Assessment of absorbed dose distribution for the in vitro setup at the VITA facility

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The efficacy of Boron Neutron Capture Therapy (BNCT) is determined by the interaction between administered boron-containing compounds and biological tissues at the cellular level. The precision of physical absorbed dose measurement within the irradiated volume represents a critical factor for ensuring the reproducibility and reliability of in vitro study outcomes. In BNCT, the predominant contribution to the total absorbed dose is made by the boron dose, resulting from the energy released during the nuclear reaction $^{10}B(n,\alpha)^{7}Li$. Accurate determination of the absorbed boron dose constitutes a complex experimental challenge, effectively addressed via prompt gamma spectroscopy methodology. Indirect assessment of the absorbed dose relies on numerical simulation of neutron transport processes and their interactions with cellular suspension and boron-containing compounds. The proposed approach allows for the reliable determination of absorbed dose component distribution through indirect means, thereby considerably simplifying both the preparation and implementation of experimental studies.

The Budker Institute of Nuclear Physics SB RAS in Novosibirsk is recognized as the leading center for BNCT research and development in Russia, where the VITA (Vacuum Insulated Tandem Accelerator) neutron source has been successfully developed. Evaluation of the neutron field parameters generated by the VITA facility is performed utilizing Monte Carlo simulations within the Geant4 software environment. A detailed computational model of the facility's target section has been developed, including the output accelerator tube, frontal lithium target for neutron generation, backplate cooling system, and neutron moderator system. The simulation enables precise determination of both energy and spatial distributions of neutron flux intensities within the configuration designed for irradiation of small biological specimens at a proton energy of 2.05 MeV. The results demonstrate excellent agreement between calculated neutron flux intensity values and target specifications, ensuring feasible irradiation times for biological samples. Furthermore, the simulated relative energy release profiles in boron-enriched scintillators exhibit good agreement with experimental measurements.

The results of spatial distribution evaluation for absorbed doses in the VITA facility's *in vitro* setup have been presented for the first time, derived from Monte Carlo simulations in the Geant4 software environment. Assessments were made for two variants of the simulated system, which use moderators with different materials and geometric characteristics: a polymethyl methacrylate (PMMA) moderator with a diameter of 200 mm, and a polyethylene moderator with volumetric bismuth inclusions (Poly-Biz) with a diameter of 160 mm. Different thickness parameters of each neutron moderator were studied, and the best options were chosen considering the uniformity of cryovials irradiation and the boron absorbed dose to total dose ratio. These simulation results and the developed detailed model of the in vitro setup will enhance optimization of experimental planning procedures for in vitro studies at the VITA accelerator-based neutron source.

Acknowledgments

This research was supported by the Russian Science Foundation No. 24-62-00018, Advanced Combined Technologies of Neutron Capture Therapy Program, https://rscf.ru/en/project/24-62-00018/.

References

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