Monte Carlo Evaluation for SSRF Beam Holes Shielding Neutrons of Front End Ratchet Walls

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Abstract This study investigated the characteristics of bremsstrahlung and induced neutrons from the electron storage ring in the Shanghai Synchrotron Radiation Facility (SSRF). The EGSnrc and MCNP Monte Carlo code has been used to perform the assess neutron and photon dose profiles for a variety of shield materials ranging from 5 to 115cm thick. The Monte Carlo simulations show that single material such as lead, iron and polyethylene have been found to be ineffective biological shield materials, while the mixed materials serve as effective shields for shielding high energy neutron. Mixed materials such as lead or iron combined with polyethylene or with concrete are good materials combination for high energy neutron radiation shield. And high-Z materials such as lead or iron combine with low-Z material containing some hydrogen such polyethylene are effective for shielding high energy neutrons as well as bremsstrahlung.

Key words MCNP, EGSnrc, neutron radiation shielding, synchrotron radiation, SSRF

1 Introduction

The mainly concerned radiation of this study is the forward peaked photons and neutrons from the beam losses in the ring chamber or a front end component. The bremsstrahlung production from the insertion-device straight section causes a serious challenge in shielding because of its high energy and long straight section. And the high neutrons are thought to be the most difficult for radiation protection in this facility. As reported in Ref. [1], for a concrete wall up to 90cm thick, the photon dose exceeds the neutron dose. However, for a 150cm thick concrete wall, measurements show that the dose is dominated by neutrons with an equilibrium spectrum and neutrons above 20MeV contributing about 50% to the total neutron dose equivalent. So neutron radiation is very important in this study at SSRF.

2 Simulations

2.1 Beam loss scenarios and radiation source

The shielding criterion adopted is a total dose rate of 2μSv/h. This corresponds to an annual cumulative dose of 4 mSv for 2000 hours. SSRF includes 7 initial beamlines (see Fig. 1) and five ID beamlines and two bending magnet beamlines. There are 40 bending magnets, 16 standard straights (6.5m) and 4 long straights (12m) along the ring, so more than 60 beamlines could be installed in the ring, where 26 of them

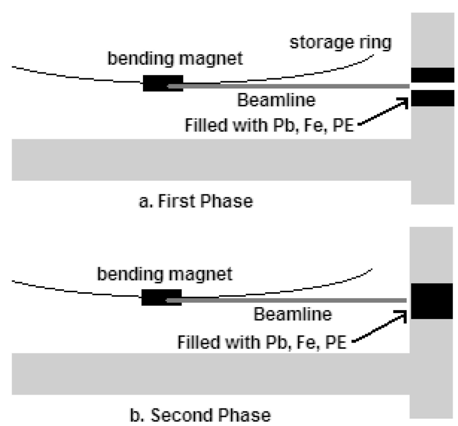

Fig. 1. Schematic of front end concrete ratchet walls used in the study for Monte Carlo simulation(a. for first phase; b. for second phase).

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will be based on insertion devices, 36 lines are based on bending magnets.

A total of 2.7×10^{12} electron will be injected into the ring and it is supposed to lose out in 8 hours with the average loss of 9.38×10^{7}e/s. The beam holes of concrete ratchet walls are 115cm or 150-cm thick. The radiological aspects that are addressed include bremsstrahlung (BREM), giant resonance neutrons (GRN), medium neutrons (MEN) and high-energy neutrons (HEN) produced by electrons interacting in a beam stop or in component structures[2—4].

2.2 Monte Carlo simulation

The modeling used in these simulations was performed using the MCNP[5] to investigate neutron dose rates resulting from an electron storage ring neutron source. Bremsstrahlung interactions with materials are simulated by the electron gamma shower (EGSnrc[6]) code system. All simulations were run to ensure that the statistical errors in significant particle dose deposition tallies were less than 5.0%. The composition of the shielding materials such as iron, lead, polyethylene (PE) and concrete were taken from NIST[7]. These materials were chosen because they are in common use in generic shielding problems and have the potential for being used for radiological protection shielding.

3 Results

The results calculated by Monte Carlo method are provided in Table 1, Fig. 2 and Fig. 3. Table 1 is the Monte Carlo calculation results for the dose outside the front end concrete wall with the material combination of number 9 (5cm (Pb)+20cm (Fe)+30cm (PE)+5cm (Fe)+40cm (PE)+10cm (Fe)+5cm (Pb)) which will be used for SSRF. The corresponding values for BREM, GEN, MEN and HEN are listed in Table 1. The total dose is 0.0863μSv/h for the first phase (Fig. 1(a)) of SSRF and 0.0808μSv/h for the second phase (Fig. 1(b)), which is much lower than the value of design criterion (1μSv/h).

Figure 2 shows a variety of material combinations for shielding 20MeV neutron. Fig. 3 is the comparison for the neutron shielding between 100MeV and 20MeV. As might be expected, shielding with single lead or iron was an effective solution for shielding photons, while it was thought to be ineffective for neutrons. Our results also demonstrate that polyethylene is the most ineffective solution for shielding HEN, while it is good for low energy neutrons. Models such as Pb+PE /concrete +Pb and Fe+PE /concrete +Fe are good pattern for shielding HEN. Models such as PE+Pb and PE + Fe are not effective for HEN as well as photons.

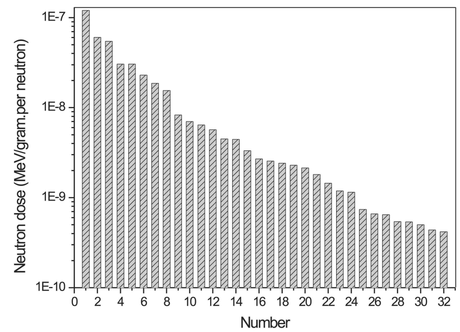

Fig. 2. Comparison of neutron dose in different material combination for shielding 20MeV neutron in 115cm thickness front end wall.

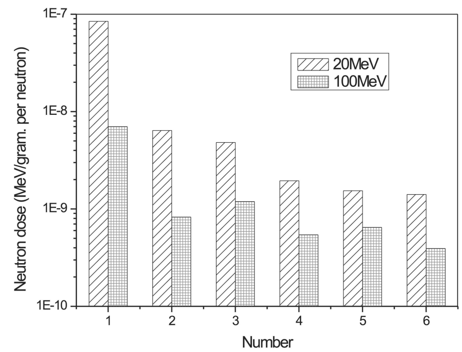

Fig. 3. Comparison for the neutron dose between 100MeV and 20MeV.

4 Conclusion

The bremsstrahlung is highly peaked in the forward direction of the particle beam and materials such as lead and iron which are thought to be good for BREM shielding. GRN is produced by photonuclear interactions (threshold energy in most materials in the range 7-20MeV). They are emitted almost isotropically and have an average energy of about 2MeV and low-Z materials such as polyethylene and water which are good for shielding. Electrons or positrons above several hundred MeV, HEN ($E>100$MeV) are produced. The high energy component is not isotropic and single high-Z[8] as well as low-Z materials are found to be not effective in this study; but high-Z materials such as lead or iron combine with low-Z material containing some hydrogen such polyethylene are the most effective material for high energy neutrons shielding. But in many shielding situations, we need to shield high energy photons as well as HEN such as SSRF. Patterns such as Pb+PE /concrete +Pb and Fe+PE /concrete +Fe are good choices for this kind of radiation shielding.

Table 1. Monte Carlo calculation results for the dose outside the front end concrete wall (μSv/h).

beamlines	material	BREM	GRN	MEN	HEN	total
first phase:	number 9	1.73×10^{-2}	1.16×10^{-6}	3.31×10^{-2}	3.59×10^{-2}	8.63×10^{-2}
second phase:	number 9	2.77×10^{-2}	2.26×10^{-6}	2.94×10^{-2}	2.37×10^{-2}	8.08×10^{-2}

Num1: 115cm (PE); Num2: 115cm(Pb); Num3: 115cm (Fe); Num4: 30cm (PE) + 7×(5cm (Pb) + 5cm (PE)) + 15cm (Pb); Num5: 30cm (PE) + 20cm (Pb) + 20cm (PE) + 15cm (Pb) + 15cm (PE) + 15cm (Pb); Num6: 30cm (PE) + 40cm (Pb) + 30cm (PE) + 15cm (Pb); Num7: 5cm (Pb) + 15cm (Fe) + 40cm (PE) + 5cm (Fe) + 40cm (PE) + 5cm (Fe) + 5cm (Pb); Num8: 20cm (Pb) + 30cm (PE) + 30cm (Pb) + 20cm (PE) + 15cm (Fe); Num9: 5cm (Pb) + 20cm (Fe) + 30cm (PE) + 5cm (Fe) + 40cm (PE) + 10cm (Fe) + 5cm (Pb); Num10: 30cm (PE) + 7×(5cm (Fe) + 5cm (PE)) + 15cm (Fe); Num11: 30cm (PE) + 20cm (Fe) + 20cm (PE) + 15cm (Fe) + 15cm (PE) + 15cm (Fe); Num12: 115cm (Conc.); Num13: 5cm (Pb) + 30cm (Fe) + 20cm (PE) + 5cm (Fe) + 40cm (PE) + 10cm (Fe) + 5cm (Pb); Num14: 30cm (PE) + 40cm (Fe) + 30cm (PE) + 15cm (Fe); Num15: 5cm (Pb) + 25cm (Fe) + 30cm (PE) + 5cm (Fe) + 50cm (Conc.); Num16: 10(5cm (Pb) + 5cm(PE)) + 15cm (Pb); Num17: 40cm (Fe) + 20cm (PE) + 5cm (Fe) + 50cm (Conc.); Num18; 30cm (Pb) + 7×(5cm (PE) + 5cm (Pb) + 15cm (Pb); Num19: 20cm (Fe) + 30cm (PE) + 30cm (Fe) + 20cm (PE) + 15cm (Fe); Num20: 25cm (Fe) + 15cm (PE) + 6×(5cm (Fe) + 5cm (PE)) + 15cm (Fe); Num21: 25cm (Fe) + 15cm (PE) + 6×(5cm (Fe) + 5cm (PE)) + 15cm (Pb); Num22: 70cm (Fe) + 45cm (PE); Num23; 30cm (Fe) + 7× (5cm (PE) + 5cm (Fe)) + 15cm (Fe); Num24: 10×(5cm (Fe) + 5cm (PE)) + 15cm (Fe); Num25: 70cm (Fe) + 30cm (PE) + 15cm (Fe); Num26: 80cm (Fe) + 30cm (PE) + 5cm (Fe); Num27: 5cm (Pb) + 55cm (Fe) + 15cm (PE) + 35cm (Fe) + 5cm (Pb); Num28: 5cm (Pb) + 50cm (Fe) + 15cm (PE) + 40cm (Fe) + 5cm (Pb); Num29: 70cm (Fe) + 10cm (PE) + 10cm (Fe) + 20cm (PE) + 15cm (Fe); Num30: 5cm(Pb) + 40cm(Fe) + 5cm(PE) + 30cm (Fe) + 15cm (PE) + 15cm (Fe) + 5cm (Pb); Num31: 90cm (Fe) + 25cm (PE); Num32: 80cm (Fe) + 20cm (PE) + 15cm(Fe). Num1: 30cm (PE) + 7×(5cm (Fe) + 5cm (PE)) + 15cm (Fe); Num2: 45cm (Fe) + 3×(5cm (Fe) + 5cm (PE)) + 40cm (Conc.); Num3: 30cm (Pb) + 7×(5cm (PE) + 5cm (Pb) + 15cm (Pb); Num4: 5cm (Pb) + 55cm (Fe) + 15cm (PE) + 35cm (Fe) + 5cm (Pb); Num5: 75cm (Fe) + 40cm (Conc.); Num6: 5cm (Pb) + 50cm (Fe) + 15cm (PE) + 40cm (Fe) + 5cm (Pb).

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SSRF 前端区锯齿墙束流孔洞中子屏蔽的蒙特卡罗估算

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摘要 主要关于上海同步辐射装置 (SSRF) 储存环电子引发产生的韧致辐射和中子辐射的研究. 中子和光子经多种组合材料 (厚度在 5cm～115cm 之间) 屏蔽后的剂量特征由蒙特卡罗代码 MCNP 和 EGSnrc 估算得到; 蒙特卡罗计算表明, 单一的材料如铅, 铁和聚乙烯对高能中子是无效的生物屏蔽材料, 而组合材料如铅或者铁加聚乙烯和铅或者铁加混凝土被认为是屏蔽高能中子很好的组合材料. 铅铁等高 Z 材料加点包含有氢的低 Z 材料如聚乙烯是同时屏蔽高能中子和韧致辐射的一种比较好的组合材料选择.

关键词 MCNP EGSnrc 中子辐射屏蔽 同步辐射 SSRF

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