Radiation Safety Studies for LCLS-II Experiment Systems

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ABSTRACT

The LCLS-II (Linear Coherent Light Source II) is the upgrade of the current LCLS x-ray free-electron laser (FEL) facility at SLAC. The LCLS-II will deploy new superconducting Linac systems for up to MHz and MW electron beams and new variable gap undulators. Despite the challenges from MW electron beams, the upgraded FEL parameters will also bring challenges to the radiation safety of the experiment systems. The existing radiation safety systems, including shielding, beam containment and access control, of the experiment systems were designed for W-level FEL up to 12 keV fundamental. The LCLS-II will raise the x-ray fundamental energy to 25 keV (at 120 Hz) on one side and deliver up to 200 W FEL (up to 5 keV at 120 kHz) on the other side. This paper shows studies for the electron beam containment for experiment area, and the radiation shielding design under the upgraded LCLS-II beam parameters.

KEYWORDS
LCLS-II, Radiation Protection, Shielding

1. INTRODUCTION

The LCLS-II [1] is designed to produce high-brightness, short-pulse X-rays from two parallel undulator systems in the existing LCLS tunnel. One undulator is optimized for the soft X-ray range (called SXR), 200 to 1350 eV, will be driven with electrons from the superconducting linac (SCRF) at rates up to 1MHz. The second undulator is optimized for hard X-rays (called HXR), from 1-5 keV when driven by the superconducting linac (SCRF) at rates up to 1MHz and from 1-25keV when driven by the Cu linac (CuRF) at rate up to 120 Hz. Table I lists the LCLS-II parameters and compares them with LCLS-I.

Table I. LCLS-II parameters and comparison with LCLS-I

Parameters	SCRF SXR	SCRF HXR	CuRF HXR	LCLS-I	Units
Max electron beam power	120	120	5	5	kW
Photon energy	0.2 - 1.35	1 - 5	1 - 25	0.2 - 14	keV
Max repetition rate	929	929	0.12	0.12	kHz
Max pulse energy range	2.0	2.0	10	10	mJ
Max power coming into FEE	~ 200	~ 200	1.2 - 0.4	1.2	W

The radiation safety system for the LCLS-II accelerator is discussed separately [2]. After the accelerator, there are two separate beamlines for transport and diagnostics of the X-rays, one for each of the undulator

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systems, from the end of undulators, crossing the electron beam dump hall (EBD) and front end enclosure (FEE), to the experimental hall (EH). LCLS-II will use the existing construction designed for LCLS-I but deliver much stronger beams. The radiation safety system needs to prevent the primary electrons going to the experiment system (by the electron safety dump line in Section 2), and also construct appropriate shielding (as described in Section 3).

2. Electron Safety Dump Line

In normal LCLS-II operations, electrons will be sent to the main dump by bending magnets, but electrons may be bent to undesired locations in abnormal conditions. The electron safety dump line is designed to contain electron beams under credible abnormal conditions. The LCLS-II safety dump line is in principle same with LCLS-I, consisting of mechanical devices and electronic interlocks, as shown in Figure 1. The mechanical devices include electron collimators, and a safety dump, which will stop abnormal electron beams. The protect ion chamber and burn-through monitor (BTM) on the collimators and safety dump will detect the abnormal beams and shut-off the whole machine quickly. The outer dimensions and inner apertures of the collimators and safety dump are designed by using Monte Carlo method to track the electron envelop under credible abnormal scenarios. The heart of the electron safety dump line is the permanent magnets, which will bend all forward direction electrons horizontally to the safety dump. In addition, electronic interlocks will reduce the probability of abnormal conditions. The average electron beam current comparator will check if all electrons are sent to the main dump, and the magnet current monitor will match the electron energy with the bending power of magnets.

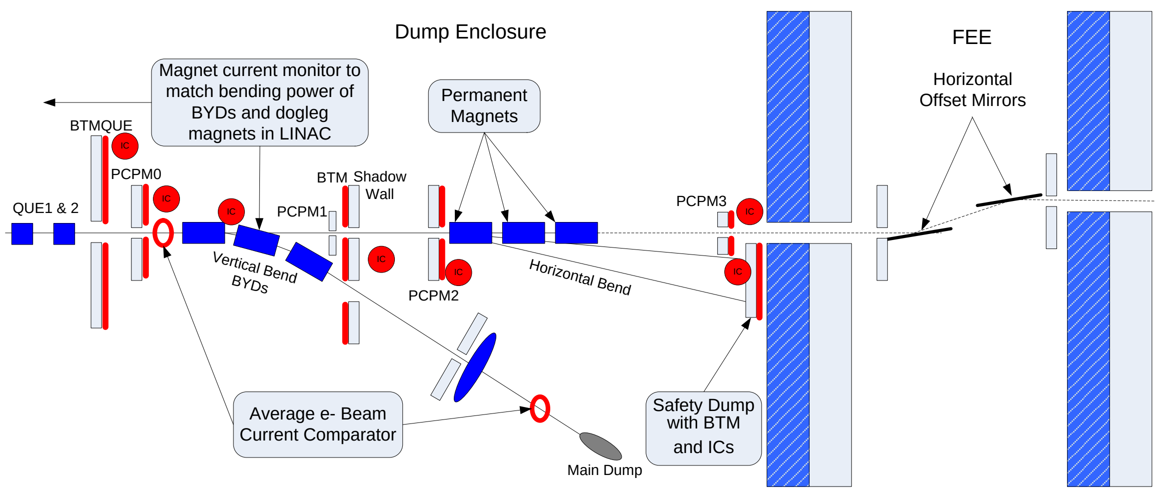


Figure 1. Layout of electron safety dump line

3. Radiation Shielding

Several radiation sources are combined together after undulators and toward the experiment system: electron beams, bremsstrahlung from residual gas, bremsstrahlung from beam intersecting devices, the desired FEL beams and spontaneous synchrotrons from undulators.

3.1. Radiation shielding for electron losses

Our studies show that the dominant radiation for shielding is from the small portion of electrons lost at the magnets bending electron beams to the main dumps. These magnets have strong bend and we conservatively estimate that 0.1% of total beams, i.e. 120 W on each of SXR and HXR beam line, will be lost at the magnets. The existing walls are still enough to shield radiation shower, however the collimation system need to be redesigned to reduce the leakage along beam pipe to an acceptable level.

Two collimators are added inside the electron beam dump hall and help to reduce the power of all particles entering the front end enclosure to 10 mW. Figure 2 shows the dose distribution at HXR beam line with 10 mW bremsstrahlung from FLUKA [3, 4] simulations. The dose inside the experimental hall is less than 0.1 μSv/h (note the unit in the figure is mrem/h), which is acceptable.

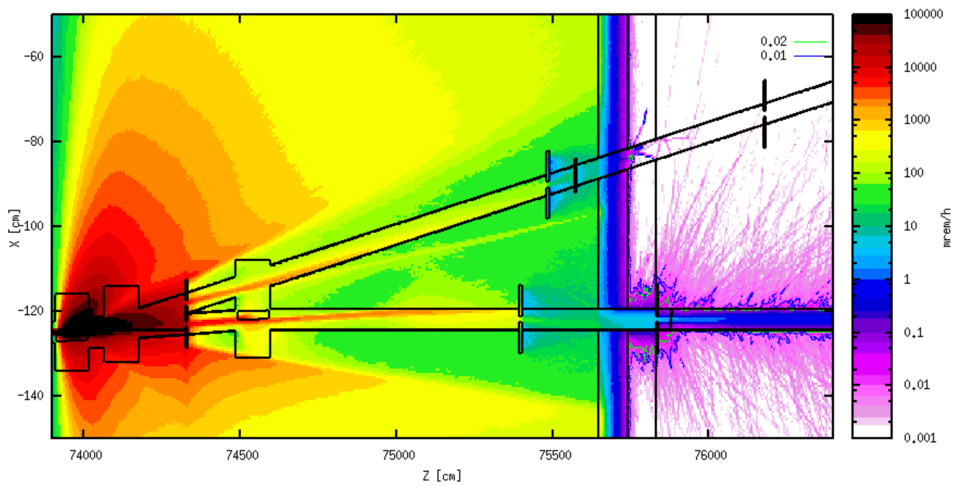


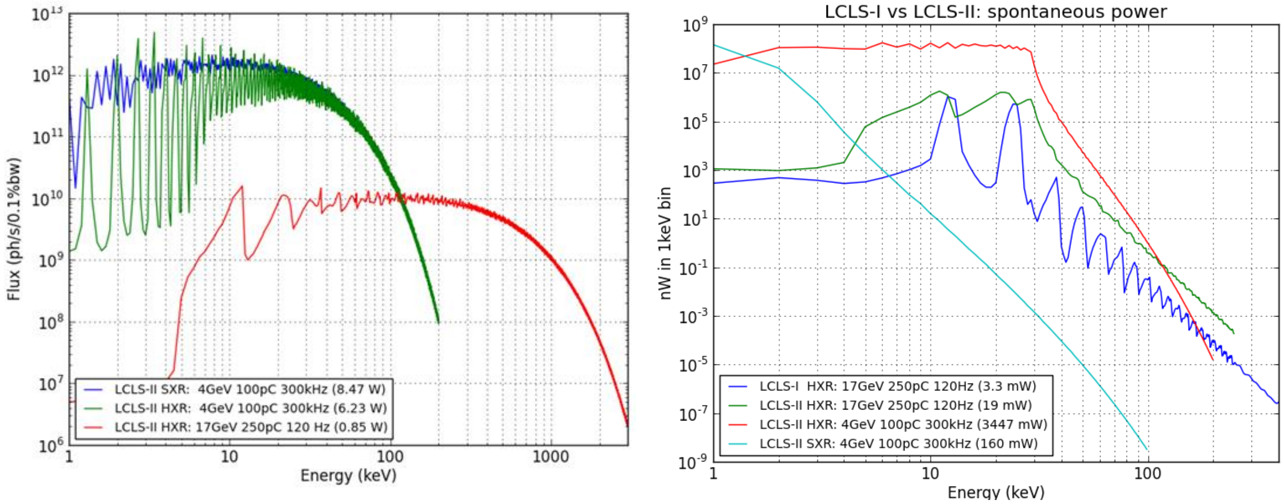
Figure 2. Radiation dose from 10 mW bremsstrahlung to HXR beam line

3.2. Radiation shielding for spontaneous synchrotron

Though it is not desired, spontaneous synchrotron radiation will be generated simultaneously with the desired X-ray FEL beams. The FEL beams have a very narrow energy bandwidth, while the spontaneous synchrotron has a long tail toward high energy and thus raise the consideration for radiation shielding. Most spontaneous synchrotron will be cut-off by mirrors inside the front end enclosure. However, the remaining spontaneous after mirrors is not negligible. Figure 3 shows the spectrum of spontaneous radiation before and after mirrors for LCLS-II and compares the after-mirror spectrum with LCLS-I. The spontaneous synchrotron was calculated by using SPECTRA [5] and the reflectivity of mirrors, according their materials and angles, were then applied. The experiment hutches in the experiment hall were originally designed for LCLS-I beams. Figure 3 shows the spontaneous synchrotron entering the hutches will be higher for LCLS-II. Because of the conservativeness of the hutch shielding implementation, the existing hutches need few modifications to shielding LCLS-II spontaneous synchrotron.

4. CONCLUSIONS

LCLS-II will use the existing LCLS-I facility (tunnels, walls, hutches, etc.) to deliver the much stronger LCLS-II beams. The designed radiations safety system, including electron safety dump line, radiation shielding and collimator system, is able to protect personnel from the future LCLS-II operations.



(a) before mirrors (b) after mirrors

Figure 3. Spectrum of spontaneous synchrotron after mirrors

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