable of absorbing the full beam, or a power supply for a steering magnet that must be on to direct the beam into the beam channel. Typically these devices operate in a fail safe mode.

Critical Energy: The point in the synchrotron radiation spectrum that divides the amount of power in the spectrum so half is above and half is below.

Cryostat: Container for maintaining apparatus at cryogenic temperatures—e.g., the helium vessel containing a superconducting magnet.

Depleted Uranium: Uranium containing a much smaller fraction of ^{235}U than the 0.7% found in natural uranium.

Destructive Loss of Beam: Mis-steering of the proton beam, by equipment failure or human error, that causes it to impinge on elements of the accelerator system, such as the guide field magnets, thereby causing the beam to be destroyed.

DESY: The German Electron Synchrotron Laboratory (Deutsches Elektronen-Synchrotron) in Hamburg, West Germany

Dewar: An insulated vessel to hold cryogenic liquids.

Dipole: An electromagnet producing a uniform magnetic field—e.g., a bending magnet in a particle accelerator.

Distributed Correctors: Correction windings located between the main dipole winding and the bore tube of the superconducting SSC dipole magnets.

DU: See Depleted Uranium.

Dump: See Beam Absorber.

EIS: Environmental Impact Statement.

EMCS: Environmental Monitoring and Control System.

External Beam: A beam of particles extracted from the accelerator.

Fermilab: Fermi National Accelerator Laboratory in Batavia, Illinois.

Fixed-target Accelerator: An accelerator in which a particle beam strikes a stationary target.

FMEA: Failure Mode and Effects Analysis.

Fermilab: See Fermilab.

GeV: One billion electron volts.

Hadron Cascade: The process of absorbing the kinetic energy of a moving particle by the production and subsequent absorption and reabsorption of hadrons through collisions with the nuclei of the absorbing medium.

Hadron: Any of the subatomic particles that take part in the strong interaction, such as a proton.

Half-cell: The smallest repetitive unit in the magnet system of a circular particle accelerator—here a quadrupole, a spool piece, and the six contiguous dipoles.

HEB: High-Energy Booster. The last stage in the SSC injection sequence, which raises the proton energy to 1000 GeV, or 1 TeV.

HEP: High-Energy Physics.

HERA: Hadron-Electron Ring Accelerator; the electron-proton collider at DESY.

Inelastic Collision: A collision in which the colliding particle loses some of its energy. In particle physics this results in the production of secondary particles.

Injector: An accelerator whose beam is injected into another, higher-energy accelerator.

IR: Interaction Region.

ISP: Invitation for Site Proposals for the Superconducting Super Collider.

ISR: Intersecting Storage Ring, or 31 + 31 GeV proton-proton collider at CERN, now decommissioned.

Kapton: A non-organic electrical insulating material.

Kicker: A special, pulsed high-voltage device to inflect or deflect the proton beam rapidly into or out of the SSC ring.

Klystron: A high-power radio frequency vacuum tube used to deliver power to an accelerating cavity in the accelerator.

Lattice: (Magnet Lattice) The sequence of bending (dipole), focusing (quadrupole), and correction (sextupole) magnets, together with magnet-free straight sections that make up the accelerator structure.

LEB: Low Energy Booster. The first circular accelerator in the SSC injection sequence, raising the proton energy to 7 GeV.

LEP: Large Electron-Positron collider with a circumferance of 27.9 km under construction at CERN.

Lepton: Any of six elementary particles that feel the weak but not the strong force.

LHC: Large Hadron Collider, proton-proton collider of up to 8 TeV/beam under consideration for eventual construction in the LEP tunnel.

Linac: See Linear Accelerator.

Linear Accelerator: A device that accelerates charged particles in a straight path—the first step in the SSC injection sequence.

LNG: Liquefied Natural Gas.

Low-β Section: A specially designed part of the accelerator that produces a small beam size at a designated point in the accelerator lattice. At a beam intersection point this results in a high beam density and consequently a high probability of interaction.

Luminosity: A term used in specifying the probability of interaction of particle beams in collision. The higher the luminosity, the greater the rate of collisions. It is expressed in $cm^{-2}\ sec^{-1}$.

Lumped Correctors: Special correction magnets in the magnet lattice (as opposed to corrections incorporated into all magnets and hence distributed, see Distributed Corrector).

MEB: Medium Energy Booster, or the third stage in the SSC injection sequence, which raises the proton energy from 7 GeV to 100 GeV.

Muon: A charged lepton 200 times heavier than the electron.

NEPA: National Environmental Policy Act.

Neutrino: Any of three uncharged, apparently massless particles associated with the electron, the muon, and the tau lepton. Neutrinos feel only the weak force and are very hard to detect.

Neutron: An uncharged hadron, very similar in mass to the proton.

NPDES: National Pollutant Discharge Elimination System.

NRC: Nuclear Regulatory Commission.

ODH: Oxygen-deficiency hazard.

ODM: Oxygen-deficiency monitor.

OSHA: Occupational Safety and Health Administration.

Photon: A massless particle, which is the carrier of the electromagnetic interaction; all electromagnetic radiation consists of photons.

Production Cross Section: The probability of producing a given secondary particle in a collision. The probability is expressed in cm^{-2}.

Proton: A positively charged hadron found in all atomic nuclei.

PSAR: Preliminary Safety Analysis Report.

Quadrupole: An electromagnet producing a uniform magnetic field gradient—e.g., a focusing magnet in a particle accelerator.

Quench (of a magnet): The sudden reversion of a superconducting magnet to the resistive state.

Quench Bypass: A current bypass system for protecting superconducting accelerator magnets in case of a quench.

Recooler: Heat exchangers located periodically along each SSC cryogenic loop for cooling the helium stream.

rf: Radio frequency.

rf Cavity: Radio frequency cavity. The device that imparts energy to the circulating particle beam in an accelerator.

Scaling: The behavior of nuclear processes according to which results at higher energies can be predicted by simple scaling of the results at a lower energy.

Scintillator: A material used in particle detectors that produces a faint flash of light when traversed by a charged particle.

Scrapers: Devices located at a number of points in an accelerator for removing the unwanted, diffuse halo of particles that surrounds the dense central core of the accelerated beam.

Skyshine: Nuclear radiation, particularly neutrons, emitted upwards and reflected back to the earth's surface by the atmosphere.

Spool Piece: Devices located in the drift spaces adjacent to every quadrupole in the SSC lattice, housing correction magnets and other instrumentation.

$sp\bar{p}s$: The proton-antiproton collider mode of operating the SPS.

SPS: Super Proton Synchrotron, at CERN.

SRD: Safety Review Document (this document).

SSC: Superconducting Super Collider.

Straight Section: An extended part of the accelerator structure containing no bending magnets.

Superconductivity: The ability of some materials to carry an electrical current with no power loss, owing to the complete absence of electrical resistance.

Superinsulation: Aluminum-coated Mylar sheets that constitute the multi-layer blankets of thermal insulation, as used in the cryostats of the SSC superconducting magnet system.

Synchrotron Radiation: Electromagnetic radiation emitted by any charged particle when it is forced in a curved path, as in a synchrotron.

Test Beam: A beam of protons or secondary particles used to develop and test particle detectors.

TeV: One trillion electron volts, or one thousand GeV.

Tevatron: TeV accelerator at Fermilab, used either for 1-TeV fixed-target experiments or as a proton-antiproton collider with a center-of-mass energy of 2 TeV.

TLD: Thermo-luminescent dosimeter. A personal radiation monitor that makes use of the linear relation between the amount of radiation absorbed and the light released when the dosimeter is subsequently heated.

TMP: 2,2,4,4 Tetramethylpentane. A flammable organic liquid proposed for use in some particle detectors.

TMS: Tetramethylsilane. A liquid proposed for use in some particle detectors.

Training (of a magnet): In superconducting accelerator magnets, the phenomenon of one or more premature quenches occurring before a magnet reaches the maximum field strength allowed by the intrinsic properties of the conductor.

TRD: Transition Radiation Detector.

Tune: The number of oscillations of particles about their equilibrium orbit in one revolution around an accelerator ring.

Waste, Radioactive: Equipment and materials (here, from accelerator operations) that are radioactive and have no further use. Such wastes from the SSC would be classified as low-level Class A radioactive waste, the lowest category.

Weak Force: A feeble, short range force that affects all particles, both quarks and leptons. It is responsible for the decay of many particles.

Yoke: The iron containing the field in an electromagnet.

ZEUS Modules: Components of the ZEUS detector at HERA.

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OUTLINE

FIGURES

TABLES