

# DESIGN OF RF DUCT SHIELDING FOR THE SPS-II 3 GeV ELECTRON STORAGE RING

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## Abstract

The Siam Photon Source II (SPS-II) is a fourth generation synchrotron light source designed to provide high brightness, low-emittance, high-energy electron beams for advanced synchrotron applications. SPS-II is equipped with a 150 MeV linear accelerator, a 3 GeV booster synchrotron, and a 3 GeV electron storage ring, enabling the production of high-quality synchrotron radiation for a wide range of scientific research fields. The 500 MHz RF system in the storage ring serves to replenish the energy lost by electrons due to synchrotron radiation. RF cavities generate oscillating electromagnetic fields at a specific frequency, accelerating the electrons each time they pass through the cavity. The RF ducts house the waveguides and transfer RF power to the RF cavities inside the storage ring tunnel. However, penetration in the storage ring tunnel may allow radiation within the shielding tunnel to leak outside the shielding. For this reason, the design of the RF ducts must be carefully considered. The FLUKA particle transport code is used to investigate the shielding. The results indicate that the radiation dose is below the design criterion, meeting the radiation safety standards.

## INTRODUCTION

The SPS-II synchrotron in Thailand is a proposed 3 GeV, 400 mA electron storage ring with a 327.6 m circumference. As electrons circulate, they lose energy via synchrotron radiation—a major limitation in high-energy rings. Without compensation, this leads to orbit shrinkage and beam instability. The RF system is essential for restoring lost energy, maintaining beam stability, and ensuring longitudinal synchronization. It provides acceleration, bunching, and energy compensation, and comprises RF cavities, power sources, LLRF controls, and cooling systems for stable operation [1].

SPS-II will employ a 500 MHz RF system using solid-state amplifiers (SSA) to deliver 400 kW to the beam. RF cavities will be installed in the tunnel near the transmitter room to improve efficiency. Power will be transmitted via short rectangular waveguides; each penetrating the shielding wall individually to minimize losses and ensure reliable energy delivery.

## METHODOLOGY

The dark current in an RF cavity refers to unintended electron emissions that can negatively impact accelerator performance. These emissions lead to various detrimental

effects, such as beam quality degradation, RF power losses, and material damage. Dark current electrons can generate X-rays when they collide with the cavity walls or other components within the accelerator. This phenomenon is especially significant in high-gradient accelerators, where strong electromagnetic fields can accelerate dark current electrons to relativistic speeds. The primary causes of dark current are field emission, thermionic emission, and multipacting. Field emission occurs due to the quantum tunneling effect, where electrons escape from the surface under high electric fields (MV/m) as described by the Fowler-Nordheim equation [2,3]. Thermionic emission happens when the cavity walls are heated to high temperatures, providing electrons enough energy to escape the surface, as explained by the Richardson-Dushman equation. Multipacting occurs when primary electrons impact a surface and cause secondary electrons to be emitted, potentially sustaining the dark current and contributing to RF breakdown. These phenomena can lead to significant operational challenges in RF cavities and must be addressed to ensure stable performance.

$$J = AT^2 e^{-W/kT} \quad (1)$$

where  $J$  is the current density,  $A$  is the Richardson constant,  $T$  is temperature,  $W$  is work function, and  $k$  is Boltzmann's constant.

For resonant secondary emission, secondary electrons are emitted when primary electrons impact a surface, which can lead to sustained dark current and potential RF breakdown. These are the effects of dark current. Furthermore, radiation is emitted when electrons lose energy. Due to the high-energy electron beam in the storage ring, electrons are decelerated or deflected by the electric field of an atomic nucleus or another charged particle.

The RF system of 500 MHz, six of a single-cell cavity is designed to generate a maximum cavity voltage of 2.5 MV. It is planned to be installed inside the machine tunnel. The tunnel shielding wall will be penetrated for waveguides of each cavity, also called an RF duct. This means that radiation inside the tunnel can be emitted through the RF duct.

To prevent radiation from the sources mentioned above, the FLUKA code, a computational tool for simulating particle transport and interactions with matter, is used to study the shielding design. The RF duct, with dimensions of 57 cm in width and 38 cm in height, is required to accommodate the waveguide at 238.56 cm from the floor. The shielding consists of 4 cm of lead and 6 cm of polyethylene for the exterior, while the interior shielding, designed to protect against radiation from each duct, is made of 3 cm of lead

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and 3 cm of polyethylene. The RF cavity is simplified as a cylindrical shape with a height of 30 cm, a radius of 20 cm, and a 4 cm thick copper wall. This simulation aims to estimate radiation transmission through the RF duct shielding in three cases:

- (i) A primary electron at 3 GeV interacting with the part of the cavity.
- (ii) A 700 keV dark current electron beam.
- (iii) X-ray radiation at 700 keV generated by the dark current electron inside the RF cavity.

The location of the RF cavity, string of four cavities, for SPS-II is illustrated in Fig. 1, and the simulation geometry of the RF duct shielding is demonstrated in Fig. 2.

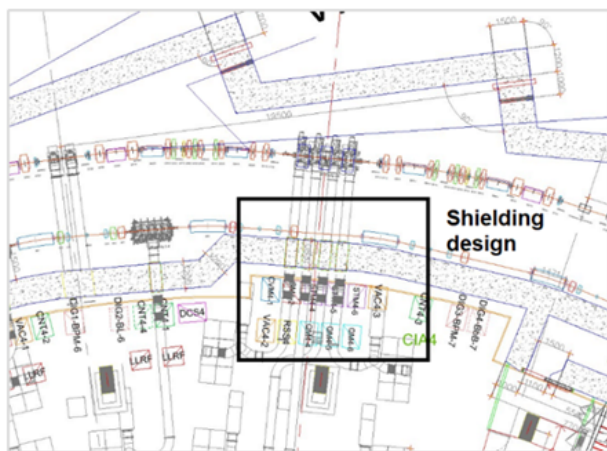


Figure 1: A technical schematic details of RF cavity installation inside the tunnel.

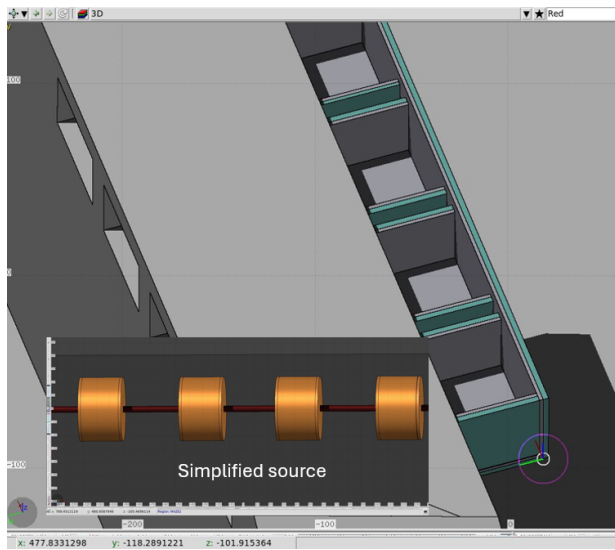


Figure 2: A 3D geometry of RF duct shielding design.

## RESULTS AND DISCUSSION

The investigation of RF duct shielding design was conducted using FLUKA simulation results to evaluate the ambient dose equivalent, expressed in pico-sievert per primary electrons. The focus of the simulation was on the radiation distributions from high-energy electron beams, specifically those of 3 GeV, generated within the RF cavity.

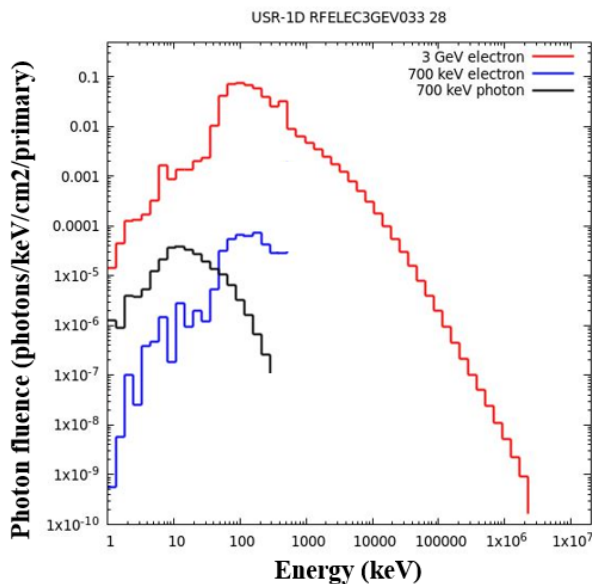


Figure 3: A comparison of photon fluence between the different sources.

Fig. 3 presents photon fluence as a function of energy (in keV) for 3 GeV electrons, 700 keV electrons, and 700 keV photons. The 3 GeV electrons produce the highest photon fluence due to strong Bremsstrahlung radiation. The 700 keV electrons yield lower fluence across a narrower energy range, while the 700 keV photons show the lowest fluence, mainly from secondary interactions [3]. These results highlight the significant influence of particle energy and type on photon emission characteristics.

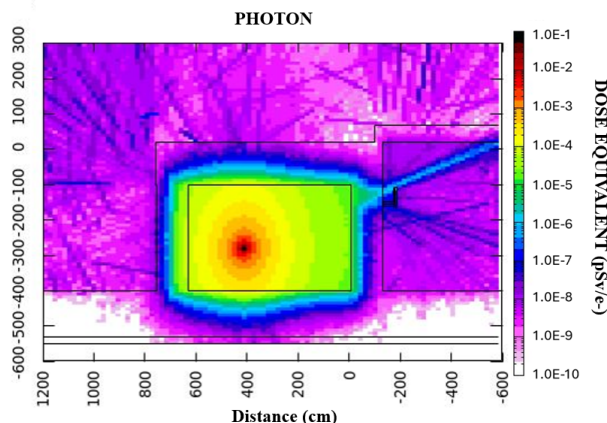


Figure 4: Photon distributions through RF duct shielding.

Figures 4 and 5 show photon and neutron distributions through RF duct shielding, demonstrating its effectiveness in attenuating radiation produced by high-energy electron interactions inside the RF cavity. The RF duct shielding effectively reduced radiation intensity, as confirmed by simulations. It deflected residual radiation toward non-occupancy areas. Radiation from 700 keV dark current electrons and photons was observed to be lower than that from higher-energy beams, indicating that the RF duct shielding is more effective at attenuating lower-energy particles.

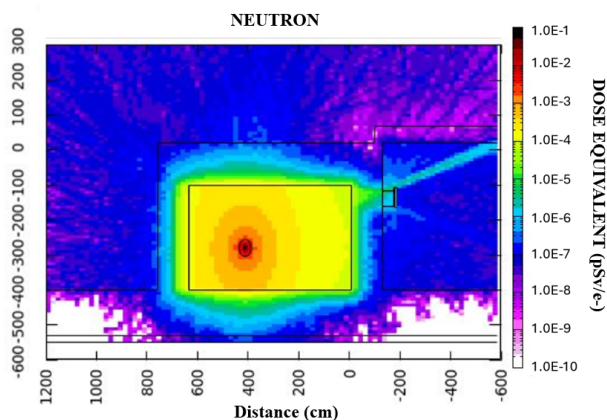


Figure 5: Neutron distributions through RF duct shielding.

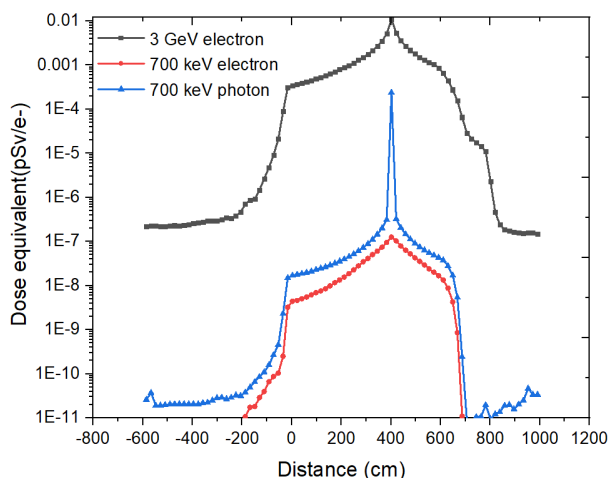


Figure 6: Dose equivalents through RF duct shielding.

This enhanced efficiency contributes to improved radiation protection in accelerator environments. As shown in Fig. 6, a comparison of dose rates from various radiation sources—such as photons, neutrons, and secondary particles provided valuable insights into their individual contributions to the overall radiation dose. The FLUKA simulation results emphasize the importance of a well-designed RF duct shielding system in minimizing radiation exposure. Such shielding helps protect personnel and maintain safe operating conditions, particularly in facilities using high-energy electron

beams. By effectively reducing radiation emissions, the RF duct shielding plays a critical role in ensuring compliance with radiation safety standards. These findings highlight the essential function of shielding in supporting long-term operational safety and protecting both workers and sensitive equipment in high-radiation environments.

The radiation shielding analysis focuses on the attenuation of radiation from RF duct shielding originating from various sources. To estimate the radiation dose, it was assumed that the annual stored beam loss amounts to  $7.43 \times 10^{15}$  electrons per year at a single point. A key factor in this analysis is the remaining radiation dose behind the shielding at a given distance. For a high-energy 3 GeV electron beam loss, the estimated radiation dose is  $0.743 \mu\text{Sv/h}$ .

In comparison, the radiation dose from a 700 keV photon beam is significantly lower, at below  $0.00186 \mu\text{Sv/h}$ . Additionally, radiation from the 700 keV electron beam is effectively blocked by the booster enclosure, as shown in Fig. 6.

## CONCLUSION

FLUKA simulations of the SPS-II RF duct shielding demonstrate its effectiveness in minimizing radiation exposure. The shielding reduces radiation from a 3 GeV electron beam to  $0.743 \mu\text{Sv/h}$ , while radiation from a 700 keV photon beam is as low as  $0.00003 \mu\text{Sv/h}$ . Radiation from the 700 keV electron beam is fully blocked. The combination of lead and polyethylene materials, along with well-placed RF cavities and waveguides, ensures low radiation transmission. This design meets safety standards and supports the SPS-II synchrotron's long-term, safe operation in high-energy environments.

## ACKNOWLEDGEMENTS

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