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# Radiation Safety Analysis for the Experimental Hutches at the Linac Coherent Light Source at SLAC

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**Abstract**

The LCLS, the world's first x-ray free electron laser, will be constructed at the Stanford Linear Accelerator Center and is expected to be completed in 2009. A two-mirror system will be used in order to reduce background radiation in near and far experimental hutches. This paper describes the layout of the two-mirror system and also reports on the shielding requirements for the experimental hutches. Two beam loss scenarios for radiation sources are discussed: losses from the high energy electron beam hitting beam components and x-rays produced in the 130 m long undulator and scattered on x-ray mirrors. The FLUKA Monte-Carlo particle transport code was used for the shielding design and for the determination of the radiation levels around the experimental hutches.

## 1. Introduction

The Linac Coherent Light Source (LCLS) is a Self-Amplified Spontaneous Emission based Free Electron Laser (FEL) that is being designed and built at the Stanford Linear Accelerator Center (SLAC). This facility will provide ultra-short pulses of coherent x-ray radiation with the fundamental harmonic energy tunable over the energy range from 0.82 to 8.2 keV. One-third of the existing SLAC Linac will compress and accelerate the electron beam to energies ranging from 4.5 GeV to 14.35 GeV. The beam will then be transported through a 130-meter long undulator, emitting FEL and spontaneous radiation. After passing through the undulator, the electron beam is bent onto the main electron dump.

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The LCLS will have two experiment halls, the Near experimental Hall (NEH) and the Far Experimental Hall (FEH).

Radiation from the high energy electron beam hitting beam components and spontaneous synchrotron radiation produced in the undulator have to be minimized to conduct FEL experiments successfully. In order to reduce the background radiation in the experimental hutches a two-mirror system and a set of collimators will be installed upbeam of the experimental hutches.

This kind of application is the first of its kind and no experimental data for spontaneous radiation at this energy exists. But the FLUKA code [1] has been successfully benchmarked for high energy bremsstrahlung [2, 3] and the long experience at SLAC has shown its reliability for synchrotron radiation calculations.

## 2. Layout of the mirror system

A mirror system and a set of collimators will be installed in the Front End Enclosure FEE (upbeam of the NEH hutches), working as a low pass filter and reducing most of the spontaneous radiation in the NEH hutches. Furthermore, such a system also avoids that high energy bremsstrahlung produced in electron beam interactions with beam line components or diagnostic devices can enter the hutches.

The system consists of a set of two SiC mirrors and four collimators (0.5 cm ID). The two mirrors have a vertical offset of 2.5 cm from each others. A sketch is shown in Fig. 1.

The SiC mirrors have a photon cut-off energy of 24 keV. Thus, the reflectivity of photons with higher energies are reduced significantly (at 30 keV it is already reduced to 0.05). The FEL laser with a fundamental harmonic between 0.82 keV at 8.2 keV (depending on the electron beam energy) will pass through the mirror system nearly without losing intensity.

## 3. Details of the Calculations

The FLUKA Monte-Carlo particle transport code was used to determine the radiation levels at the experimental hutches of LCLS. The design of the shielding should ensure that the effective dose rate outside the hutches is below 0.05 mrem/h (0.5 μSv/h).

### *3.1. Beam losses*

The radiation shielding requirements of the hutches are based on radiation from electron beam intercepted by beam diagnostics devices, as well as on spontaneous synchrotron radiation. Unlike at synchrotron radiation facilities, gas bremsstrahlung is negligible [4]. Contribution to the dose in the hutches from electron beam halo interactions with collimators upstream of the LCLS undulator was found to be smaller than from beam intercepted by diagnostic devices downstream of the undulator [5].

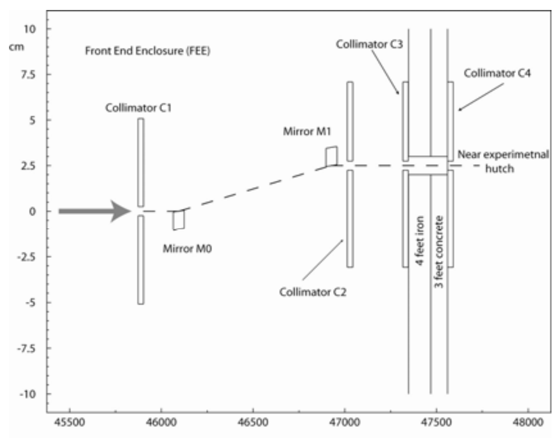


Fig.1: Schematic view of the mirror system

### *3.2. Two-step calculations*

FLUKA calculations for the shielding design from high energy bremsstrahlung were done by a two-step run technique. In a first set of calculations, information about particles entering the first experimental hutch through C4 was written on a file.

This information included:

- number of total primary particles
- total weight of the primary particles

and details of the dumped particles, like:

- energy
- particle type
- weight
- co-ordinates
- direction cosines

This information was then used as a source for the second set of calculations. Thus, the time consuming calculation of beam interception by the mirror/collimator system in the FEE was avoided in the second step runs.

*3.3. Beam parameters and energy thresholds*

The electron beam energy assumed in all calculations was 14.35 GeV (2 kW) and the profile of the beam was assumed to be a δ-function. In the simulations the threshold for particles transport was set to 1 MeV for all hadrons, electrons and positrons (except for anti-n and K-Long, both 50 MeV, and neutrons which were transported down to $4.14\times10^{-10}$ GeV). For photons, the energy threshold was set to the minimum allowed threshold, namely 1 keV and therefore the effects on the results should be considered negligible.

*3.4. Scoring*

For the calculation of the effective dose, the fluence of all particles was scored and was weighted during the scoring procedure by energy- and particle type-dependent conversion coefficients using data of ICRP74 and the concept of the worst value of effective dose for any body orientation.

**4. Results**

*4.1. Spontaneous synchrotron radiation*

The LCLS spontaneous radiation spectrum (average power 2.78 W with a critical energy of 140 keV) as shown in Figure 2 has been folded with reflection coefficients for a SiC mirror with a 24 keV cut-off. The reflected x-ray spectrum has been used in FLUKA for dose calculation at the hutches. Note, that this approach is conservative as, in reality, the beam will be reflected on two SiC mirrors.

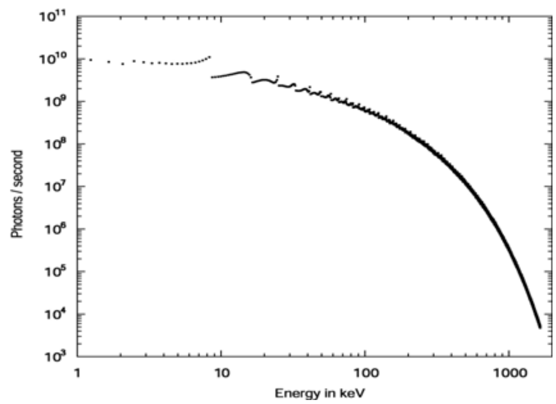

Fig. 2: LCLS spontaneous x-ray spectrum

Based on the FLUKA calculations [5] the following hutch shielding is required for spontaneous radiation:

- On the sides 6 mm iron or 1.2 mm lead or 8.2 cm concrete
- Down beam wall: 2 mm of lead with a 1m × 1m × 70 mm iron or 9 mm lead plate.
- Roof: 4 mm of iron or 1 mm of lead or 6 cm concrete

*4.2. High energy bremsstrahlung*

FLUKA calculations were conducted to determine the amount of power and the type of particles which pass through C4 into the first hutch in the NEH. In the simulation, a 14.14 μm thin Titanium Optical Transition Radiation (OTR) detector (similar to a 10 μm OTR tilted by 45 degree) was inserted into the electron beam line downstream of the undulator. The electrons are intercepted by the screen and produce high energy bremsstrahlung which is not deflected to the main LCLS e-dump but enter the Front End Enclosure and is intercepted by the mirror/collimator system. Calculations have shown that a 2 kW electron beam with an energy of 14.35 GeV passing through the OTR produce about 800 mW of bremsstrahlung. About half of this, namely 385 mW ± 0.02 % will pass through collimator C1 and generates an electromagnetic shower in the mirror/collimator system.

As the vertical offset of these collimators is only 25.0 mm, a conservative approach was chosen for the design of the shielding thickness of the experimental hutches. Collimator C2 was assumed to be removed completely. In this configuration 17 μW ± 2 % of bremsstrahlung will pass through Collimator C4 and reach the first experimental hutch.

The spectra of the particles (99.999 % photons) passing through collimator C1 and through C4 is shown in Fig. 3.

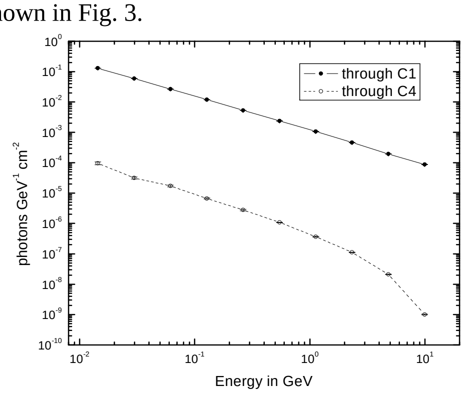


Fig. 3: Energy spectra of photons passing through C1 and C4 respectively. Collimator C2 out

Furthermore, calculations have shown that an aligned collimator C2 results in 0.17 μW ± 18 % bremsstrahlung through C4.

In order to determine the required shielding thickness for the downstream and side hutch walls, a 16.4 cm$^3$ (1×1×1 inch$^3$) Cu cube and a 15 cm long, 2.54 cm diameter Cu cylinder were placed into the beam line, respectively. These targets were found to give the highest dose levels in forward and side directions [6]. Collimator C2 was assumed to be out completely. Calculations have shown, that for the downstream wall, a photon stopper and a two feet thick concrete back wall with 40×40×10cm$^3$ local iron shielding at the zero degree line is required to reduce the dose rate outside the hutch to 0.5 mrem/hr. Considering that Collimator 2 is aligned, the dose rate will be a factor of 100 smaller (17 μW vs. 0.17 μW leakage). Note, that a 61 cm (2 feet) thick concrete shielding wall plus local iron shielding is only required for the first hutch. The requirements for the other hutches are purely dominated by synchrotron radiation.

For the side shielding against high energy bremsstrahlung, a 1.2 mm thick lead wall at a distance of 4.75 m from the beam line, as required for synchrotron radiation, reduces the dose levels outside the hutch to ~ 0.005 mrem/h.

## 5. Summary

The FLUKA code was used for the calculation of radiation levels at the experimental hutches of the SLAC LCLS. The required shielding for the experimental hutch was determined by using the methodology of splitting FLUKA runs.

## Acknowledgments

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