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The Linac Coherent Light Source at SLAC. Radiological Considerations and Shielding Calculations

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Abstract

The Linac Coherent Light Source (LCLS) at SLAC will be the world's first X-ray free electron laser when it becomes operational in 2009. Pulses of X-ray laser light from LCLS will be many orders of magnitude brighter and several orders of magnitude shorter than what can be produced by other X-ray sources available in the world. These characteristics will enable frontier new science in many areas. This paper describes the LCLS beam parameters and its lay-out. Results of the Monte Carlo calculations for the shielding design of the electron dump line, radiation damage to undulator, the residual radiation and the soil activation around the electron dump are presented.

Keywords: X-ray free electron laser, radiological considerations, shielding

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1. Introduction

The LCLS project will use several existing facilities at SLAC to create the world's first ultra fast (230 fs) X-ray laser (0.82 keV – 8.2 keV) [1]. These facilities include: the last kilometer of the existing SLAC Linac; the off-axis injector vault at sector 20 along the Linac, and the Beam Switchyard section of the Final Focus Test Beam (FFTB) tunnel.

Electron bunches of 230 fs FWHM duration and 3400 A peak current will pass through a 130-meter undulator producing a burst of fully transversely coherent X-rays with peak brightness ten orders of magnitude higher than is presently available from any third-generation storage ring source. The brightness and coherence are the result of the "self-amplified spontaneous emission" (SASE) process. Figure 1 shows a schematic view of the LCLS and the main Linac at SLAC.

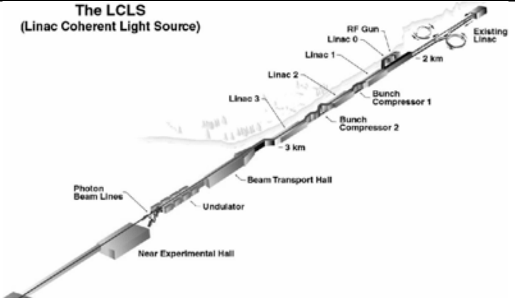

Figure 1 Schematic view of the LCLS

2. Radiation Safety System

Most of the radiation protection issues for the LCLS are normally encountered at SLAC and in most of the high-energy electron linacs and synchrotron radiation facilities, but there are some unusual aspects due to the size and characteristics of this unique machine.

The dose limits for personnel working inside and around the LCLS are listed in Table 1.

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Table 1. Dose limits at LCLS

Normal operation	1 mSv/y
Maximum Credible Incident	250 mSv/h 30 mSv (integrated)
Mis-steering conditions	4 mSv/h

3. Shielding Design of the Electron Dump Line

After the electron beam passes through the undulator, three DC magnets (BYDs 1, 2 and 3) bend it to a dump located underneath the ground. The X-ray beam produced in the LCLS undulator is not affected by the magnetic field and is transported to the experimental hutches through the X-ray line (see top part of Figure 2).

A Monte Carlo simulation with the MARS15 code [2] was used to design the shielding for the electron beam line [3]. The MARS geometry was prepared for the region from just upstream of the bending magnet to the beginning of the hutch. As shown in Fig. 2, the beam line, the concrete shield wall, the vertical iron walls for muon shielding, and the beam dump have been taken into consideration.

In one calculation, a beam loss was assumed to occur at the entrance of first bending magnet. Electrons of 14.1 GeV-30 W were injected into the beam pipe at a 1 mrad angle in the horizontal plane. The middle part of Figure 2 shows that the calculated dose rate is 1×10^{-3} mSv/hr inside the experimental hutch. On the bottom part of Figure 2, it can be seen how the produced muons are dispersed upwards (μ^{+}) and downward (μ^{-}) by the dipole magnetic fields.

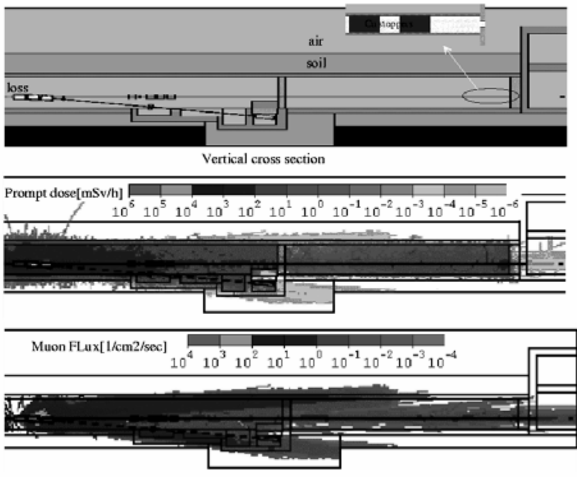

Figure 2 MARS geometry and calculation results

4. Residual Radiation and the Soil Activation

Another MARS15 simulation [4] was performed to estimate residual radiation and soil activation around the LCLS electron dump. Figure 3 shows a vertical cross section of the LCLS beam dump area described in MARS15 geometry. The beam dump is a 40 cm diameter cylinder consisting of 150 cm aluminum and 20 cm iron, inclined downward at an angle of 28.67 mrad. The beam dump is shielded by a concrete-iron-concrete sandwich structure in all directions except upstream. Behind the outer concrete, 4 detector volumes in the soil region were defined in the forward, left- and right-sides and bottom directions to estimate the produced activities in soil and ground water.

A 14.1 GeV electron beam of 5 kW (2.21×10^{12} e/sec) was injected into the upstream surface center of the beam dump with the same angle of the dump line. The energy cut-off for charged hadrons, muons, electrons and photons was set to equal 0.2 MeV. Neutron transportation was carried out down to thermal energy (10^{-3} eV) to estimate dose rates and activation due to low energy neutrons. Low energy neutron transportation below 14.5 MeV was performed using the MCNP option in MARS15.

MARS15 provides residual dose rates on the material surface assuming a 30-day irradiation and 1-day cooling (Figure 3). These results do not include the dose contribution from neighbor materials. Although dose rate levels are of the order of 2~several mSv/h at the inner surface of the concrete, a person in the dump room would get a larger dose contribution from the dump. The dose rate in the surface of the Al target is about 10 mSv/h.

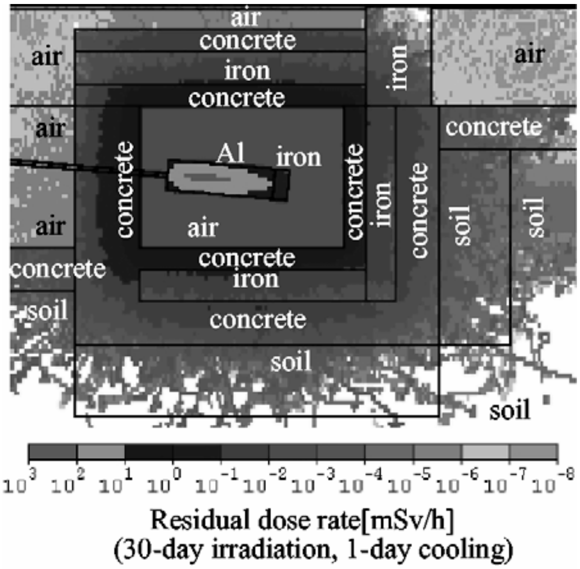

Figure 3 Residual dose rate around the dump

The numbers of produced ^{3}H (tritium) and ^{22}Na nuclides in the four detector volumes were obtained by MARS15 calculation and converted to the concentration in the soil (A_{soil}). Table 2 lists ^{3}H and ^{22}Na Activity in soil (A_{soil}) of the detector cell after 10 years operation.

Table 2 ^{3}H and ^{22}Na Activity in soil (A_{soil}) of the detector cell after 10 years operation

	^{3}H [Bq/cm^3]	^{22}Na [Bq/cm^3]
Forward	0.78	0.076
Side	0.68	0.078
Bottom	0.25	0.027

5. Radiation damage to the undulator

To study the radiation damage to LCLS undulator, the FLUKA Monte Carlo code [5] was used to calculate the dose absorbed in the LCLS undulator magnets when a 14 GeV beam would hit a 100 µm Diamond Profile Monitor [6]. The LCLS undulator, about 130 m long, will consist of 33 identical segments of 3.38 m length, separated by short gaps. Each segment will contain 226 poles 0.6 cm thick and 225 magnets 0.9 cm thick, and will be terminated at both ends by a steel magnetic shield. Each gap between segments contains a quadrupole and diagnostic devices. The first 21 segments of the undulator (about 83 m of length) have been simulated in detail.

Dose (energy deposited) does not seem to be a good indicator of radiation damage. However, since this quantity has been used as a reference in many papers on demagnetization, it has been decided to study its space distribution, scoring separately total dose and dose due only to heavy particles (neutrons and other hadrons). All the above quantities have been scored as averages over the volume of each magnet, as maximum values and as longitudinal and transverse distributions around the most affected region of the undulator. The FLUKA geometry description of a short undulator section is shown in Fig. 4.

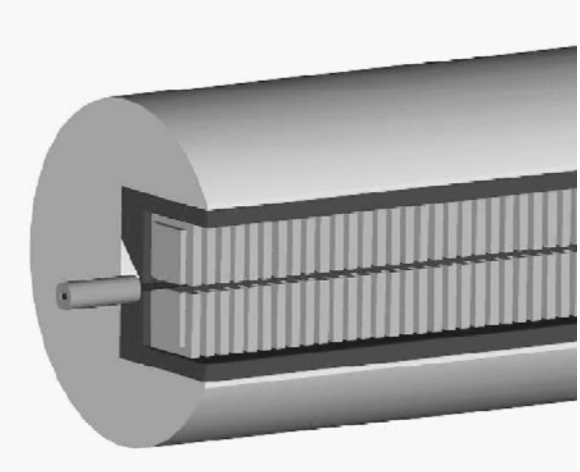

Figure 4. LCLS undulator in FLUKA geometry.

The calculated longitudinal distribution of dose over the first 21 segments of the undulator, averaged over each magnet volume, is presented in Figure 5. The two upper sets of data refer to the maximum and to the average total dose and the two lower sets to hadron dose only. It can be seen that the maximum value is reached only at a distance of about 70 m from the beginning of the undulator. This value is consistent with a rough estimation based on the characteristic angle of emission for thin-target bremsstrahlung. The apparent spikes in the volume averaged dose curves is due to the lack of self-shielding in correspondence of the gaps.

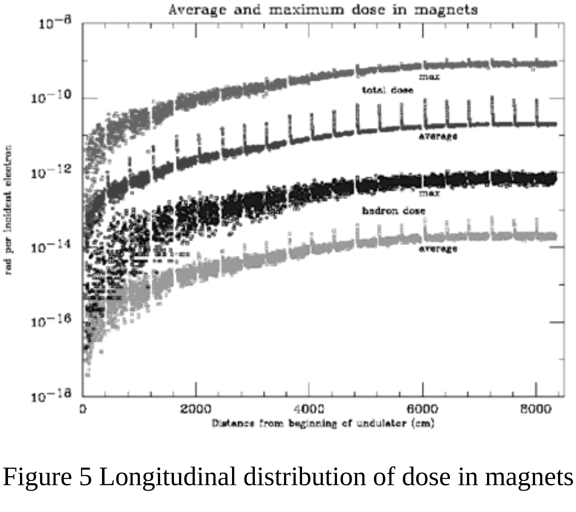

Figure 5 Longitudinal distribution of dose in magnets

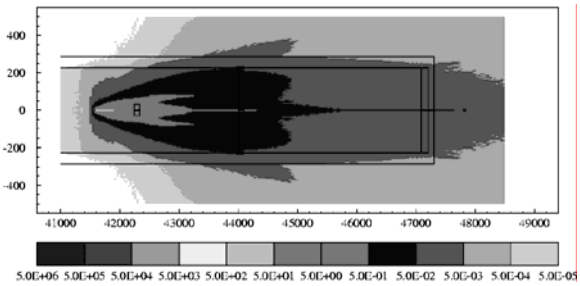

Figure 6. Muon dose with muon spoiler

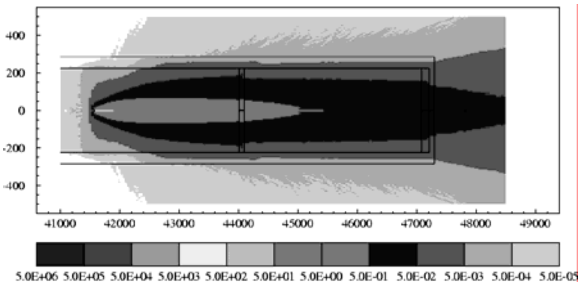

Figure 7. Muon dose without muon spoiler

6. Effect of a Magnetic Spoiler on Muon Doses

Due to the LCLS longitudinal configuration, muons will be the dominant component in the forward direction. To minimize the required shielding thickness for these penetrating particles, the possibility of installing a magnetic spoiler inside the tunnel has been investigated [7]. The muon source was obtained by the MUCARLO code [8], and the muon transport was simulated with FLUKA. The dose distributions in the tunnel with and without the spoiler are shown in Fig. 6 and 7, respectively.

Acknowledgments

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