SLAC-PUB-5714
December 1991
(M)

SHIELDING AND RADIATION PROTECTION AT THE SSRL 3 GeV INJECTOR

N. E. Ipe and J. C. Liu
Stanford Linear Accelerator Center, Stanford University
Stanford, California 94309

ABSTRACT

The Stanford Synchrotron Radiation Laboratory (SSRL) Injector is comprised of a linear accelerator (linac) capable of energies $\leq$ 150 MeV, a 3 GeV booster synchrotron, and a beam line to transport the electrons into the storage ring SPEAR. The injector is shielded so that under normal operating conditions, the annual dose equivalent at the shield surface does not exceed 10 mSv. This paper describes the shielding and radiation protection at the injector.

INTRODUCTION

Figure 1 shows a layout of the injector. The injector is comprised of an electron linac capable of energies up to 150 MeV, a 3 GeV booster synchrotron, and a beam line to transport the electrons into the storage ring SPEAR.

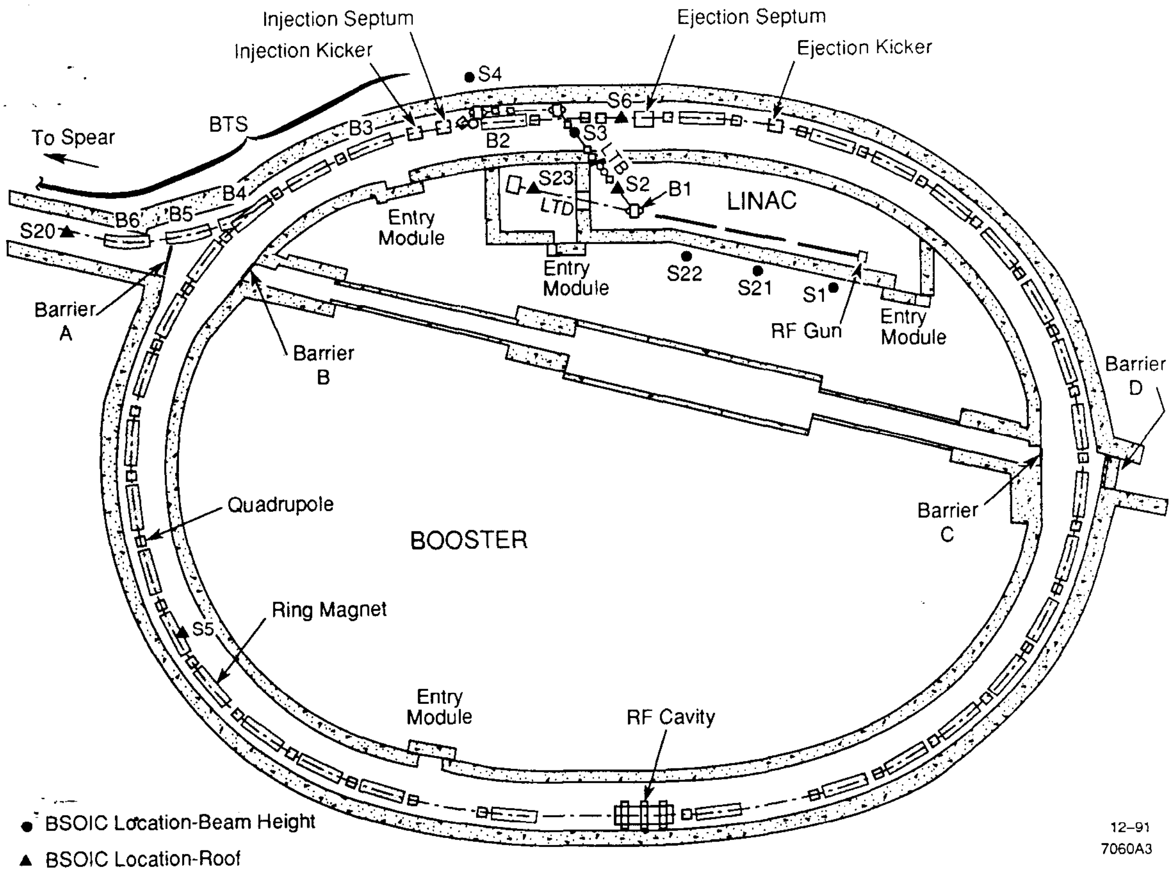

Fig. 1. SSRL injector layout.

---

* Work supported by Department of Energy contract DE-AC03-76SF00515.

Contributed to the American Nuclear Society Topical Meeting, New Horizons in Radiation Protection and Shielding, Pasco, Washington, April 26-May 1. 1992.

Table 1. Operating parameters

	Maximum No. of Electrons/Pulse	Pulse Rate	Energy	Annual Operating Hours
Linac	3.1 x 10^9	10 pps	150 MeV	2000
Booster	3.1 x 10^9	10 pps	3 GeV	~120

The linac produces a string of electron bunches within a single pulse. The bunches are then injected into the booster synchrotron. The booster consists mainly of a racetrack array of magnets and an rf accelerating cavity. The electrons are accelerated to 3 GeV by slowly ramping the synchrotron ring magnets to higher fields. At the final energy, the electron bunches are transferred from the booster to the transport line that carries them to SPEAR. The operating parameters, shield design criteria, shielding methodology (including beam losses), and the Personnel Protection and Beam Containment Systems are described in this paper. Other radiological aspects of the injector have been discussed elsewhere.[1]

OPERATING PARAMETERS

The design parameters for the linac and booster are shown in Table 1. The maximum intensity in the linac is limited to 3×10^{10} e^-/sec by a beam chopper and a pair of beam-current monitoring toroids. A trip caused by excessive current through either toroid will turn the beam off.

The maximum intensity in the booster is limited by the maximum intensity in the linac. The annual booster operating hours are much lower than the linac operating hours, because the booster is used mainly to fill the storage ring SPEAR. It takes about 5 to 15 minutes to fill SPEAR. The lifetime of the stored beam is about 8 to 12 hours.

SHIELD DESIGN CRITERIA

Shielding for the injector was specified by the SLAC Radiation Physics Department. The following shield design criteria were used:

According to the first criterion, the integrated dose equivalent for a 2000-hour operating year should not exceed 10 mSv at the outer shield surface. This meets the DOE requirements, according to which the design criterion for any shielded facility within an area that can be controlled will be one-fifth of the normal operating limit, or 10 mSv/year for normal beam losses.[2] Thus the linac is shielded for 5-μSv/h, since it operates annually for 2000 hours. The booster is shielded for 80 μSv/h, since it operates for only 120 hours/year.

The second criterion is an internal guideline set by SLAC. This requires that the dose equivalent rate or integrated dose equivalent at the shield surface, under the worst-case scenario, should not exceed 0.25 Sv/h or 30 mSv, respectively. Inherent in the 0.25 Sv/h criterion is the assumption that this situation will persist only for a few minutes, and will be either corrected by an alert operator or terminated by the Beam Shut Off Ionization Chamber (to be discussed later). An example of the worst-case scenario would be the failure of two out of three protective devices, such as the Personnel Protection System (PPS) stoppers or beam containment devices. For the injector, the first criterion is more limiting than the second.

Another guideline used for shielding the booster limits the maximum dose equivalent rate to 4 mSv/h at the shield surface, if the entire beam were to be lost at a point due to some extreme case of mis-steering. Again this assumes that an alert operator will correct the situation within 15 minutes; thus, the integrated dose equivalent will not exceed 1 mSv. The annual limit for non-radiation workers is 1 mSv.[2]

In addition, since SLAC has many machines, each machine—including the injector—has been shielded so that under normal operating conditions, the annual boundary dose equivalent from external radiation is less than 50 μSv.

SHIELDING METHODOLOGY

The shielding calculations were performed using beam-loss scenarios provided by the SSRL physicists. Before describing the shielding models used, it is appropriate to briefly discuss the interaction of high-energy electrons with materials.

Electromagnetic Shower

When a target is hit by a high-energy electron, only a small fraction of the energy is dissipated as a result of collision processes. A large fraction is spent in the production of high-energy photons or bremsstrahlung. These photons interact through pair production or Compton collisions, resulting in the production of electrons. These electrons radiate more photons, which in turn interact to produce more electrons. At each new step, the number of particles increases and the average energy decreases. This process continues until the electrons fall into the energy range where radiation losses can no longer compete with collision losses. Eventually, the energy of the primary electron is completely dissipated in excitation and ionization of the atoms, resulting in heat production. This entire process, resulting in a cascade of photons, electrons, and positrons, is called an electromagnetic shower.

The photon field, after passing through a target and any intervening shielding, consists essentially of two components[3]: (1) a broad photon field that is peaked in the forward direction, but extends to backward angles with decreasing intensity; and (2) a very sharp forward spike, which contains photons of the highest energy possible for that primary energy.

A very small fraction of the bremsstrahlung energy in the shower goes into the production of hadrons, including neutrons, protons, and pions.

Neutrons will be produced in any material struck by the electron or bremsstrahlung beam above threshold energies, which vary from 10 to 19 MeV for light nuclei and 4 to 6 MeV for heavy nuclei.[4] For photon energies below 30 MeV, neutron production results mainly from the giant photonuclear resonance. The electric field of the photon transfers its

Table 2. Injector shielding

	Linac		Booster			
	Wall	Roof	Inner Wall	Outer Wall	Roof (Arcs)	Roof (Straight Sections)
Distance From Beam Pipe (cm)		107	168	61	107	107
Concrete Thickness (cm)	55	30	55	75	30	61

energy to the nucleus by inducing an oscillation, so that the protons as a group move in a direction opposite to the neutrons. Giant resonance neutrons are of low energy, with an average energy of the order of a few MeV.[5] At low photon energies the giant resonance dominates, because of the large number of low-energy photons and the large cross-sections at these low energies.

At energies between 30 and 300 MeV, the photon interacts with a neutron-proton pair within the nucleus, instead of with the nucleus as a whole.[3,4] This mechanism is called the *pseudo-deuteron* or *quasi-deuteron* effect. The *pseudo-deuteron* cross section is about an order of magnitude below the giant resonance cross section.

Above photon energies of 140 MeV, the cross section rises again due to photopion production, and goes through a number of resonance peaks.[4] These peaks are only a fraction of the giant resonance cross section. However, the neutrons released as a product of photopion reactions are much higher in energy, and therefore much more penetrating than giant resonance neutrons. For shield thicknesses greater than about 2 m of concrete, these neutrons dominate and continually regenerate a field of lower-energy neutrons and neutron-capture gamma rays.[3] Therefore, the dose equivalent outside the shield will have both photon and neutron components.

Shielding Model

The shielding calculations for thick targets were performed using a computer program that puts the two-photon and three-neutron components together to give the total dose equivalent outside the shielding. The program is based on measurements made by Jenkins,[6] with subsequent modifications to photon terms based on Monte Carlo calculations. Details of this program can be found in Ref. 1.

For thin targets, the EGS4 Code was used[7] (EGS4 is an electron-photon transport code that utilizes Monte Carlo techniques). The results of measurements and calculations by Dinter and Tesch were also used for thin targets.[8]

Both local lead shielding and external concrete shielding have been used to meet the design criteria for the injector. Beam losses under normal operating conditions, and cases of mis-steering and accidental beam loss were considered. Table 2 shows the external shielding for the injector.

Losses In The Linac

Figure 2 shows the linac, which is composed of an electron gun, the Gun-to-Linac section (GTL), and three accelerating sections. The gun is an rf gun with a thermionic cathode. The frequency of the gun is 2856 Hz, which is the same as the linac. The gun produces a continuous train of bunches spread about 350 psec apart. Thus a 2-μsec-wide rf pulse will produce about 6000 bunches. The energy of the electrons is about 2.5 MeV. The GTL section includes an alpha magnet, quadrupoles, steering magnets, and a beam chopper. The alpha magnet filters out the low-energy electrons and compresses the bunch length. There are about 3000 electron bunches at the at the exit of the alpha magnet. The booster rf bucket can only accept 3 to 5 bunches. Hence, the beam chopper selects a triplet of consecutive bunches from the 3000 bunches, so that only three bunches are allowed to enter the first linac section.

Each linac section is driven by a separate klystron. The nominal energy of the beam at the end of the three linac sections is about 150 MeV. Once the electrons have been accelerated to 150 MeV, they can be directed into a shielded dump in the diagnostic room via the Linac-to-Diagnostic (LTD) transport line, or be bent into the booster. The Linac-to-Booster (LTB) transport line, consisting of a bending magnet B1, a quadrupole magnet QF1, and two stoppers ST-1 and ST-2, guides the beam into the booster.

The maximum beam power into the diagnostic room and booster is 0.75 Watt (3.1×10^{10} e^-/sec at 150 MeV). The linac was shielded assuming a 3% loss in linac Section 1, and 0.25% losses in Sections 2 and 3. The transverse walls and roof of the linac are 55 and 30 cm thick, respectively. Local lead shielding has been used to supplement the external shielding in areas where local losses are expected, such as in the vicinity of the alpha magnet, the chopper and the downstream half of the first linac section. If the entire beam (0.75 Watt) were to be lost at a point at the end of the third linac section, the maximum dose equivalent above the roof and outside the west wall would be 1.9 mSv/h and 1.25 mSv/h, respectively. The magnet B1 in the LTB line has been locally shielded with lead. The 10 cm of lead in front of, and on the west side of, the magnet ensures that any mis-steered beam or beam in reverse polarity strikes the lead, thus producing an electromagnetic shower close to the beam pipe. The walls of the linac and diagnostic room will then provide the required shielding. If the lead was not in place, electrons could strike the beam pipe, which acts as a thin target. The electrons in the forward direction from the electromagnetic shower could be energetic enough to propagate the shower in the concrete walls. In addition, the dose rates in the forward direction can be extremely high.

Whenever there is a potential for the beam to strike a thin target and the shielding in the forward direction is thin, local lead shielding has been added to provide a thick target close to the beam pipe, thus propagation of the shower in the shielding walls is prevented. This, in a sense, is the concept of beam containment, a concept which has been used in shielding the injector. All possible beam-loss scenarios for the LTB and LTD lines are discussed in Ref. 1.

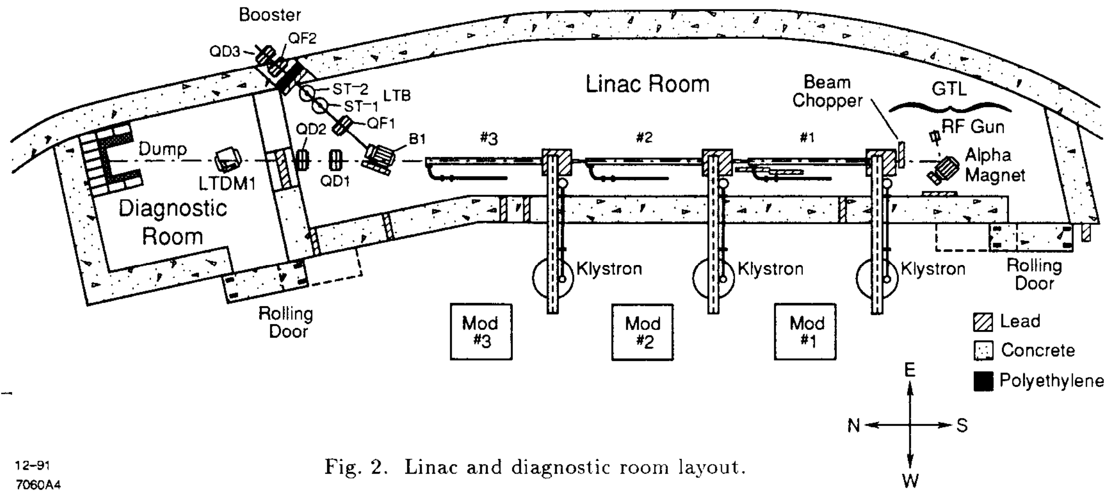

Fig. 2. Linac and diagnostic room layout.

Losses In The Booster

The Linac-to-Booster (LTB) beam transport system—consisting of magnets and quadrupoles—guides the beam from the linac into the booster, where it is injected by means of a septum and a kicker magnet into the booster (Fig. 1). The septum magnet is strong enough to accommodate a large deflection angle so that the incoming beam need not pass through a ring magnet. A pulsed magnetic field from the kicker magnet in the booster deflects the incoming beam into the booster orbit. The kicker magnet must be turned off before the first injected particle arrives again at the kicker location, after one turn in the booster. The kicker is therefore on for a very short period, and is synchronized with the injector bunch. The injected beam is matched to the optical parameters of the booster at the injection point by means of bending and focusing magnets. The rf frequency for the booster is 358 MHz. The booster circumference is 133 m. Injection of the beam into the booster occurs near the low point of the sinusoidal 10 Hz cycling of the booster magnets. As the currents to the magnets increase, the magnets reach higher fields. At the same time the rf drive to the booster klystron is increased, thus increasing the energy of the electron bunches, while keeping the effective strength of the magnets constant. In other words, as the energy of the bunches increases, the magnetic fields increase, so as to keep the bending radius constant. The three injected bunches coalesce into a single bunch (due to radiation damping) as they circulate into the booster.

After the beam is accelerated to the storage ring energy (3 GeV), it is ejected and deflected into a transport system that guides the beam into SPEAR. A fast full aperture kicker magnet in the booster deflects the beam into the magnetic aperture of the ejection septum magnet. Since the kicker kicks the booster bunch out at the peak of the cycle, only one pulse (composed of one bunch) at 3 GeV can be lost, since the magnets are cycling at 10 Hz. This corresponds to 1.5 Watts-sec/pulse ($3.1 \times 10^9\ e^-$/pulse at 3 GeV). The septum deflects the beam vertically out and away from the booster components into the Booster-to-SPEAR (BTS) transport line. The BTS line consists of a system of quadrupoles and bending magnets that steer the beam into SPEAR.

The maximum allowable beam injected into the booster from the linac is 0.75 Watt ($3.1 \times 10^{10}\ e^-$/sec at 150 MeV). The booster was originally shielded assuming that, under normal operating conditions, 50% of the 150 MeV electron beam is likely to be lost in the LTB at the septum during injection. The remaining 50% will be accelerated to 3 GeV, and 10% of this was expected to be lost during ejection. The shielding calculations were done assuming that both these losses could occur at the same point, anywhere along the ring. The outer and inner walls of the booster are 75 and 55 cm thick, respectively. The distance between the beam pipe and the outer and inner walls is 61 and 168 cm, respectively. The arcs of the booster have a series of magnets, and therefore in this case, some shielding is provided by the magnet iron in the vertical direction, so the roof is only 30-cm thick in the arcs. However, in the straight sections, there are very few magnets; hence, the roof is 60 cm thick. The distance from the beam pipe to the roof is 107 cm.

In addition to external shielding, local shielding has been used in areas where local beam losses are expected. For instance, due to timing errors, a 150 MeV beam injected into the booster could experience a magnetic field set for the wrong energy. This could happen continuously during injection. The worst timing error would result in a 150 MeV beam experiencing a field set for 3 GeV. The beam would be bent, and would strike the beam pipe, but may not necessarily be intercepted by the magnet iron. Since the beam pipe is a thin target, lead bricks have been placed at the exit of the first three-ring magnets. The lead acts as a thick target, confining the shower to the proximity of the beam pipe. If the entire injected beam (0.75 Watt) were to strike the lead, the maximum dose equivalent rate outside the outer wall would be 3 mSv/h.

All the ring magnets are connected in series to one power supply. If the power supply trips the stored energy in the magnets or capacitor, banks will discharge in about one second. The beam will be lost over thousands of revolutions in the focussing quadrupoles, where the beam size is a maximum. Only one pulse will be lost at 3 GeV. The remaining pulses will be lost at 150 MeV, since the magnet fields are decaying or are off.

If the linac and booster are mis-adjusted by more than 2% compared to each other, the beam will not be captured in the booster. In such a case, the beam will be lost in one of the 20 focussing quadrupoles in the booster, because the dispersion function reaches its largest value in the focussing quadrupole. If the entire beam is lost in one of the quadrupoles due to energy mismatch between the linac and the booster, the dose equivalent rate outside the outer wall will be about 0.1 mSv/h. If the rf system is too low, or is turned off, when the beam is captured in the booster orbit, the beam spirals horizontally inwards over tens-of-thousands of turns. This is because of the long damping times at 150 MeV. The electrons will get scraped off in the focussing quadrupoles, where the beam size is a maximum. This will result in a distributed loss around the booster, and this is what would be expected under normal operating conditions. However, due to poor orbit correction, the beam can be lost in a single quadrupole. The dose equivalent rate outside the inner wall would be 90 μSv/h.

During normal operating conditions, the rf system could trip at any energy up to 3 GeV. If this happens, the beam will spiral inwards and be lost in the focusing quadrupoles. The distribution of losses will again depend upon the orbit distortions. However in this case, only one pulse will be lost at that energy. The remaining pulses will be lost at 150 MeV, because the rf is off.

In the BTS line, it is possible to lose all ten pulses at 3 GeV (14.4 Watts), due to mis-steering. The BTS has been shielded to limit dose equivalent rates under cases of mis-steering to less than 4 mSv/h. All possible beam-loss scenarios for the booster and the BTS line are discussed in Reference 1.

While the machine is operating, the radiation levels inside the beam housing can be extremely high. For instance, if 14.4 Watts at 3 GeV were to be lost in an iron target of radius and length 5 cm, the dose equivalent rate at 90°, at 5 cm from the target, would be 140 Sv/h. The dose equivalent rate at 0°, at 5 cm from the target, would be 1.4×10^6 Sv/h. An acute whole body dose of about 4.5 to 5 Gy could be fatal to about fifty percent of the persons exposed. Fatalities could occur within thirty days.

In addition to shielding, the Personnel Protection System and Beam Containment System (BCS) protect people from radiation exposure. The PPS and BCS for the injector have been described by Yotam et al.[9]

THE PERSONNEL PROTECTION SYSTEM (PPS)

The PPS consists mainly of an access control system which prevents accidental or unauthorized entry into the beam housing.[10] This includes the following elements: PPS security perimeter, entry modules, annunciator/status panels, warning lights, emergency off buttons, flashing lights and audible warning, search controls, and stoppers. The PPS design includes complete redundancy, high-reliability components, and fail-safe circuits.

The PPS security perimeter is essentially an enclosure for the beam delivery area , and includes shielding. All moveable shielding blocks are interlocked.

Entry modules are remotely controlled entry facilities into a PPS area. An entry module consists typically of two interlocked and remotely controlled doors or gates. These doors or gates have emergency exit functions, local door controls, controlled keybank, and audio and video communication with the injector control area. There are four entry modules for the injector, one each at the the entrance to the linac and diagnostic rooms, and one each at the east and west access to the booster (Fig. 1).

Annunciator/status panels are display panels, usually located at the entry module. They show local PPS access states, and other status information. The linac has two access states: Permitted Access and No Access. The booster has five access states: Permitted Access, Controlled Access, Restricted Access, Restricted Access Safety Key (RASK), and No Access. The transfer of the booster access is always done in a sequence starting from Permitted Access to No Access or starting from No Access and proceeding to Permitted Access.

Warning lights are located at the entry modules and on top of linac and booster roofs, to indicate the status of the beam.

Emergency off buttons are wall-mounted redundant switches, which are primarily used if one finds oneself in an area that is ready for beam. Activating the emergency off button will turn the beam off, or inhibit the beam from turning on. Emergency off buttons are also located in the booster and linac control areas, to turn the beam off in case of an emergency.

Flashing lights and audible warning are used to indicate that an area is ready for beam. All areas have to be searched prior to delivering a beam. Search controls are located throughout the beam housing, so as to require a prescribed search route by the search team.

Stoppers are devices which absorb beam power for short periods of time, or change direction of beam delivery when required. The LTB stoppers are required to be "IN" and the booster rf "OFF" when the booster is in either a permitted, controlled, or restricted access state.

The magnet B1, and stoppers ST-1 and ST-2 are considered to be the "LTB Stoppers." A worst-case scenario is defined as one in which two out of three stoppers fail. In such an event, the maximum dose equivalent rate in the nearest occupied area should not exceed 0.25 Sv/h. If the booster is in "Permitted Access," and there is a failure, so that B1 is "ON" when it should be "OFF" and ST-1 is "OUT" when it should be "IN", then the beam will strike ST-2. The dose equivalent rate in the booster tunnel would be 0.15 Sv/h, which is less than 0.25 Sv/h. Stoppers ST-1 and ST-2 consist of 15 cm (10.42 X_o) of copper and 2.54 cm (7.26 X_o) of tungsten, where X_o is the radiation length. A BSOIC S3. (Fig. 1) has been placed inside the booster tunnel to detect radiation in the event that any two of the LTB stoppers fail. This BSOIC is set to trip at 0.1 mGy/h, and is automatically bypassed when the booster is in "NO ACCESS."

The BTS stoppers are the ejection septum, magnets B2–B6, and a stopper ST-17 (not shown in Fig. 1). The BTS stoppers are required to be "IN" when SPEAR is in either a permitted, controlled or restricted access state. Stopper ST-17 is equipped with a disaster monitor that is interlocked to the PPS. A burn-through detected by the disaster monitor will put the LTB stoppers in, and turn the booster rf off. A BSOIC S7 has been placed above ST-17. All stoppers are PPS interlocked.

THE BEAM CONTAINMENT SYSTEM (BCS)

The BCS has two major components:

(1) Beam containment devices limit the current;

(2) Beam Shut Off Ionization Chambers (BSOICS) prevent excessive beam loss by detecting unacceptable radiation levels in occupied areas.

Beam Containment Devices

There are three beam-containment devices in the linac, a beam chopper, and two average current toroids, which limit the electron intensity into the booster to $3.1 \times 10^{10}\ e^-$/sec. The beam chopper is interlocked so that if the high voltage pulse applied to the chopper is too high, the rf power to the three linac sections is removed by interrupting trigger signals to the linac modulators and rf amplifiers. A trip caused by excessive current through either toroid will also turn the beam off in the same way. The addition of a third toroid has been proposed.

Beam Shut Off Ionization Chambers (BSOICS)

BSOICS are interlocked so that if radiation levels exceed a preset level, the beam is turned off. BSOICS have been placed at strategic locations (Fig. 1) where beam losses are expected, either due to normal operating conditions, cases of mis-steering, or failure of PPS stoppers or BCS devices. The BSOICS S1–S3 and S21–S23, at the linac, trip the beam by turning off the klystron high-voltage power supply and removing the triggers to the modulators. BSOICS S4–S7 and S20 trip the beam by removing triggers to the modulators and removing the low level rf drive to the modulators.

All BSOICS are set to produce an alarm if radiation levels exceed 0.1 mGy/h, and in most cases (except S1, S3 and S21–S23) turn the beam off if radiation levels exceed 0.5 mGy/h. BSOICS S1, S3, and S21–S23 are set to trip at 0.1 mGy/h. All BSOIC faults are latched, and can be reset locally or via the injector computer. BSOICS turn the beam off within 50 to100 msec, depending upon the relay system used.

A BSOIC consists of an ionization chamber and a three decade electrometer (10 μSv/h to 10 mSv/h) enclosed in a weather-tight container. The aluminum-walled ionization chamber is filled with ethane at one atmosphere. The volume of the chamber is 10,000 cm^3. A small ^{90}Sr source mounted inside the chamber provides a constant current to the electrometer, thus acting as a continuous internal check. Because ~~of~~ this, the BSOIC will always show a readout of 10 to 30 μSv/h. Loss of power to the BSOICS will result in a beam trip. The ethane in the chamber enhances the response to fast neutrons. The BSOIC responds on an equal dose basis to both photons and neutrons; however, on a dose-equivalent basis, the neutron response is about 10% to 30% of the photon response, depending upon the incident neutron spectrum.

CONCLUSIONS

In addition to the shielding, the Personnel Protection System, and the Beam Containment System discussed above, there are other administrative controls and procedures used to ensure safe operation of the injector.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the SSRL staff for the many useful discussions on beam-loss scenarios. Acknowledgements are also due to Digna Lacey and to the SLAC Publications Department for their help with the preparation of this manuscript.

REFERENCES

1. N. E. IPE, "Radiological Aspects of the SSRL 3 GeV Injector," SLAC TN-91-11, Stanford Linear Accelerator Center (1991).
2. Department of Energy, "Radiation Protection for Occupational Workers," DOE Order 5480.11, Department of Energy, Washington, DC (1988).
3. W. P. SWANSON and R. H. THOMAS, "Dosimetry for Radiological Protection at High-Energy Particle Accelerators," in The Dosimetry of Ionizing Radiation, Volume III, Academic Press, Inc. (1990).
4. W. P. SWANSON, "Radiological Safety Aspects of the Operation of Electron Linear Accelerators," Technical Report Series, No. 88, International Atomic Energy Agency, Vienna (1979).
5. W. H. PATTERSON and R. H. THOMAS, Accelerator Health Physics, Academic Press, New York (1973) 115.
6. T. M. JENKINS, "Neutron and Photon Measurements Through Concrete from a 15 GeV Electron Beam on a Target–Comparison with Models and Calculations," Nucl. Instrum. Methods 159 (1979) 265–268.
7. W. R. NELSON, H. HIRAYAMA, and D.W.O. ROGERS, "The EGS4 Code System," SLAC Report 265, Stanford Linear Accelerator Center (1985).
8. H. DINTER and K. TESCH, "Dose and Shielding Parameters of Electron-Photon Stray Radiation from a High-Energy Electron Beam," Nucl. Instrum. Methods 143 (1977) 349–355.
9. R. YOTAM, J. CERINO, R. GAROUTTE, R. HETTEL, M. HORTON, J. SEBEK, E. BENSON, K. CROOK, J. FITCH, N. IPE, G. NELSON AND H. SMITH, "Personnel Protection and Beam Containment Systems for the 3 GeV Injector," in Proc. of the IEEE 1991 Particle Accelerator Conf., San Francisco, CA (1991).
10. H. V. WALZ, "Personnel Protection System—Technical IIntroduction," presented at Operations Training, Stanford Linear Accelerator Center (1991).