

# ФОТОЯДЕРНІ ПРОЦЕСИ У ВОЛЬФРАМОВОМУ МАТРИЧНОМУ КОЛІМАТОРІ ДЛЯ ПРОСТОРОВО-ФРАКЦІОНОВАНОЇ ПРОМЕНЕВОЇ ТЕРАПІЇ

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Metal matrix collimators are a practical approach for producing mini-beam fields for spatially fractionated radiation therapy. Earlier studies [1-3] demonstrated that tungsten provides compact attenuation and favorable peak-to-valley dose ratios. However, at photon energies approaching 25 MeV, photonuclear reactions in tungsten become significant and introduce secondary neutrons and activation effects that were not previously included in collimator optimization studies. The novel contribution of this work is the quantitative coupling of dosimetric performance (peak-to-valley dose ratio) with photonuclear neutron production and radiation-protection quantities within a unified FLUKA [4] simulation framework. This allows simultaneous evaluation of beam-shaping efficiency and secondary radiation hazards.

The FLUKA model used a 25 MeV photon beam incident on a modular tungsten matrix collimator. The simulation normalization corresponds to  $10^7$  primary histories per run, 10 runs, and 24 spawns, giving a total of  $N = 2.4 \times 10^9$  incident photons. For a  $1.5\text{cm} \times 1.5\text{cm}$  beam area, the incident photon fluence is  $1.0667 \times 10^9 \text{ cm}^{-2}$ . Neutron fluence was scored using spatial mesh tallies, and neutron spectra were obtained in the collimator, air gap, exit, and phantom regions. Absorbed dose in the silicon detector plane was derived from energy deposition and scaled to absolute irradiation. All FLUKA results were initially normalized per primary particle and subsequently scaled to the absolute irradiation conditions to obtain physically meaningful dose and dose-equivalent values.

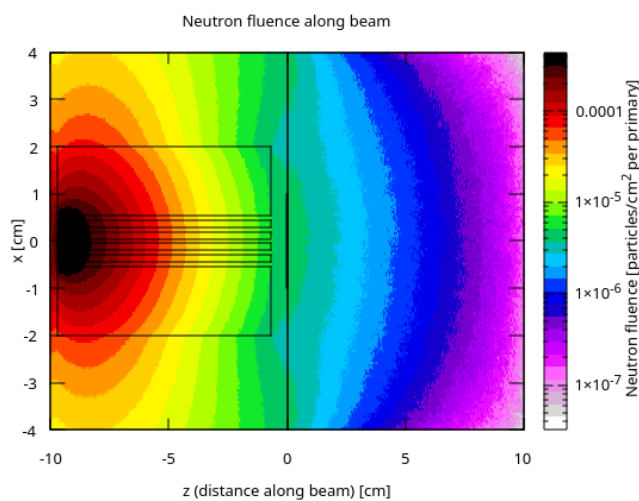


Fig. 1. Neutron fluence along the beam axis. The plot illustrates photoneutron production in tungsten and the decrease of neutron fluence through the 9 cm collimator length.

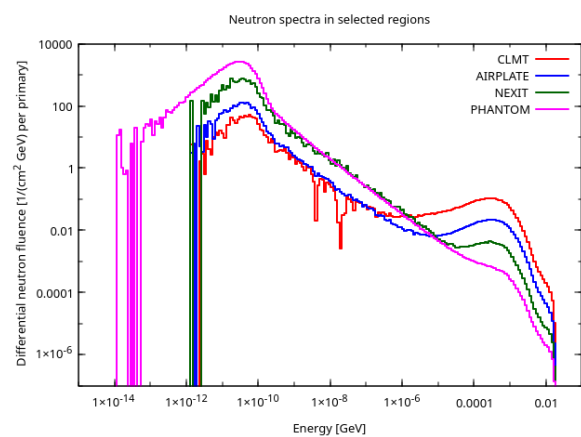


Fig. 2. Neutron spectra in selected regions used for dose-equivalent folding with ICRP 74 [5] coefficients.

Neutron ambient dose equivalent was calculated by folding differential neutron spectra with energy-dependent fluence-to-dose conversion coefficients. Photonuclear neutrons are generated primarily within the upstream tungsten volume and transported through the collimator channels and surrounding air. The longitudinal neutron-fluence distribution demonstrates that the collimator acts simultaneously as a neutron source and attenuator (Fig.1). A strong reduction in neutron fluence is

observed along the 9 cm collimator length, indicating substantial moderation, absorption, and scattering before reaching the exit region.

The folded neutron spectra show that the ambient dose equivalent is highest in the collimator region (102  $\mu\text{Sv}$ ), decreases to 3.55  $\mu\text{Sv}$  at the exit, and reaches 0.62  $\mu\text{Sv}$  in the phantom region for the same irradiation. This confirms that only a small fraction of photoneutrons contributes to downstream dose. The neutron contribution is primarily associated with valley and out-of-field regions. Even at relatively low levels, this component can increase the valley dose and influence the peak-to-valley dose ratio, while the primary photon-driven spatial modulation remains dominant. The detector-entry absorbed-dose profile) preserved a pronounced mini-beam structure. After scaling to  $N = 2.4 \times 10^9$  photons, the peak dose is  $6.16 \times 10^{-4}$  Gy and the valley dose is  $2.53 \times 10^{-5}$  Gy, yielding a peak-to-valley dose ratio of 24.4.

Photonuclear processes affect collimator performance through three main mechanisms: conversion of part of the photon field into secondary neutrons; increase of valley and out-of-field dose due to neutron penetration; and induced activation of tungsten and surrounding materials.

Although the photon beam retains strong spatial modulation, neutron production introduces an additional radiation component that must be considered in both dosimetry evaluation and radiation protection. Practical mitigation strategies include using the lowest photon energy compatible with treatment goals; minimizing unnecessary collimator thickness; implementing local neutron shielding (hydrogen-rich moderators combined with neutron absorbers); optimizing collimator geometry to reduce neutron leakage; performing neutron monitoring and activation control during operation.

FLUKA simulations demonstrate that tungsten matrix collimators maintain high spatial dose modulation at 25 MeV, with a peak-to-valley dose ratio of 24.4. However, photonuclear reactions produce secondary neutrons that contribute to valley and out-of-field dose and cause activation effects.

The main impact of photonuclear processes is not a degradation of photon beam shaping, but the introduction of an additional radiation-protection constraint that must be addressed through energy selection, geometry optimization, and shielding design.

### **Список літератури**

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- [3] I. E. Anokhin, V. M. Pugatch, and D. M. Ramazanov, "Matrix metal collimators studies for the spatially fractionated radiation therapy. Part III: Particle spectrums," 2022 IEEE NSS/MIC/RTSD, NSS-03-243.
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## **РЕЄСТРАЦІЙНА СТОРІНКА**

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### PHOTONUCLEAR PROCESSES IN A TUNGSTEN MATRIX COLLIMATOR FOR SPATIALLY FRACTIONATED RADIATION THERAPY

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