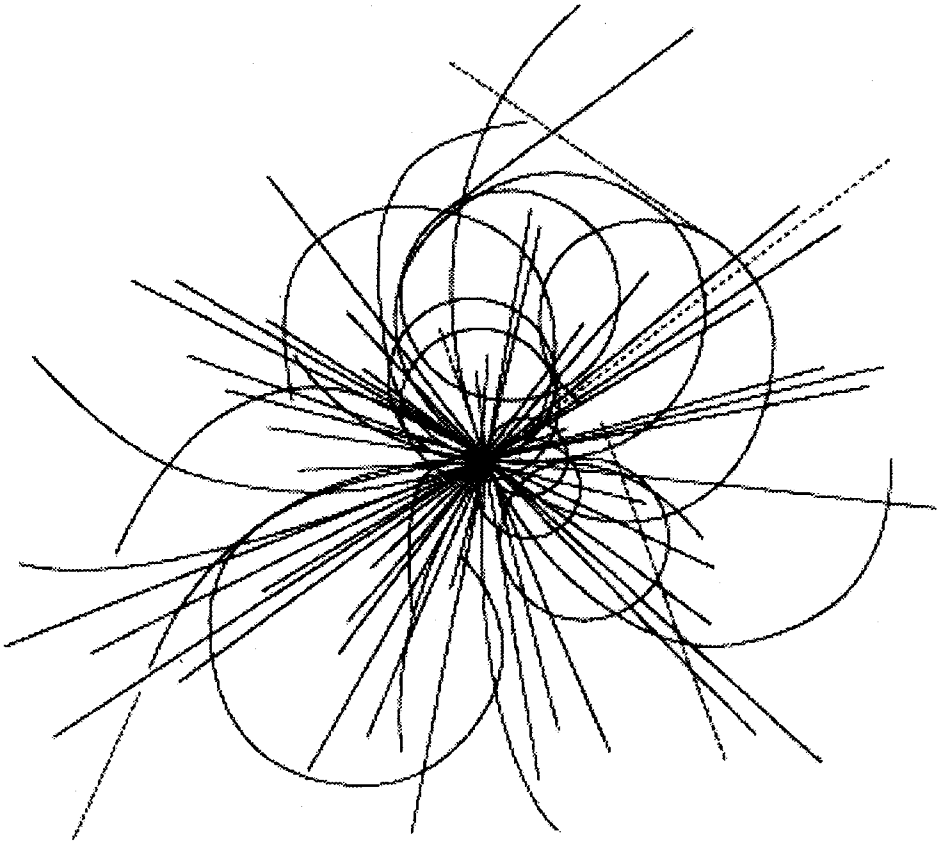
SSCL-Preprint-559
March 1994
Distribution Category: 400

S. Baker
G. Britvich
J. Bull
L. Coulson
J. Coyne
N. Mokhov
V. Romero
G. Stapleton

Overview of Radiation Protection at the Superconducting Super Collider Laboratory



Superconducting Super Collider Laboratory

SSCL-Preprint-559

Overview of Radiation Protection at the Superconducting Super Collider Laboratory*

S. Baker, G. Britvich, J. Bull, L. Coulson and J. Coyne
N. Mokhov, V. Romero, and G. Stapleton

Superconducting Super Collider Laboratory†
2550 Beckleymeade Ave.
Dallas, TX 75237, USA

March 1994

---

*To be presented at the Eighth International Conference on Radiation Shielding in Arlington, Texas April 24–27, 1994.

†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

Overview of Radiation Protection at the Superconducting Super Collider Laboratory

S. I. Baker, G. I. Britvich, J. S. Bull, L. V. Coulson, J. J. Coyne,
N. V. Mokhov, V. D. Romero, and G. B. Stapleton
Superconducting Super Collider Laboratory
2550 Beckleymeade Ave., Dallas, TX 75237
(214) 708-1590

ABSTRACT

The radiation protection program at the Superconducting Super Collider Laboratory is described. After establishing a set of stringent design guidelines for radiation protection, both normal and accidental beam losses for each accelerator were estimated. From these parameters, shielding requirements were specified using Monte-Carlo radiation transport codes. A groundwater activation model was developed to demonstrate compliance with federal drinking water standards. Finally, the environmental radiation monitoring program was implemented to determine the effect of the facility operation on the radiation environment.

I. INTRODUCTION

The Superconducting Super Collider Laboratory (SSCL) is a high-energy research laboratory whose mission was to design and build the largest particle accelerator in the world, the Superconducting Super Collider (SSC). When embarking on the construction of such a large project as the SSC, it is vital that all aspects of radiation control be folded into the design at the beginning to insure not only compliance with all applicable regulations, but that the project is operated in a safe and cost-efficient manner. The purpose of this paper is to provide an outline to the philosophy, techniques, and implementation of radiation protection at the SSC.

The SSC facility design consists of a series of five proton accelerators, culminating with the 20 TeV collider. The booster complex, consisting of a linear accelerator (Linac), two resistive magnet synchrotrons (the Low Energy Booster [LEB] and Medium Energy Booster [MEB]), and a superconducting magnet synchrotron (the High Energy Booster [HEB]), provides 2 TeV proton beams for injection into the Collider. The Collider itself is a pair of superconducting magnet accelerators contained in an underground tunnel 87 km in circumference. The proton beams are steered to interact at several experimental halls, which are also located underground. In these halls, massive detectors, weighing over 20,000 tons, study the particles produced by the proton interactions. The laboratory also includes a test beam facility used to calibrate portions of the large detectors. All of the injector accelerators, experimental halls, and test beam facilities are located on two main campuses placed on the either side of the accelerator ring. The majority of the collider tunnel, however, will be constructed 20 to 100 m underneath privately owned land.

II. DESIGN GUIDELINES

Since its inception, the design of the SSC has been shaped by the conscious effort to keep the radiological impact on the work place and to the environment As Low As Reasonably Achievable (ALARA). In support of that goal, the SSCL established a stringent set of radiological design guidelines for off and on-site radiation exposure. These goals and the corresponding legal limits are presented in Table 1.

The design limit for the site-boundary dose limit from all sources of radiation, is 0.1 mSv/y, or 10% of the Department of Energy (DOE) limit specified in DOE Order 5480.11. This limit has been further broken down into air emissions and water activation. For air activation, the SSCL has chosen a limit that is 1% of the 0.1 mSv limit specified by the Environmental Protection Agency (EPA). At this level, the monitoring of air stack emissions is not as restrictive, giving the laboratory more flexibility in emissions monitoring. The drinking water radiation limit is the same as the EPA limit of 40 μSv/y for community drinking water systems, often expressed in terms of

Table 1

Superconducting Super Collider Radiation Limits and Design Goals

	Limit	Design Goal
Member of public off-site (all pathways)	1 mSv/y	0.1 mSv/y
Member of public on-site non radiation workers etc. (all pathways)	1 mSv/y	0.2 mSv/y
Radiation worker (direct "prompt" radiation)	50 mSv/y (ACL 5 mSv/y)	2 mSv/y
Air activation (actually immersion) Member of public off-site	0.1 mSv/y	1 μSv/y
Water activation Member of public off-site (Water supply)	40 μSv/y	40 μSv/y (at 1 m from protected zone)

radionuclide concentrations. A more detailed explanation of the groundwater activation model is discussed later in this paper.

On-site criteria used as the basis for shielding policy at the SSCL stems from a requirement by the Director that most of the SSCL property (site) can be accessed by members of the public without any radiation protection concerns. This policy extended to such areas as shielding berms, which have typically been fenced to exclude the public. Thus for on-site "open areas" i.e., those areas not controlled for radiological protection purposes, the radiation design goal will be less than 0.2 mSv per working year. This means that average hourly dose rates will not exceed 0.1 μSv in those limited regions close to controlled area boundaries. In the case of a catastrophic beam accident, the maximum allowed dose equivalent is 1 mSv. Thus apart from personnel such as accelerator operators and technical staff who work in control rooms and other similar places close to controlled areas, and who would normally be badged radiation workers because of their need to work periodically in controlled areas, persons on-site are unlikely to receive any radiation dose above natural background.

The shielding criteria for controlled areas is set at ten times the open area criteria discussed above. Any area where radiation levels could be elevated above background will be considered as a controlled area. The fact that a large portion of the accelerators are underground or covered by thick earth berms means that the controlled areas associated with the accelerators will be located at only a few limited places. Most of these will be the very top of access shafts and in selected utility buildings. Because of the nature of work inside controlled areas it is unlikely that any person will be exposed to the highest radiation levels for a whole working year (2 mSv per work year) so that annual equivalent doses from prompt radiation are unlikely to exceed 1 mSv. However, the Administrative Control Level (ACL) of 5 mSv/y given in DOE Order N5480.6 could be a challenging goal for some workers, since most of the annual dose equivalent received by radiation workers is through work on activated components. For this reason, the design goal for general shielding is set at a substantially lower annual dose equivalent.

Although accelerators are considered low hazard facilities, the particle beams they produce can be extremely hazardous. Beam losses may occur which will cause, locally, very high levels of radiation. Therefore, it is of the utmost importance to ensure that all areas where accelerator beams are present are absolutely cleared of personnel before introducing beam. This may be done by a lengthy search process prior to a state change to exclusion or by a system based on a "take key" system with very strict control over personnel access or a combination of both. The distances involved at the SSC make routine searching to secure beam enclosures impractical. A prototype safety interlock system, known as the Personnel Access Safety System (PASS), was developed based on Programmable Logic Controller technology instead of the more common system of redundant mechanical switches and hard wiring.[1] The concepts of "fail-safe" and "redundant" were employed whenever possible, including requiring that two complete programmable logic controllers, programmed independently by two different programmers, be on line at all time, either one of which can cause the system to alarm or turn off the accelerators. SSCL policy requires the use of two independent critical devices to prevent the accelerator beam from entering an occupied area. These devices, such as beam plugs or bending magnets, are constantly monitored by the

Table 2

Beam Intensities and Loss Assumptions Used in Shielding Calculations

Accelerator	Beam Energy	Annual Beam Intensity	Beam Losses		
			Injection	Acceleration	Extraction
Linac (Linear Accelerator)	1 GeV	3×10^{20}		1%	1%
LEB (Low Energy Booster)	11 GeV	3×10^{20}	10%	2%	5%
MEB (Medium Energy Booster)	200 GeV	3×10^{20}	10%	5%	10%
HEB (High Energy Booster)	2 TeV	1.5×10^{19}	10%	2%	10%
SSC (Superconducting Super Collider)	20 TeV	2×10^{17}	1%	2%	15% (collisions)

PASS system. At least one of the two devices must be fail-safe in case of any anticipated problem. If any of these devices fail, the PASS system will disable the accelerator beam earlier in the accelerator chain.

III. BEAM INTENSITIES AND SOURCE TERMS

The most difficult task in designing the shielding for a research accelerator is defining beam loss terms. These definitions must be agreed upon as a compromise between the optimism and desire of the machine designer to save shielding costs and the pessimism of the radiation physicist who knows that weak shielding designs will be costly to mitigate or will significantly impact the operating plans. Loss terms that must be defined include the losses during routine injection, acceleration and extraction. More difficult to agree upon are conditions of accidental beam loss. For example it must be decided what abnormal conditions will be assumed to calculate the maximum beam loss condition--design bases loss condition. These conditions are machine design dependent. For example, it is known that small losses will cause superconducting accelerator magnets to quench and thus quit operating. However, at any time a full power beam could be lost at a point. Even though this would result in great damage to the accelerator it is the limiting case that the shielding must be designed to protect against. For resistive accelerators other conditions may be more limiting. For example often the case of "high but sustainable beam loss" results in more protons being lost during an hour than the maximum power loss which damages the accelerator in a short time. For the SSCL these various scenarios were used to calculate pessimistically high but possible beam power loss conditions for each accelerator, test beam and transport beam line.

The beam parameters used in these calculations are based on the accelerator characteristics listed in the Site Specific Conceptual Design Report (SCDR) and listed in Table 2.[2] Initially, the Linac energy will be 600 MeV and only the 200 GeV test beam utilizing the accelerators up to the MEB, will be built. However, an upgrade is planned to increase the Linac beam energy to 1 GeV and to construct a 2 TeV test beam, using beam from the HEB. Since adding shielding after a facility is operational is often prohibitively expensive, the shielding for both accelerators and the test beams was based on these potential upgrades. The use of the MEB and HEB to supply beam for the test beam drives the accelerator shielding requirements. They will be used at most a few hundred hours per year to fill the collider. However, both are designed to deliver beam to the test beams for over 5000 hours per year.

The beam losses used for these calculations are based on the beam loss estimates established by the accelerator designers, with consultation with the radiation protection group. These losses, shown in Table 2, represent reasonable, yet conservative estimates of beam loss due to injection, acceleration, collisions, and extraction, based on experience with other proton accelerators and full-scale Monte Carlo simulations. Since these estimates were provided at a very early stage of the SSCL, many of the accelerators had not been completely designed. Often, additional work on the accelerator design or changes in the original beam parameters have resulted in a reduction of the annual beam intensities, but for consistency, the beam intensities and losses given in the above table remain the basis for the shielding design.

In a like manner, the parameters for beam accidents were defined. For the superconducting accelerators, the catastrophic beam accident is easily identified. A relatively small amount of beam lost on a cryogenic magnet would heat the cryogens in the magnet enough for it to loose its superconducting properties, instantly disabling the accelerator. Thus, the maximal accident is a full energy full intensity beam loss at a point--a catastrophic event for the accelerator magnets. This accident is what determines the shielding for the collider. For the resistive magnet accelerators, the beam accident is less clear-cut. A major beam loss lasting for more than several minutes should be noticed by either the beam instrumentation monitors or the personnel using the beam downstream. Nevertheless, major beam losses have occurred at other laboratories lasting for a large fraction of an hour. Therefore, SSCL has conservatively defined a beam accident in the resistive magnet machines as the full loss of beam for one hour at one spot.

IV. SHIELDING CALCULATIONS

Once the radiation design goals and the beam loss terms are established, the actual shielding calculations can be performed. When a high energy particle interacts with a target, a shower of particles is produced, consisting mainly of proton, neutrons, and pions. These secondary particles in turn trigger more showers, until a large cascade of particles is generated. This process occurs in a few mean free path lengths, by which time the angular distribution of the secondaries has become more isotropic. It is the intensity of this hadronic cascade that determines the lateral shielding dimensions. For accelerator beams above a few GeV, the shielding in the forward direction is controlled by muons. These muons are produced primarily from pion and kaon decays, although above a few hundred GeV prompt muons from direct processes are created. Muon momenta are strongly peaked in the forward direction, and their flux is usually reduced by ranging them out. This requires relatively long shields behind beam loss points.

Much of the shielding calculations at the SSC are performed with Monte-Carlo computer programs that simulate the hadronic cascade and muon production induced by accelerator beams. These programs generate particles and transport them through a user-defined geometry. Interactions occurring in the geometry are simulated, based on known particle cross sections. The output of these programs consists of tables of star (inelastic interaction) densities and energy densities in specific areas of the modeled geometry, as well as particle fluences. From this information, dose rates, temperature changes, and material activation can be calculated. Most of the shielding design at the SSC have been calculated with CASIM,[3] and MARS12.[4] Each of these codes utilizes weighted techniques in which the particles produced to simulate the interactions are weighted to represent several particles. These codes are also used to estimate muon fluxes. Both codes have been used extensively at other accelerator laboratories, and their results have been shown to agree with existing data.[5,6]

Although the primary responsibility for making shielding calculations and other provisions for radiation safety rested with the Radiation Control Office, other groups and individuals were delegated responsibility for special problems. For example, an energy deposition group was formed to study the specific concerns associated with the 20 TeV collider beam. To insure reliability, calculations performed by one person are required to be independently reviewed, including direct comparisons using different shielding codes or methods. As an additional layer in the approval process an independent design review by a Radiation Control Review/Advisory Group was obtained. This group consisted of international experts in radiation protection from other laboratories. Additional reviews were performed by the Environment, Safety, and Health Oversight Office.

V. SHIELDING COVER REQUIREMENTS FOR THE ACCELERATORS

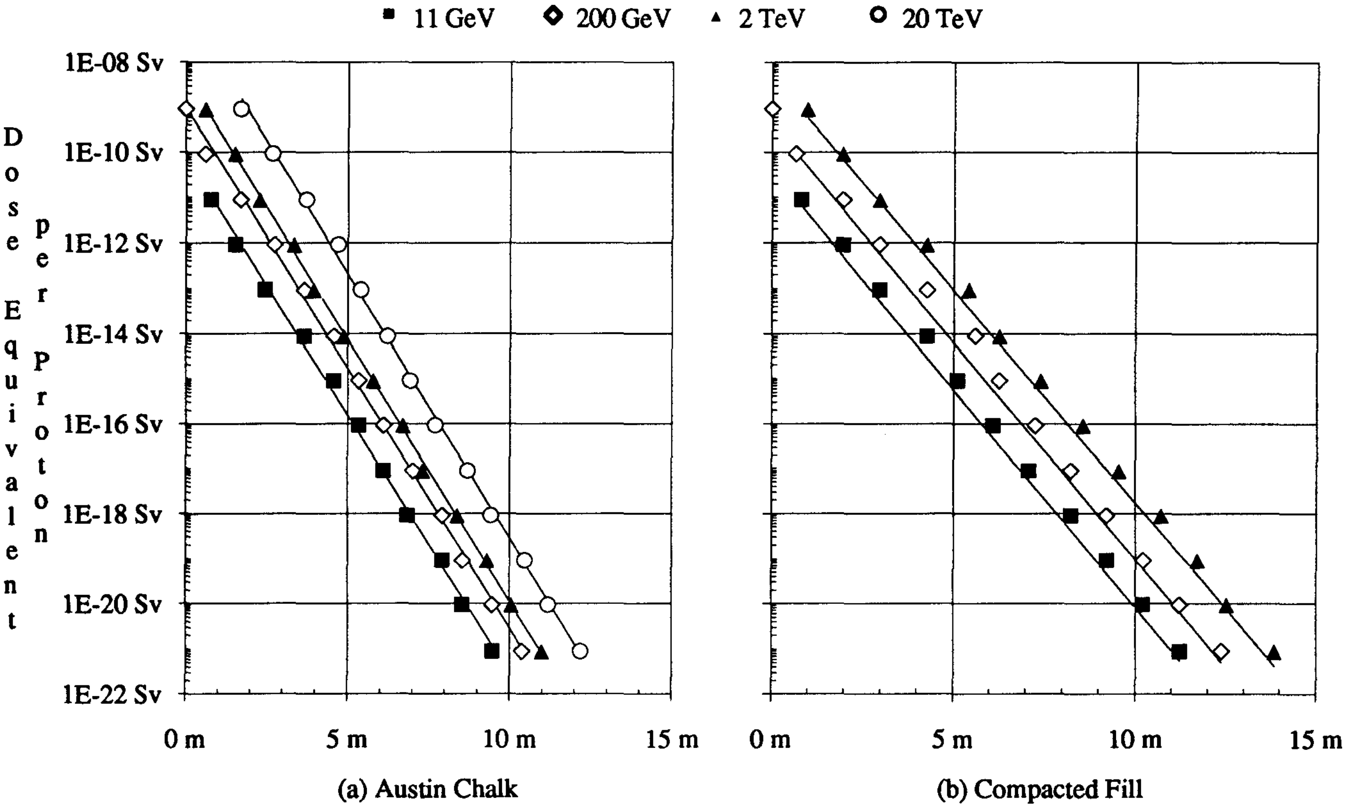
One of the first questions asked of the shielding designer is how much shielding is required over the accelerators. For the Linac, the shielding was determined utilizing a Moyer-type model as described in Thomas and Stevenson.[7] The dose equivalent, H, from a proton beam hitting a target can be expressed as

$$H = H_0 \frac{\exp(-d/\lambda_{\mathrm{eff}})}{(a+d)^2}, \tag{1}$$

where d is the shield thickness, a is the accelerator enclosure radius, λ_{eff} is the effective attenuation length, and H_0 is the dose equivalent extrapolated to zero depth in the shield. For 1 GeV protons, H_0 is 7.6 x 10^{-15} Sv•m^2 and λ_{eff} is 1100 kg/m^3. The Linac tunnel radius is 1.5 m.

For the rest of the accelerators, the code CASIM was used to determine the cover requirements. A similar geometry was used for each accelerator. A magnet, represented by a cylinder of iron with a hole through the center, was placed inside a cylindrical accelerator enclosure. A proton beam with a lateral Gaussian distribution (σ_x, σ_y = 1 mm) was made to hit the magnet 1 mm from the aperture edge. To closer approximate the conditions for each machine, variations in magnet size, tunnel radius, and shield material were made in the modeled geometry. In addition, the magnets were centered in each enclosure, except for the Collider geometry, where the magnet was placed 90 cm from the center of the tunnel.

Results of these calculations for two shielding materials are shown in Figure 1, expressed in terms of dose equivalent per proton lost.[8] Austin Chalk is the rock in



(a) Austin Chalk (b) Compacted Fill

Figure 1. Dose equivalent per incident proton (point loss) versus shielding thickness of (a) Austin Chalk (density = 2.3 g/cm^3) and (b) Compacted Fill (density = 1.85 g/cm^3) for several proton energies. The solid lines represent fits to the data.

which the booster accelerators and much of the SSC will be constructed. Compacted fill, composed of excavated Austin Chalk, will be used to form the shielding berms. As shown in the graph, the slope of the lines is similar, indicating that the shielding mechanism in the lateral direction is independent of incident beam energy. In addition, the dose equivalent falls off approximately one order of magnitude per meter of shield, a useful rule of thumb used for making shielding estimates.

Using this graph, and knowing the expected beam losses, the shielding requirements can easily be determined. These results are presented in Table 3. This table also reflects an extra meter of shielding added as an additional safety factor. As can be seen, just less than 10 meters of shielding is required for all the accelerators. Since the Linac and the LEB were constructed only three meters below the ground surface, shielding berms up to six meters high would have been constructed. The MEB was built into a slope, such that only one fifth of it required a berm. The Collider and HEB are located tens of meters deep, and thus no surface shielding would have been required.

Table 3

Shielding Cover Requirements

	Injection	Accelerator	Extraction
Linac	—	8.25 m	8.25 m
LEB	10 m	8.25 m	9.25 m
MEB	9.25 m	8.5 m	9.75 m
HEB	8.25 m	6.5 m	8.75 m
SSC	7.5 m	7.5 m	—

Where the accelerator tunnels are tens of meter below the surface, the 0.1 mSv/y contour line remains well below the surface. Therefore, it was not necessary to obtain the surface land in order to enforce shielding design limits. In areas where the surface land was not owned, a volume of rock, known as stratified fee, was purchased at the elevation of the accelerator. Where stratified fee was purchased, the site boundary was interpreted to mean the boundaries of the underground purchased volume. The volume of the rock was shaped to fully contain the 0.1 mSv/y contours. For the SSC, the cross section volume was defined as 25 m high and 300 m wide.[9] The extra width allowed for minor changes in the accelerator placement. Within this stratified fee area, the 4.25 m diameter tunnel will be bored, with the additional restriction that at least 9 m of rock is maintained between the tunnel and the edge of the stratified fee. However, to reduce the possibility of a landowner digging a basement or other structure into this radiation zone, at least 14 m of cover will be maintained over the Collider in areas where the land surface is not controlled by the SSC. The closest the Collider does come to the surface is 9 m, at the bottom of a couple of creek beds that cross over the ring. The banks of these creeks will be controlled by the SSC to the 14 m point.

VI. MUON SHIELDING

The need to shield for muons produced from beam losses had a great impact on the land acquisition requirements. As discussed earlier, the easiest method to shield muons is to range them out. Since muons are produced in a highly directional forward cone, the distance they travel until the dose equivalent is reduced to a specific value (0.1 mSv for this discussion) is commonly called the muon vector. The lengths of these muon vectors for the SSCL, calculated with the CASIM and MARS12 codes, are given in Table 4.[10] Again, stratified fee was purchased wherever these underground vectors extended beyond the surface land owned by the SSCL. To insure that the site boundary radiation limits are not exceeded, muon monitoring stations are planned at the ends and midpoints of the muon vectors.

Table 4

Muon Vector Lengths

	Loss Point	Muon Vector
MEB	Beam Absorber, Test Beams	0.5 km
HEB	Beam Absorber, Test Beams	2 km
	Accidental Loss	0.6 km
SSC	Beam Absorber	5.2 km
	Experimental Hall	4.3 km
	Beam Scrapers	3.6 km
	Accidental Loss	1.9 km

VII. GROUNDWATER ACTIVATION

Activation of groundwater due to routine beam losses has always been a concern at high energy accelerator laboratories. In the past, elementary hydrological models were developed to demonstrate compliance with federal drinking water standards.[11] In these models, radionuclides produced in near the accelerator are carried off-site by groundwater flow at a set rate to a person's well, and diluted into an individual's annual water usage. These models assume a homogeneous medium for the water to travel. Unfortunately, the geology of the SSCL site is not as accommodating. Although the rock consists primarily of low permeability chalk, shale, and marl, ancient seismic activity has produced fractures in the rock, which can provide conduits for rapidly transported activated water off-site without dilution. Also, well models are not practical in instances when the activation is distributed over large regions, such as distributed losses along a large accelerator. It is difficult to divide the region into drawdown areas for specific wells. In addition, stiffer regulatory requirements have recently been imposed at some accelerators.[12]

To tackle its own site requirements, the SSCL has developed a groundwater activation model that requires that the activation concentration in the groundwater one meter outside the accelerator enclosure meets the federal drinking water standards.[13] This model is based on the concept of an "activation zone," the region outside any accelerator enclosure, shielding or protected region that contains over 99.9% of the activation produced in the soil. In this volume, the average groundwater activation concentration can be calculated, and used to demonstrate compliance with the radionuclide concentration limits. Since the induced activation falls off exponentially with the distance into the soil, the average activity concentration in the activation zone can be equated with the activity concentration at a certain distance into the soil. At the SSC, this distance chosen was one meter, which corresponds to an activation zone extending approximately four meters from the tunnel enclosure. The one meter distance criteria also provides a reasonable clearance from any disturbance produced by the excavation process. In addition, it also permits credit to be taken for water movement toward and into the tunnel itself, which would result in an average concentration lower than the value calculated. As extra conservatism, the groundwater model assumes saturation levels of activity. It will take many years of operation before the activation levels build up to these levels.

Earlier studies of radionuclide transport in groundwater indicate that ^{3}H and ^{22}Na are the only long lived nuclides (half-live greater than 30 days) with high leachability factors induced in the soil around particle accelerators.[14]

Recent experiments were completed with samples of Ellis County rocks have confirmed this for the SSCL site, and provided production and leachability factors specific for this site.[15] Utilizing the radiation transport codes discussed earlier, the radionuclide concentration can be expressed as a function of beam loss.[16] These calculations show that the beam losses which could be allowed are well within the operating envelope of the accelerators, with the addition of local shielding at some expected beam loss points. The shielding for beam absorbers and scrapers for all the accelerators was designed to meet the groundwater activation criteria.

VIII. ENVIRONMENTAL RADIATION MONITORING

The primary purpose of the environmental radiation monitoring program at the SSCL is to determine the effect, if any, of the operation of the facility on the on-site and off-site radiation environment. The data obtained from this program will be used to estimate the exposure to the public. Any radiation that might reach the public would be through two pathways: direct radiation (muon, neutron, and gamma exposure) and indirect radiation from induced activation products in air, water, plants, and rocks. The natural radiation background (both direct and indirect) was measured to establish the base line for these studies. The monitoring program at the SSCL will be challenged by the need to document adherence to the stringent radiation design guidelines established by the laboratory.

Since the environmental monitoring program at the SSCL preceded operations, the first stages of the radiological monitoring focused on characterizing the magnitude and variability of the natural radiation background. A *graded approach*[17] was employed to expand the monitoring as the various accelerators moved into production. The intent of the graded approach is to make background measurements in the vicinity of an accelerator for one year prior to commissioning to determine precise needs for monitoring.

Direct radiation will be monitored at several key locations on and off the SSCL site:

- Near site boundaries on both East and West Campuses,
- Site interior locations on both East and West Campuses,
- Selected shaft locations along the accelerator,
- Boreholes and surface locations along muon flux paths, and
- Several high schools in the communities in and around the SSCL.

Measurements are made with on-line instruments, passive integrating devices, and grab sampling techniques. On-line instrumentation will make continuous measurements and will be connected to a central data-logging system. Data will be recorded locally for down-loading at the instrument location when necessary. Integrating devices (typically TLDs and activation monitors) will be in place for specific periods and read out using standard equipment. Grab sampling, which provides a snapshot of the radiation environment at the time the sample is taken, will be conducted periodically.

On-line muon and neutron detectors will contain electronics, as necessary, to make the detectors more sensitive by allowing directional and time discrimination of radiation coming from the accelerator. This will permit the low level flux produced by SSCL operations to be distinguished from the natural cosmic ray background flux. Time gating will use the accelerator pulse to differentiate between accelerator produced events and background radiation.

Unique monitoring stations were designed and constructed that also could be used in the local high schools. The stations employed a NaI(Tl) scintillator and an energy-compensated Geiger counter. The base station, operating at the facility, would communicate via telephone lines with field stations in local high schools (as well as at remote locations on site). From the base station the operator can display and transfer field station data and troubleshoot problems. Teachers could assume control for classroom use and return the system to ambient radiation monitoring via single key strokes. While acquiring background radiation data, the system stores the data hourly on a hard disk and displays a week's worth of counts each of one minute duration for the two detectors.

Production of radionuclides in the soil and water could take place through the interaction of particles with the rock and ground water. Subsequent leaching of radioactivation products by water could carry the activation away from the accelerator. As mentioned above, the principal long-lived radionuclides leachable from the rock surrounding the accelerator into the groundwater are ^{3}H and ^{22}Na. An additional primary source of radioactivation products is air from the accelerator enclosures. High energy protons interact with residual gas in the beam tube, initiating a cascade of secondary particles, which produce some radioactivation of the air surrounding the accelerator components. Some of this air may subsequently be exhausted from the tunnel at ventilation shafts. The primary exposure route is external from submersion. The principal radionuclides of concern are ^{11}C, ^{13}N, ^{15}O, and ^{41}Ar From these primary routes, secondary pathways of minor significant arise: deposition from air, sedimentation from water, and uptake by vegetation. The measurements of indirect radiation at the SSCL monitored both these primary and secondary sources.

Concentrations of radioactive products will be measured by sampling environmental media at various locations:

- Site interior locations on both East and West
- Monitoring wells near the accelerator and in zones of fractured rock,
- Surface water at monitoring sites and effluent points, and
- Air, soil, and vegetation at accelerator sites, meteorological stations and selected off-site locations.

IX. SUMMARY

This paper has presented the key elements of the developing SSCL radiological control program. The goals of the program are to ensure the facility, as designed and built, would not only be compliant with all current regulations but also would be recognized by the local community as a good neighbor because of the conservative design requirements. Furthermore, with any foreseeable changes in regulations and any anticipated upgrades in the accelerator parameters, the SSCL would be able to continue to carry out the best possible high energy physics research program, without compromising the safety of its employees or the general public.

ACKNOWLEDGEMENTS

This work was sponsored by Universities Research Associates, Inc., supported by the U. S. Department of Energy under Contract DE-AC35-89ER40486.

REFERENCES

1. SSCL, "System Specification for the Linear Accelerator Personnel Access Safety System", **AQA-2200605**, 1993.
2. SSCL, *Superconducting Super Collider Site Specific Conceptual Design*, **SSCL-SR-1056**, July 1990.
3. A. Van Ginneken, "Program to Simulate Transport of Hadronic Cascades in Bulk Matter," **FN-272**, Fermi National Accelerator Laboratory, 1975.
4. N. Mokhov, "MARS12 Code System", *Proceedings of SARE Workshop*, Santa Fe, 1993.
5. J. D. Cossairt, S W. Butalla, and M.A.Gerardi, "Absorbed Dose Measurements at an 800 GeV Proton Accelerator: Comparison with Monte-Carlo Calculations," *Nucl. Instr. and Meth.*, **A238**, p. 504, 1985.
6. A. Kalinovsky, N. Mokhov, Yu. Nikitin, "Passage of High Energy Particles Through Matter," *AIP*, New York, 1989.
7. R. H. Thomas and G. R. Stevenson, *Radiological Aspects of the Operation of Proton Accelerators*, International Atomic Energy Agency, Vienna, 1989.
8. "Radiation Control Review Advisory Group Report and Presentations," **SSCL-E13-000194**, Sept., 1992.
9. L. Coulson, *et. al.*, "Footprint Characterization Document," **SSCL-SR-1041**, June 1992.
10. J. D. Jackson, "SSC Environmental Radiation Shielding," **SSC-SR-1026**, July 1987.
11 P. J. Gollon, "Soil Activation Calculations for the Anti-Proton Target Area," **TM-816**, Fermi National Accelerator Laboratory, 1978.
12. Virgina Pollution Abatement Permit No. VPA01001, State Water Control Board, Commonwealth of Virgina, 1989.
13. V. Romero, *et. al.*, "SSCL Groundwater Model," SSCL, 1993.
14. S.I. Baker, "Soil Activation Measurements at Fermi Laboratory," *Proceedings of Third Environmental Protection Conference ERDA-92, Vol.1*, 1975.
15. S.I. Baker, "Groundwater Activation Summary," April 7, 1992, SSCL internal memo.
16. S.I. Baker, J. S. Bull and G.B. Stapleton, "Groundwater Activation Calculations at the SSC," Health Physics Society Annual Meeting, July 1993.
17. DOE, "Safety of Accelerator Facilities," and "DOE Guidance for Accelerator Facility Safety Programs," **DOE Order 5480.25**, 1992.