ACCELERATOR SYSTEMS OF THE SSC*

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The Accelerator Systems Division

The Accelerator Systems Division (ASD) of the SSC is primarily concerned with the technical components of the main collider rings. The division is not directly responsible for the superconducting magnets, but the detailed design of the magnet package is strongly influenced by the designs of the other technical systems. Table I is a list by work breakdown of the major subsystems for which the ASD has responsibility. Those subsystems shown in parentheses are ones that are not the direct responsibility, but require considerable design input from the ASD.

In this paper, we outline the objectives and tasks of the ASD during the R&D phase of the SSC project, present the proposed organization of the division, and discuss the R&D work that is presently taking place.

Objectives

The primary objective of the Accelerator Systems Division is to develop, design, test, construct, and install the devices and processes that will result in reliable, cost effective, and high performance collider rings.

These activities are divided in general into two major catagories, the R&D, and the construction. The R&D is expected to extend well into the construction phase of the SSC, and is in turn divided into two parts, Phase I, that takes place before the start of construction, and Phase II, after construction has started. Phase I is presently scheduled to last for three years, through FY1987. The construction phase will begin at the start of FY1988, and is anticipated to last six years.

Table I
WORK BREAKDOWN - ACCELERATOR SYSTEMS DIVISION

1. (Magnets)
2. Cryogenic Systems
3. Vacuum Systems
4. Main Power Supplies and Quench Protection
5. Correction Element Power Supplies and Quench Protection
6. R.F. Acceleration and Feedback
7. Injection System
8. Abort System
9. Beam Loss Calculations
10. Control Systems
11. Safety and Interlocks
12. Beam Instrumentation
13. Interaction Regions and Experiments
14. External Beams
15. Installation
16. Reliability Evaluation and Quality Assurance
17. Operations
18. (Conventional Mechanical Systems)
19. (Conventional Electrical Systems)

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Program Plan for R&D, Phase I

Objectives for Phase I

The major R&D objectives during Phase I of the SSC project are to design and conduct sufficient studies, including testing, modeling, and prototyping, to assure cost effective and reliable systems. This work will require a steadily increasing effort on the part of the CDG, some of the major U.S. and foreign research laboratories, and a considerable number of industrial organizations.

Major Milestones: The major milestones involved in the R&D phase are listed in Table II. Each of the major milestones must be preceded by a series of studies, experiments, and reports. The first of the primary milestones, the submission of a Site Parameters Document to the DOE has already been completed. Most of the effort of the ASD is presently being directed toward assisting with the magnet type selection, and preparing to develop a Conceptual Design Report, to be submitted in March, 1986.

Table II MAJOR MILESTONES

	Phase I Milestones	Date
1.	Site Parameters Document *	April, 1985
2.	Magnet type selection *	Aug. -Sept., 1985
3.	Start Pre-production Prototype Magnets	February, 1986
4.	Conceptual Design Report *	March, 1986
5.	Magnet Systems Tests Begin	October,1986
6.	Site Selection by DOE *	December, 1986
7.	Preliminary Report on Systems Tests	June, 1987
8.	Recommended Phase II Management and Procurement Plans	August, 1987
9.	SSC Construction Start (NTP) *	October, 1987

* Denotes Primary Milestone of Phase I

Organization of The Accelerator Systems Division for Phase I

The ASD will be organized into four groups. The groups and the tasks for which they are responsible are shown in Table III. There is considerable overlap of responsibilities among the groups, requiring interaction among them, and with the Headquarters. The purpose of this organization is to divide the work necessary to complete Phase I, and to make a smooth transition to more intense development work necessary in the later phases of the R&D effort, and into construction. It is expected that each group will have a leader who is in long term residence at the CDG. During the early part of the R&D effort, most of the work will be done by people at the national labs, and by industrial organizations. They will work at their home institutions, and also spend some time at the CDG for more intense work, and to promote better communications. As Phase I progresses, it is expected that the CDG manpower will increase, although the intention is to rely heavily on industrial participation.

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Table III. ACCELERATOR SYSTEMS GROUPS

HEADQUARTERS
Safety
Reliability
Quality Assurance
Desorption experiment
Systems tests

MECHANICAL	ELECTRICAL
(Magnets)	Main power supplies
Cryogenic systems	Quench protection
Vacuum systems	Correction elements
Installation	Control systems
(Conventional mech.)	(Conventional electrical)

BEAMS
Injection
Abort
Beam loss
Interaction regions
External beams
R.F. systems
Beam instruments
Operations

Objectives for ASD Groups for Phase I

Headquarters Group: The main tasks of the Headquarters Group of ASD will be to ensure a coherent set of systems designs, to design the subsystems specifically assigned to Headquarters, and to act as editor for the ASD part of written reports. Another important responsibility of the Headquarters group is to manage the large R&D experiments that are taking place early in Phase I. These are the Photodesorption Experiment, designed to measure the importance of synchrotron radiation as a contributor to the residual gas pressure in the beam tube, and the Systems Tests, designed to be development tools for the accelerator systems, and to be life tests of components and systems.

Mechanical Group: The major tasks of the Mechanical Group will be to design and cost the cryogenic and vacuum systems, to determine the installation method, cost, and schedule, to determine parameters that affect the conventional construction, and to ensure that the magnet design effort results in devices that meet proper standards, and fit in with the overall accelerator design.

Electrical Group: The most important jobs for the Electrical Group involve the design and cost estimates of the main power supplies and quench detection and protection of the magnets, and the same for the correction magnets. In addition, a preliminary design must be done for the controls systems, and estimates and specifications made for overall power needs, which are used as input to the conventional construction design. The power supply and quench protection designs have a considerable impact on the magnet design and development. The systems will be tested and perfected during the Systems Tests.

Beams Group: The primary objective of the Beams Group in the early part of Phase I is to analyze the needs for and design the injection and beam abort systems. This will involve a considerable amount of modeling of beam loss phenomena, particularly they affect the operation of superconducting magnets, and experimental equipment. Another important early task is the development of realistic interaction regions of different types, efficiently designed for the many different experiments at the SSC.

Present R&D Activity

Most of the work that has occurred up to now has been directed at determining which type of magnet to choose for the subsequent R&D effort. As a result, there is a reasonably well established plan to collect the data needed to make an informed choice. The Secondary Milestones for the magnet type selection, as far as they affect the ASD, are listed in Table IV.

Table IV
SECONDARY MILESTONES FOR MAGNET TYPE SELECTION

1. The Report of the Taskforce on Commissioning & Operations of the SSC.	June, 1985
2. The Report of the Taskforce on Power Supplies and Quench Protection.	June, 1985
3. A preliminary report on the photo-desorption experiment for cryogenic beam tubes.	Aug, 1985
4. Analyses of the costs of the systems and installation for the various magnet types.	Aug, 1985
Magnet type selection	Aug-Sept, 1985

Report on Operations

A Taskforce on Commissioning and Operations was formed in January, 1985, for the purpose of making a careful study of the commissioning and operating characteristics of collider rings constructed from the various magnet designs. The study began with a workshop at UC Berkeley, January 14-18, 1985, attended by more than 30 experts on various phases of accelerator operations from the U.S. and Europe. The Taskforce itself has met three times since the workshop, and has reached preliminary conclusions, which are shown in Table V. A preliminary Report of the Taskforce on Commissioning and Operations will be submitted to the SSC Director by May 20, 1985. The final Report is due on July 1.

Table V

PRELIMINARY CONCLUSIONS OF THE TASKFORCE
ON COMMISSIONING AND OPERATIONS

- Machines with reasonable operational characteristics can built with any of the magnet types now under development.

- There are real differences among the magnet types that result in variances in operational behavior and flexibility, and operating costs.

- One-in-one magnet types are preferred over two-in-one types for their greater flexibility, ease of operation and commissioning, and a number of design details of the complete machine. These factors are considered more important than having fewer cryostats, the major advantage of two-in-one types.

- Over/under magnet configurations are preferred side-by-side configurations, when considering one-in-one types, because of better use of tunnel space and easier installation and replacement. There are also more options for configuring the injection and abort functions for either two-in-one or one-in-one magnet types.

- There is no obvious choice to be made at this time between low field and high field magnet types. From the designs presently available, it appears that the low field design results in a machine that is 5% to 10% more costly to operate than a ring made out of high field magnets. However, there are other issues, such as synchrotron radiation and collective effects, which may be more important than the operating cost, and have yet to be completely evaluated.

Report on Power Supplies and Quench Protection

During the studies conducted for magnet type selection, it became obvious that the CDG would need detailed information about the power supply requirements, and the quench behavior of the different magnet types. A workshop was held at the CDG on April 1-5, 1985, attended by ten experts in the field. A report was submitted at the end of that workshop, containing the results of the preliminary studies, and an outline of the continuing work that was deemed necessary. A final report is due before July 1, 1985. The issues that were studied are listed in Table VI.

Table VI

ISSUES FOR THE TASKFORCE ON POWER SUPPLIED AND QUENCH PROTECTION

- The behavior of the multiple power supplies of the superferric design, particularly taking into account the strongly coupled coil configuration.

- The capability of attaining the required power supply regulation. It appears that a regulation of $\Delta I/I \lesssim 10^{-5}$ will be necessary to maintain the tune within an acceptable range.

- An investigation of the expected transmission line behavior of the power supply and magnet system.

- Reaching agreement about the input parameters that should be used for the quench propagation calculations.

- A study of various questions having to do with passive quench protection, such as the maximum permissible magnet length, the required sensitivity of detection schemes, and the quench propagation velocities.

- The pressure rise in cryostats during a quench, especially the high field magnets.

Report on the Photodesorption Experiment

The SSC will be the first proton accelerator or storage ring in which synchrotron radiation will be a significant effect. This radiation manifests itself in at least two ways:

1. Thermal energy deposited in the liquid helium coolant must be removed by the refrigerators.
2. Photons desorb gas molecules that are on the walls of the beam tube, thus increasing the gas density in the beam pipe.

The first of these effects necessitates the design of a refrigerator system of enough capacity to remove the heat. It also puts requirements on the size and position of flow passages, and the amount of cryogen flow in the magnet structure. Although the added power is significant, it is not a difficult problem to solve. The amount of power necessary to operate a smaller ring of 6T magnets, is about the same as that required to operate a larger ring of 3T magnets, even though the total synchrotron power radiated in the latter ring is half that in the former. A few examples of the parameters of synchrotron radiation at the SSC are shown in Table VII, along with typical parameters from the PEP electron-positron storage ring.

The second effect, that of photon induced desorption, has aspects that are less well understood. It is known from electron storage rings that the pressure rise in the presence of synchrotron radiation can be very large. The problem is solved in electron rings by designing distributed pumping into the beam tube, which removes the gas as it evolves from the wall. Eventually, the strip on the beam tube that is hit by most of the synchrotron power becomes depleted of gas, and the pressure decreases to tolerable levels.

Table VII

Synchrotron Radiation Parameters[a)]

Energy (TeV)	Field (T)	Bend Radius (km)	Energy Loss Per Turn (keV)	Critical Energy (eV)	Radiated Power Per Beam (kW)	Photons Per Second Parameter
20	3.0	22.2	56	130	3.9	4×10^{15}
20	5.0	13.3	94	220	6.5	7×10^{15}
20	6.5	10.3	122	280	8.5	9×10^{15}
0.015[b)]	0.3	0.165	27000	45000	2440	1×10^{18}

a) Assumptions: $\mathscr{L} = 10^{33} cm^{-2} sec^{-1}$, bunch spacing 10m, $\beta^* = 1m$, $\varepsilon_N = 1 \times 10^{-6} m$; *these imply a beam current of 70mA.*

b) Electrons on positrons at $\mathscr{L} = 10^{32} cm^{-2} sec^{-1}$, bunch spacing 733m, beam current of 90mA. This power is radiated into a room-temperature bore tube.

The cryogenic beam tube of the SSC is different in a number of ways:

1. It is not known what the yield of molecules will be per photon, or per unit power.
2. The desorbed photons do not leave the beam tube as when there are distributed pumps, but merely move to some other place on the tube, where they remain, due to the high sticking probability of the cold tube walls. They are then available to be desorbed by photons that have been reflected from the walls.
3. The probability of reflection is high, since the angle of incidence of the photons is very small, a few milliradians.
4. It is possible that there might be desorption processes that are active at cryogenic temperatures that are absent or insignificant at room temperature. For example, it is generally thought that the desorption process at room temperature is mediated by photoelectrons created in the metal that remove molecules when they exit and return to the surface.[1] This implies a cutoff energy for the process of a few electron volts. If there are weakly bound molecules on the beam tube surface, they could be directly desorbed through resonant excitation by

very low energy photons. Such weakly bound molecules do not exist at room temperature, but may be present at cryogenic temperature.

5. The energy spectrum of the desorbed molecules is not well known,[2] either at normal or cryogenic temperatures. Since the probability of being hit by the beam depends inversely on the velocity, and the sticking probability is also some inverse function of velocity or energy, the calculations that one can do are very uncertain.

It became apparent during previous studies[3, 5] that there were essentially no data on photon induced gas desorption from cryogenic surfaces. It was decided to perform an experiment at a synchrotron light source to measure the effect in a geometry that is as close to the real SSC geometry as possible. This experiment is presently being set up at the VUV ring of the National Synchrotron Light Source, at Brookhaven National Laboratory. This facility was chosen because it has photons of approximately the right critical energy, and can supply the needed power density.

The results of this experiment are crucial to the magnet type decision. Low field magnets (3T) result in 1/4 of the linear power density of synchrotron radiation, and 1/2 of the linear number density of quanta, relative to high field (6T) magnets. Depending on the dominant phenomena, this might result in 1/4 to 1/2 of the gas desorption in the low field machine, assuming the same initial beam tube conditions.

If the results of the experiment indicate that there might be an operational problem due to desorption, it is possible to design a "fix" into the beam tubes. It is unlikely, however, that a factor of two to four will allow us to choose one of the fields over the other, since by there very nature, vacuum systems are uncertain and unpredictable. A more likely result would be a redesign of the beam tubes and magnets to allow for some sort of pumping, probably of a distributed cryogenic design. Whatever the field choice, this solution will certainly have an influence on the size of the superconducting coils, and therefore on the cost of the magnets. Furthermore, the costs of the different magnet types scale in different ways with respect to beam tube size. In this case, it would be important to redesign the magnets, in order to obtain correct cost figures.

First results of the experiment will be from a room temperature aluminum beam tube. There is more experience with aluminum beam tubes than with any other material,[4] permitting a check on the technique and the calibrations. The experiment on the cryogenic tube, stainless steel plated on the inside with copper, will start on June, 1985, and some preliminary results should be available by the end of July, 1985. The experiment will continue in order to refine the data and to test different materials, and, if necessary, different beam tube designs.

Other R&D Tasks

In addition to the work that has been described above, there are a number of other activities that are being started by the ASD. These are listed below, with only short descriptions.

1. The cost estimates of the accelerator systems that were presented in the Reference Designs Study [5] are being updated to reflect new knowledge of the various designs and new design options. In the RDS, only the 6.5T design had a cost estimate for the accelerator systems. That cost estimate will be extended to include all of the magnet types now being considered.
2. A more careful cost estimate of the testing and installation of the various magnet types will be completed before the magnet style choice is made.
3. Planning, and some serious design work, has started, in order to make a smooth transition to a preliminary design phase. This will allow us to generate a Conceptual Design Report by March, 1986.

Summary

The objectives, organization, and immediate plans for the Accelerator Systems Division of the SSC have been presented. The preliminary results of a study on the commisioning and operational characteristics of the SSC as they are influenced by the various magnet types has been presented. The status of the present R&D work has been described, with particular attention to the experiment on synchrotron radiation induced gas desorption.

References

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