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Shielding design of laser electron photon beamlines at SPring-8

Yoshihiro Asano [a*], Shuji Miyamoto [b] and LEPS-II collaboration

[a] *RIKEN, SPring-8,1-1-1 Koto, Sayo, Hyogo-ken, 679-5148, Japan;* [b]*University of Hyogo, NewSUBARU, 1-1-2 Koto Kamigori, Ako-gun Hyogo, 678-1205, Japan*

Shielding design for two new laser electron photon beamlines using backward Compton scattering with the photon energy of up to 76 MeV at NewSUBARU and 2.9 GeV at SPring-8 have been performed by using the Monte Carlo code FLUKA with a modified user source code including the beam dumps which have double-layer and triple-layer structures, respectively. The leakage dose distributions depending on the various conditions of photon beam transport lines and local shields were simulated to estimate the effect of the shield components to transport high energy photons at long beamlines.

Keywords: laser electron photon; SPring-8; backward Compton scattering; NewSUBARU; Monte Carlo; shielding design; FLUKA; radiation safety

1. Introduction

Laser electron photon, otherwise known as backward Compton scattering photon**,** is a powerful tool for various scientific investigation and engineering because of its unique characteristics such as quasi-mono energy photons by using electron tagging system or differential angular system and polarized high energy photons. Various experiments using the laser electron photons have been carried out such as Kaon physics and penta-quark physics[1], transmutation experiments such as the production of useful radio-isotopes of Mo-99[2], and nondestructive inspection[3] etc.

At the SPring-8 site, we have two synchrotron radiation rings, one is small ring with the electron energy of up to 1.5 GeV (NewSUBARU) and the other is the world's largest ring with the energy of up to 8 GeV (SPring-8). Up to now, each ring has one laser electron photon beamline which can operate routinely. One is the NewSUBARU BL01 beamline [4] and the other is the SPring-8 LEPS beamline[5]. The BL01 beamline is reconstructed to intensify the power of the laser electron photon up to 0.33mW and to increase the energy up to 76 MeV (BL01UG) to investigate transmutation etc. The larger experimental hutch will be also constructed to improve the experimental conditions. In addition to the LEPS beamline, LEPS-II is now under construction to complement the current beamline (LEPS) at SPring-8. The LEPS and LEPS-II beamlines provide polarized photons of a few GeV energies with high intensity, and the new beamline, LEPS-II, will be operated at about 5 times higher beam intensity than the LEPS beamline to be used for

investigations of quark nuclear physics with high accuracy and wide solid angle detectors. Experimental hutch of this beamline has been constructed outside the experimental hall of the SPring-8 to install a large acceptance spectrometer. Therefore estimations of radiation levels along a relatively long beam transport pipe comparing to the LEPS becomes important.

2. Laser electron photon

Laser electron photons can be produced by electron photon interactions of Compton scattering process. **Figure 1** shows the concept of the production of the laser electron photon. The polarized laser photons from the oscillator are injected to high energy stored electron beam to make a head-on collision. Then, the back scattered photon becomes energetic according to the Lorentz boost. In the case of a head-on collision and small photon back scattering angle θ, as shown in the Figure 1, the energy of the laser electron photon can be expressed as follows,

$$E_\gamma = \frac{4 \cdot E_l \cdot \gamma^2 /(1+R)}{1+\gamma^2 \cdot \theta^2 /(1+R)} \qquad (\theta \ll 1)$$
(1)

$$R = 4 \cdot E_l \cdot \gamma / m_0 c^2$$
(2)

$$\gamma = E_e / m_0 c^2$$
(3)

where E_l is the energy of laser photon, γ is the Lorentz factor, E_e is the stored electron energy, and $m_0 c^2$ is electron rest mass energy. The stored electron energy E_e is 1.5 GeV and 8 GeV at NewSubaru and SPring-8, respectively. The design parameters of the laser electron

*Corresponding author. Email: asano@spring8.or.jp

Table 1. Specifications for laser electron photon beamlines at SPring-8 site.

	NewSUBARU		SPring-8	
Electron energy	1.0GeV, 1.5GeV		Max. 8GeV	
Beamline	BL01	BL01UG	LEPS	LEPS-II
Laser wave length	(1) 10.59μm	(1)10.59μm[*1]	(1) 355nm[*4]	(1) 355nm
	(2)1.064μm	(2)1.064μm[*2]	(2) 200nm[*5]	(2)266nm[*6]
	-	(3)532nm[*3]	-	-
Max. photon energy	(1)4.02MeV	(1)4.02MeV	(1) 2.4GeV	(1) 2.4GeV
	(2)39.1MeV	(2)39.1MeV	(2) 3.5GeV	(2) 2.9GeV
	-	(3)76.2 MeV	-	-
Max. photon power	0.19mW	0.33mW	2.7mW	9.5mW
Distance from the source to the beam dump	12.7m	25.9m	75.8m	140m

*1:CO_2 laser, *2:NdYVO$_4$(w) laser, *3:NdYVO$_4$(2w) laser,* 4:Paladin laser,* 5:UV laser
*6:semiconductor + BBO laser

photon beamlines are indicated in **Table 1**. The intensity of the laser electron photon increases in proportion to both the laser intensity and the stored electron current. In BL01A, a short wave length laser will be employed so that maximum beam energy will be increased up to 76 MeV. In LEPS-II, a set of four lasers, Paladin semi-conductor UV laser (355nm) by Coherent, will be shaped to match electron beam cross-section and combined to increase intensity so that about five times higher beam intensity will be obtained as compared to that of LEPS. Calculation data for total photon energy spectra of laser electron photon beam at NewSUBARU (BL01,BL01UG) and SPring-8 (LEPS, LEPS-II) are shown in **Figures 2** and **3**, respectively. As shown in the Figures, the laser electron photon spectra are quite unique and the maximum intensity of the laser electron photons is appeared at the highest energy which corresponds to the 0 degrees of scattering angle θ. The minimum energy of laser electron photons is also derived by the aperture size of θ.
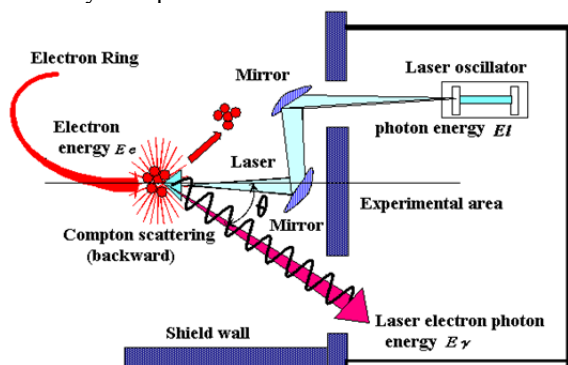

Figure 1. Illustration of the production of the laser electron photon.

3. Shielding calculation

Radiation shielding calculations were performed by using the FLUKA Monte Carlo code [6] with the modified user source code which can generate the laser electron photon spectrum.

3.1. BL01UG beamline at NewSUBARU

The BL01A beamline has two experimental hutches which were constructed in tandem and sizes of the hutch1 and hutch2 are 200cm in wide x 200cm long x 215cm high and 240cm(W) x 560cm (L) x 260cm (H), respectively. Beam dump is installed in each hutch, and the dump in the upstream hutch1 is movable. The upstream hutch1 and the downstream hutch2 are connected by using a beam transport pipe with 20cm in diameter. The sizes of the dumps which made of lead are 60cm in wide x 60cm high x 30cm in thickness and 30cm (W) x 30cm (H) x 30cm (T) for hutch1 and hutch2 as shown in **Figure 4** and **Figure 5** with the gamma ray dose and neutron dose distributions, respectively. The dump made of lead in hutch2 is enclosed with ordinary concrete of 25cm in lateral and 40cm in perpendicular direction. Additional shields of ordinary concrete are installed to shield the scattered photons from targets, and the thicknesses are 45cm and 10cm for the perpendicular direction of the beam and sidelong of the wall, respectively as shown in Figures 4 and 5. These are the case which the photons distribute up to 76.2 MeV, and the wave length of the laser and the electron energy are 532nm and 1.5 GeV with the photon power of 0.33mW, respectively. Lead target of 1.76cm long was considered.

The maximum photon doses outside the side wall of the hutch2 for each case (laser wave length and electron energy) are about 5 μSv/h to 7 μSv/h under the same photon power of 0.33mW. The lowest photon energy case with the electron energy of 1.0 GeV and the laser of 10.59 μm appears the highest leakage dose for the same shielding geometries as shown in the Figures. In this case, the photons are more isotropic scattering and the total number of the photons is larger under the same power of 0.33mW so that the leakage photon dose due to scattering laser electron photons at the edge of the local shield of the side wall is higher than that for another case.

The maximum neutron leakage doses outside the hutch2 for each case distribute about 2μSv/h to 11μSv/h except 10.59μm laser wave length because of no neutron productions. These 2μSv/h and 11μSv/h leakage neutron doses are for the case of 532nm laser wave length with the electron energy of 1.5 GeV as shown in Figure 5 and the case of the 1.064μm with the 1.0GeV, respectively. Usually the target of this case is surrounded by helium-3 counters with polyethylene moderator of 60cm diameter
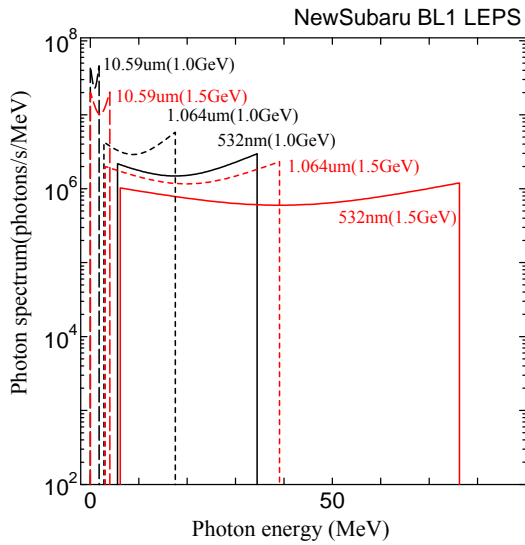
Figure 2. Laser electron photon spectra at NewSUBARU BL01UG beamline.
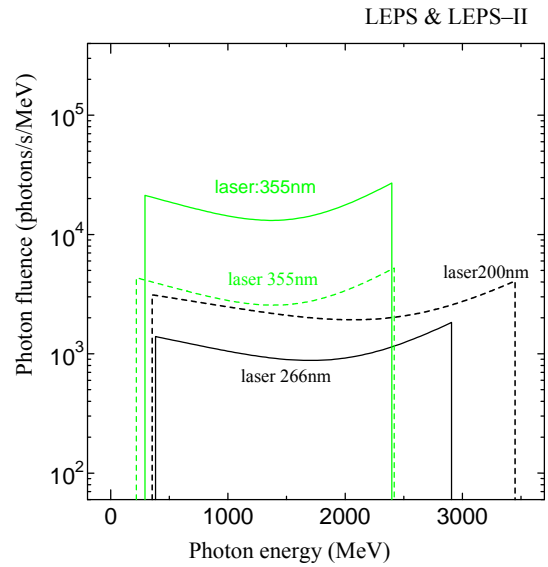

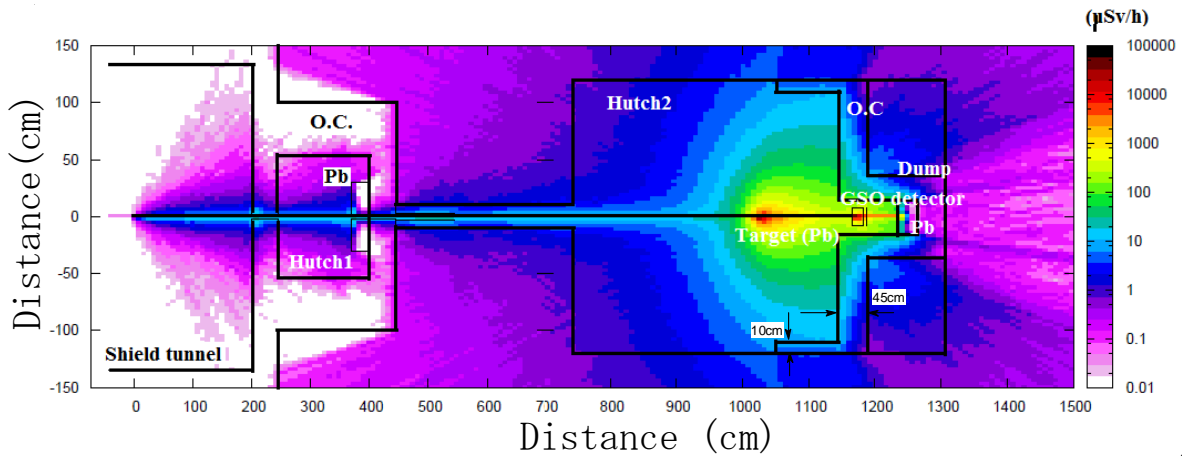Figure 3. Laser electron photon spectra for LEPS and LEPS-II beamline at SPring-8.

Figure 4. Photon dose distribution due to laser electron photons with 0.33mW at BL01UG beamline of NewSUBARU. (laser wave length: 532nm, electron energy 1.5GeV)
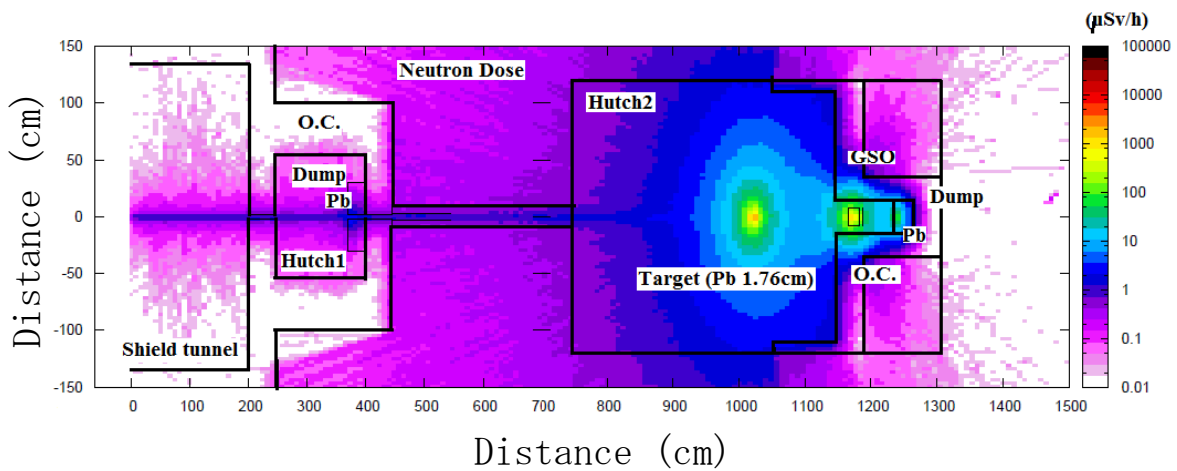

Figure 5. Neutron dose distribution due to laser electron photons at BL01A beamline of NewSUBARU. (the photon conditions are the same as that of Figure 4)
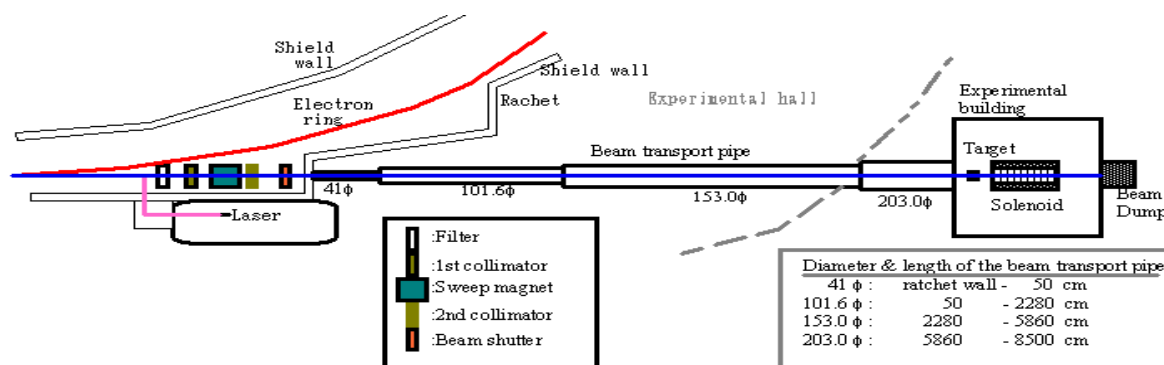
Figure 6. Illustration of LEPS-II beamline at SPring-8. Four different beam transport pipes are employed for the length of 85 m.

and 40 cm in thickness so that the maximum neutron leakage dose will be reduced to about 1/10 for all cases. For the cases of the target of 0.176 cm, the maximum neutron leakage doses are reduced to almost 1/2, and the photon leakage doses are reduced to about 1/2 to 1/6.

3.2. LEPS-II at SPring-8

The length of the beam pipe of LEPS-II is about three times longer than that of LEPS, and the transport pipe must be constructed outside the radiation controlled area of the experimental hall. The shield condition is severer than that of LEPS. To satisfy the requirements, two collimators, 1st and 2nd ones with the aperture sizes of 7 mm φ and 11mm φ, respectively, are to be installed inside the shield wall of the storage ring, and four types of the transport pipes will be employed to reduce the cost and space. These are (1) 41mm diameter from the ratchet wall to 50 cm, (2) 101mm diameter from 50cm far from ratchet wall to 2280cm, (3) 153.0mm diameter from 2280cm to 5860cm, (4) 203mm diameter from 5860cm to 8500cm, as illustrated in **Figure 6**. A 1 m long sweep magnet with 0.6 Tesla is installed downstream of the first collimator to clear off the high energy electrons produced by high energy photons interacting in the filter. The filter made of lead is installed to shield synchrotron radiation, and the local shield is to reduce the leakage dose outside the ratchet wall. The beam shutter made of heavy metal is inserted to control the photon beam. The laser hutch of the LEPS-II has been constructed at the side of the ring shield wall, and the beam dump which made of iron, lead and ordinary concrete is located just downstream of the experimental building to save space for experiments.

The sensitivity analyses were performed to know the most effective component to reduce the leakage dose outside the beam transport pipe. In these analyses, we consider the cases with and without the sweep magnet, 2nd collimator, and air inside of the transport pipe. The results are shown in **Figure 7**, and the photon doses are dominant for all cases. The dose outside the pipe will be high if the air exits inside the pipe. The sweep magnet is also important to reduce the leakage dose, especially the region near the ratchet wall. The second collimator is also required to reduce the leakage dose near the ratchet wall. Another function of the second collimator is to

define the size of the beam shutter. These results strongly depend on the diameter of the transport pipes.

The experimental hutch of the LEPS-II is 18 m (Length) x 12 m (width) x 9.7 m (height), and contains a solenoid magnet made of iron, which will be installed in the middle of the hutch. Thickness of a target is to be less than 0.1 radiation length. The wall of the experimental hutch has no shield ability, and the beam dump is constructed right behind the downstream end wall of the experimental hutch. The dump consists of triple layers; inner layer made of iron, intermediate layer made of lead, and the outer made of ordinary concrete, as indicated in **Figure 8** with the total dose distribution. The boundary of the radiation controlled area is the wall of the experimental hutch and the beam dump. As shown in the Figure, the solenoid magnet made of iron is
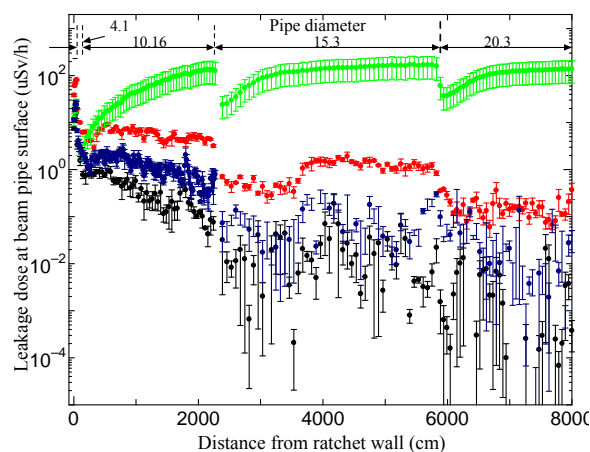

Figure 7. Leakage dose distribution along the surface of the beam transport pipe depending on the condition of the beamline components. (Black dots indicate the case of the lineup of all components. Blue and red dots indicate the case without the 2nd collimator and without sweep magnet, respectively. Green dots indicate the case of the lineup of all components with 1 atm air inside the pipe.

effective for shield. In this calculation, a copper plate of 0.1 radiation length was employed as the target, and neutron dose as well as photon dose is important at the beam dump. The dose rate outside the controlled area is less than the limit of the dose rate of 2.5μSv/h.
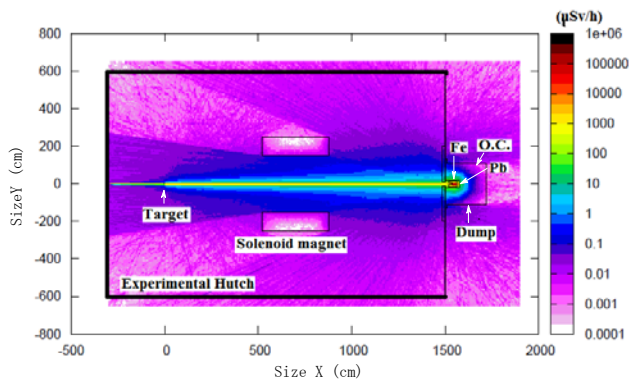
Figure 8. Effective dose distribution around the experimental hutch of LEPS-II at SPring-8.

4. Conclusion

The shielding design of laser electron photon beamlines with including the sensitivity analyses of the leakage dose outside the beam transport pipe has been performed by using FLUKA with the modified source user code. As the results, we estimated the leakage dose with satisfactory accuracy so that we can construct beamlines and experimental hutches in a narrow space.

It is important to prevent the spread of high energy photon radiation, and it is clear that air inside the pipe must be purged, sweep magnet and two collimators are also necessary for a long transport pipe.

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