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Simulation of absorbed dose rate due to synchrotron radiation and shielding thickness for radiation safety at INDUS-2 using FLUKA

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Indus-2 is a 2.5 GeV electron synchrotron radiation source at Raja Ramanna Centre for Advanced Technology (RRCAT), India. 26 synchrotron radiation (SR) beam lines are planned in Indus-2 for various research applications, Out of 26 several beam lines are in operation and many are in installation stage. Due to intense flux of SR and low energy, the dose rate in the direct beam is high and there is a potential for high radiation exposure. Appropriate shielding hutches are needed to house the beam lines and protect the workers from the radiation hazard. Simulations were carried out using computer code FLUKA to find out the absorbed dose in water due to SR and required shielding thickness in the forward direction to reduce dose within acceptable limits. SR spectrum from Indus-2 in the range 4-100 keV was used for simulating absorbed dose and shielding thickness. It was found that the absorbed dose rate is of the order of 10^5 Gy/h for the design parameters of Indus-2 (2.5 GeV and 300 mA). Forward shielding thickness of 3mm lead was found to be sufficient to reduce the dose rate to acceptable level for continuously occupied area (<1μSv/h). The details of the simulation and results are presented in the paper.

Keywords: Synchrotron radiation, Shielding hutch, FLUKA

1 Introduction

Indus-2 is a 2.5 GeV, 300 mA electron synchrotron radiation (SR) source being commissioned at Raja Ramanna Centre for Advanced Technology (RRCAT), India. Critical wavelength of SR available at Indus-2 is ~2Å, in hard X-ray region. The span of energies available at the experimental station ranges from 4 to 100 keV however, the useful flux is limited up to 50 keV. In order to ensure safety of SR beam users and workers adequate shielding and safety system are to be incorporated. Usually SR beam lines are housed in properly designed beam line hutches comprising of optics hutch and experimental hutch[1]. Since the critical energy of SR photons is in the X-ray region, the experiments are performed in air. In order to evaluate the likely dose received by a worker exposed to direct SR and to assess the shielding requirement, Monte Carlo simulation[2] using FLUKA was carried out. The paper describes the details of the simulation and discusses the results obtained.

2 Simulation Details

2.1 Simulation of SR spectrum

The synchrotron radiation spectrum in the energy range 4-100 keV for a single 2.5 GeV electron bending through 5.5 m bending radius was generated using a Fortran program[3] developed by Alberto Fasso, SLAC. The Fortran program gives output in differential flux (d*N*/d*E*) per electron where *N* and *E* represent number and energy of photons, respectively. The generated spectrum was scaled to a factor of 10^{13} (equivalent number of electrons in Indus-2 storage ring at 300 mA). The SR spectrum generated for 2.5 GeV electron beam in Indus-2 using the Fortran program is shown in Fig. 1. At higher energies, the photon flux falls off rapidly (Fig. 1).

2.2 Simulation of absorbed dose rate due to direct synchrotron radiation

The geometry used for the simulation of SR dose rate is shown in Fig. 2. The SR spectrum shown in Fig. 1 is allowed to incident on water phantom of size (10 mm × 10 mm × 300 mm). The energy absorbed was scored along the width (300 mm) of the phantom in 100 bins (bin width of 3 mm) and dose rate was calculated.

The depth dose profile obtained in water phantom due to the incident synchrotron radiation spectrum is shown in the 'Results and Discussion' section.

2.3 Simulation of Shield thickness

The geometry used for the simulation of shield thickness for SR spectrum is shown in Fig. 3. The SR spectrum from the Fig. 1 is allowed to be incident on lead target having length and breadth of 10 mm each with thickness varying from 1 to 4 mm. The water phantom of size (300 mm × 300 mm × 300 mm) was placed after the lead target. The energy absorbed was scored along the width (300 mm) of the phantom in 100 bins (bin width of 3 mm). The water phantom size was increased to 150 mm in both lateral directions to take care of the Compton scattered photons and generated electrons from the lead target (in comparison with the simulation of absorbed dose due to direct incidence of SR spectrum).

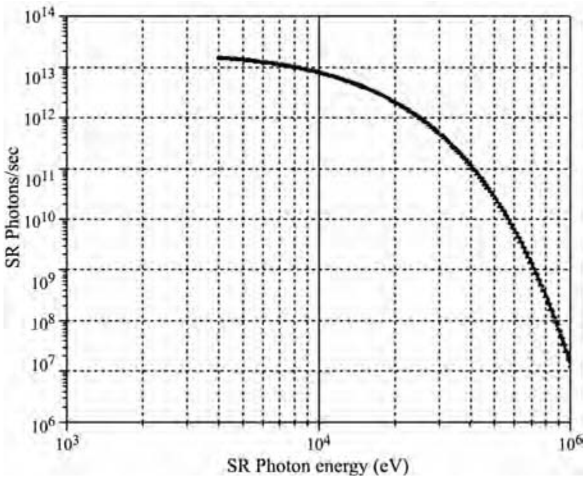

Fig.1 — Synchrotron radiation spectrum in Indus-2 (300 mA at 2.5 GeV)

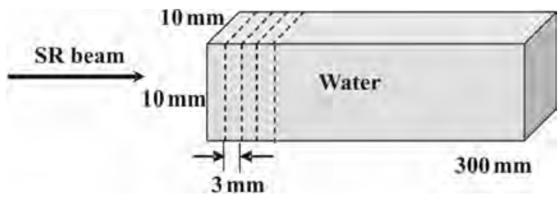

Fig. 2 — Geometry used for the simulation of direct Synchrotron Radiation dose rate simulation

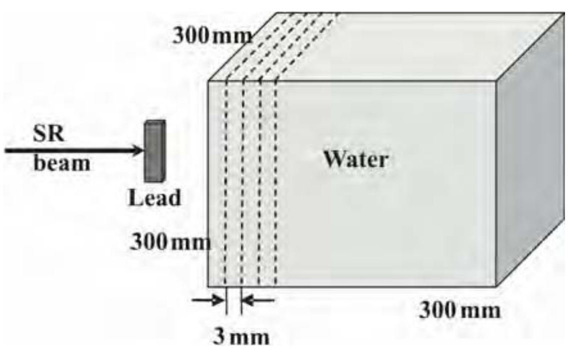

Fig. 3 — Geometry used for Shield thickness for SR spectrum

2.4 Scoring

USRBIN scoring was used in simulation for determination of absorbed energy in both the simulations (2.2 and 2.3). Electron and photon transport threshold are set at 1 keV using EMFCUT. The results from the USRBIN estimator are given in terms of GeV/cm^3-primary for absorbed energy. USRBIN output was converted to absorbed dose rate in Gray/h by using conversion factor, 5.77×10^9. The conversion factor, 5.77×10^9 has been derived for 300 mA stored electron beam current at 2.5 GeV in Indus-2. The simulation was carried out for 10^7 histories and 5 cycles run.

3 Results and Discussion

The simulated absorbed dose rate in (10 mm × 10 mm × 300 mm) water phantom due to incident SR spectrum is shown in Fig. 4. The absorbed dose rate is shown as a function of depth in water. The statistical errors found are less than 1% for all data points.

The simulated depth dose curve in Fig. 4 shows a surface absorbed dose rate of 1.12×10^5 Gray/h. SR being low energy photons, it gets attenuated significantly with the depth of water. Maximum energy deposition takes place in the first bin (3 mm) depth (considered to be the surface of the phantom). This indicates that the skin of an exposed person may get dose of the order of 10^5 Gray/h in case of accidental exposure to direct SR.

In order to prevent SR exposure, beam lines are to be housed in shielding hutches. Absorbed dose rate in water phantom after the lead target (Fig. 3) was calculated from the energy absorbed in each bin. Table 1 presents the surface dose rate obtained in 300 mm × 300 mm × 300 mm water phantom with respect to different lead thickness.

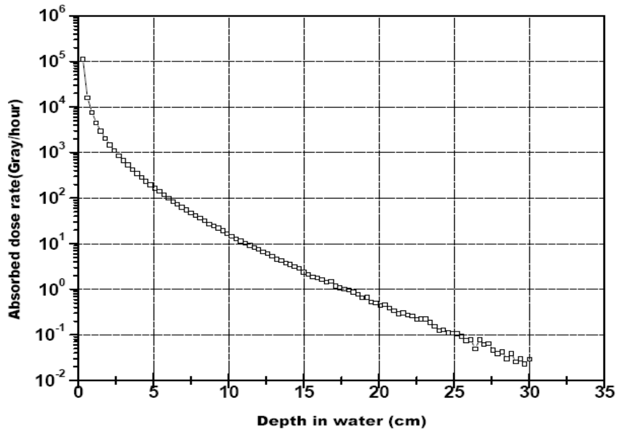

Fig. 4 — Absorbed dose rate in water phantom due to direct SR incidence

Table 1 — Surface dose rate in water after the lead target

Lead thickness (mm)	Surface dose rate in water (µGray/hour)
1	27.25
2	01.67
3	00.32
4	00.07

Significant reduction in surface dose rate in water phantom was observed as the lead thickness is increased from 1 to 4 mm. After a thickness of 3 mm lead, the surface dose rate in water phantom reduced to 0.32 µGy/h from 27.25 µGy/h. This dose rate is within permissible effective dose limit[4] of 1 µSv/h for normally accessible areas.

4 Conclusions

Using the Synchrotron radiation spectrum, maximum absorbed dose rate in water phantom was calculated. The lead shielding thickness required to reduce absorbed dose to permissible limit was also worked out. From the study, it is concluded that in case of Indus-2 SRS: (1) Maximum absorbed dose receivable by a worker during an accidental exposure in direct SR beam is ~10^5 Gy/h. (2) Pb shield thickness needed to reduce absorbed dose to less than 1 µGy/h is about 3 mm. (3) Adequate safety precautions are to be taken in order to avoid direct exposure to SR beam.

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