A Simplified Description of the SSC for the Task Force on Radiation Effects at the SSC

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Introduction

On March 7-9, 1988, the SSC Central Design Group will hold a meeting of the Task Force on Radiation Effects at the SSC. One of the topics to be considered by this Task Force is the radiation damage of "Materials, Accelerator Components, and Other Calorimeter Media." *This note provides a simplified description of the SSC accelerator, for the purpose of assessing the risk of radiation damage.*

Radiation will be produced in the SSC tunnel when high-energy particles are lost from the circulating beam and create nuclear cascades. The anticipated radiation dose near the beam pipe will consist primarily of ionizing radiation from electromagnetic showers. Further from the beam pipe, the primary radiation will be neutrons.

A simplified model of the accelerator components would be useful for the Task Force.

(1) A description of the accelerator is needed for the following two reasons:

(a) The amounts and types of materials used for accelerator fabrication (and the locations of these materials) are needed to simulate the nuclear cascades created by beam particles. A simplified model of the dipole magnet cold mass was assumed in SSC-N-439, which presented a preliminary calculation of the "Ionizing Radiation Dose in the SSC Dipole Magnet Correction Coils." A slightly more detailed description of the SSC is given in this note. The densities of the major metal subcomponents (which account for most of the mass of the SSC accelerator elements) are tabulated here. The data presented here agree well with a tabulation by Don Groom (1987).

(b) Having estimated the total radiation dose for SSC accelerator components, we need to establish whether those components will suffer radiation damage. In this note, therefore, the types, locations, and amounts of construction materials are tabulated.

(2) In the arcs of the SSC, there are two beamlines separated vertically by 70 cm. The accelerator components in the two SSC rings are dominated by the main magnets (dipoles and quads). The cold masses of these magnets are long, thin objects centered on the beam tubes, and they exhibit an approximate cylindrical symmetry. We therefore choose to describe the cold masses as simplified cylindrical objects. The distances from the beam center line of each subcomponent of the cold masses will be given. Although the radiation exposure will surely not be cylindrically symmetric (the dipole field will sweep charged particles in the horizontal plane), this simplified model should suffice for calculating the *peak* radiation exposure of each accelerator subcomponent.

Final designs are not yet available for SSC accelerator components. For the purposes of this note, the SSC design that is described in the Conceptual Design Report (SSC-SR-2020) is used as the basis of the simplified model. The magnet lattice is *assumed to be the 90° lattice as discussed in SSC-146. Also, an upgraded design for the* trim coils, as discussed in SSC-SR-1032, is assumed here.

Accelerator Subcomponents and Materials

A. **Dipole Magnets.** Only the regular arc cells of the SSC are considered in this note. In the 90° lattice, the dipole magnets take up about 87% of the space in the arc cells.

1. **Dipole cold masses of C358A design.** We assume the latest design for trim coils, as described in SSC-SR-1032. The amount of each material is expressed in grams per centimeter of dipole length. The location of each subcomponent is given in terms of its radial extent (measured from the beam center line). There is no implication that the subcomponents are volume filling: indeed, some subcomponents overlap in radial extent, and some subcomponents have voids.

Subcomponent and material [density in g/cc]	Radial extent (cm)	Amt (g/cm)
Beam tube	1.63 - 1.73	
Stainless steel (Cu plated) [7.83]		8.4
Trim Coils	1.73 - 1.95	
Kapton film		0.4
Tefzel adhesive		0.07
PK102 adhesive		0.3
S.C. wire (.014" diam., Kapton wrapped)		1.1
S-2 glass (PV coated)		0.4
Crest 7450 epoxy		0.07
Envex locating pins		--
Kapton bumpers		--
Circulating helium		
Coils [~7.0]	2.0 - 4.0	
S.C. wire [7.85]		
Cu		90.
Nb		20.
Ti		17.
Cable insulation		
Kapton		2.2
Fiberglass (epoxy impregnated)		5.0
Wedges [8.95]		
Cu		27.
Coil insulation		
Kapton		1.9
Teflon		0.1
Collars (stainless st.) [7.83]	2.1 - 5.5	460.
Yoke (steel) [7.87]	5.6 - 13.3	3300.
Bus Lead Assembly	10.6 - 13.2	
Pultruded duct (fibergl. reinf. polyester resin)		17.
S.C. cables and wires		?
Copper buses and wires		?
Electrical insulation		?
Shell (stainless st.) [7.83]	13.36 - 13.83	320.

2. **Dipole cryostats.** The magnet cryostat is a roughly cylindrical object with a radius of about 30 cm. The cryostats are not centered on the beam lines.

Subcomponent and material [density in g/cc]	Radial extent (cm)	Amt (g/cm)
Pipes and shells	15 - 40	
Steel [7.8]		1000.
Aluminum [2.7]		300.
Thermal insulation blankets		
Double alum. mylar, 25 μm (106 layers)		56.
Cerex spunbonded nylon, 10.2 g/m^2 (196 layers) [or Reemay spunbonded polyester]		200.
Cylindrical-post supports for cold mass (5 per 17-m dipole)		
Steel [7.8]		
Aluminium [2.7]		
G-11 CR tube, 1/16" wall		
Carbon-fiber reinforced tube, 1/16" wall		
Superinsulation		
Carbon-fiber-filled epoxy rods		

3. **Dipole Magnet Stands.** The Conceptual Design Report describes a dipole cryostat with five sets of support feet. It is now planned to have only two sets of support feet for each dipole. (See SSC-N-267 by Don Groom.)

B. **Quadrupole magnets.** The quadrupole magnets take up about 3% of the space along the beam line. It is a reasonably good approximation to say that the quadrupole magnet cross section is the same as the dipole magnet cross section. The quadrupole magnet actually has a different symmetry than the dipole magnet, but we are appoximating both of them as having cylindrical symmetry.

C. **Spool Pieces.** In the arc cells, about 5% of the space along the beam line is taken up by spool pieces. The *quench protection diodes* for the active quench protection system are located near the spool pieces, but not within them. For radiation protection reasons, the (room temperature) bypass diodes are located external to the cryostat, in holes in the tunnel wall, and are connected to the magnets with pairs of leads (safety leads). Also located in the spool pieces will be *temperature sensors* for the cryogenics system. Several types of sensors exist, and it will be necessary to select a radiation-resistant type.

D. ***Interconnection Sections.*** The interconnection sections, located between cryostats, are very similar to the magnet cryostats. In these 80-cm-long sections are located the bellows for the beam tube, for the cold mass liquid helium shell, for the helium and nitrogen lines, and for the cryostat vacuum vessel. Instead of the magnet cold mass, however, there is only a beam tube, bus leads, and a cold mass liquid helium shell. Therefore, organic materials in the interconnection sections (i.e., the bus lead duct and the thermal insulation blankets) are not as well shielded from ionizing radiation as in the magnets, since the *interconnections contain no magnet coils*, collars, or yokes. The CDR describes an active quench protection system, which is assumed here. However, if a *passive quench protection system* were to be chosen, then quench protection diodes operating at liquid helium temperatures would be located at every magnet, possibly within the interconnection section. There is an ongoing R&D program to study cold diodes. These diodes are sensitive to radiation damage, but they will not be discussed further in this note.

E. **Electronics and Cabling** in the tunnel. The subject of radiation damage to electronic equipment in the SSC tunnel is beyond the cope of this note and of this Task Force. It will be the subject of a future task force. However, a few words here are in order. An electronics rack containing an interface crate (with microprocessors) will be located at every other spool piece. In order to protect the electronics from radiation and environmental damage, the rack is installed in a shaft drilled into the tunnel ceiling. The increased distance from the beamlines and a shielding "plug" on the bottom of the rack will reduce the neutron fluence by a factor of one hundred. It is expected that the primary source of radiation damage to electronic components will be the neutron flux and not the ionizing radiation. The interface crates will communicate with the outside world via local area networks based on broadband cables that reside in the tunnel. These cables may be coaxial cables or fiber optics cables. When the CDR was written, the commercially available fiber optics cables were probably too radiation sensitive for SSC use.

Radiation Dose Estimates

Two approaches can be taken in measuring radiation exposures:

(1) The *absorbed dose* can be described in terms of the energy actually absorbed in the sample. As an example, 1 gray (Gy) = 1 joule/kg = 10^2 rad. Near the SSC beam pipes, the major issue for radiation damage is the degradation of organic materials by ionizing radiation. Since organics can be damaged by any radiation transferred from a radiation field, we quantify the radiation exposure in terms of the absorbed dose.

(2) The *exposure dose* can be described in terms of the radiation field to which the sample is subjected. As an example, reactor irradiations are measured in the number of neutrons per cm^2. In the SSC tunnel, away from the immediate vicinity of the beam pipes, one major concern is the damage to electronics by the neutron flux. Since the inorganic parts of electronic components are permanently damaged only when the energy transfer process involves the nuclei of the atoms of the material, it is appropriate to quantify the radiation exposure in terms of the exposure dose.

Ionizing Radiation

A preliminary estimate for the maximum total ionizing radiation dose to the correction coils in the SSC dipole magnets is given in SSC-N-439 by Don Groom (January 8, 1988). This calculation makes the following assumptions about total beam loss:

(1) The stored beam contains N = 4 x 10^{14} protons per ring. This is three times the nominal design current.

(2) The beam is lost through collisions with the beam pipe, with a lifetime of L = 300 hours or 1.08 x 10^6 seconds.

(3) The SSC operates T = 10^7 seconds per year, so the number of protons assumed lost every year = NT/L, in the appropriate units.

(4) The lifetime of the SSC is assumed to be 30 years.

The maximum integrated radiation dose to the correction coils in the dipoles is calculated to be **1 MGy**. This is probably about the highest radiation dose expected anywhere in the arcs of the SSC, except at beam scrapers.

Neutron Flux

An estimate of the integrated neutron flux is given in the SSC Conceptual Design Report. Since that estimate has been superceded by a more accurate estimate given in SSC-110, "Preliminary Simulations of the Neutron Flux Levels in the Fermilab Tunnel and Proposed SSC Tunnel" (1987), we use the results in the later document for estimating the neutron flux. If we assume the same operating parameters as was assumed above for estimating the ionizing radiation, then the integrated neutron fluence (over a 30-yr SSC lifetime) will be **2×10^{12} neutrons per cm^2**.

Radiation Resistance of Fabrication Materials

The organic materials being considered for use in the fabrication of the distributed correction coils were tested for radiation resistance in an experiment at BNL. (See Appendix K of SSC-SR-1032.) Small samples of the proposed materials were irradiated to a total dose of approximately **80 MGy**, which is considerably higher than the expected radiation dose at the SSC, and the samples were then re-examined for mechanical strength. Some samples suffered substantial damage. Materials which survived well were selected for future models of distributed correction coils, and these materials were the ones tabulated earlier in this note. (See Appendix L of SSC-SR-1032.) The results of this BNL experiment seem to be in rough agreement with CERN data which show substantial damage to organic materials at absorbed doses of 10 to 100 MGy. (See, for example, CERN 81-05 and CERN 85-02.)

"Radiation Damage to Electronic Components" is the subject of CERN 75-18 by S. Battisti *et al.* According to that document, the operation of electronic circuits is seriously affected by radiation environments with doses on the order of **10^{13} neutrons per cm^2**. If the shielding of the electronics racks in the SSC tunnel turns out to reduce the neutron fluence to around 2×10^{10} neutrons per cm^2 over the lifetime of the SSC, then it seems likely that the electronics will be able to survive the radiation environment.