Experimental and computational studies for the design of a BNCT facility based on proton accelerator and Be target

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Introduction

The BNCT project for a clinical facility in Italy is based on a RFQ proton accelerator produced by INFN, delivering a neutron beam through the (p,n) reaction on a beryllium target. With an appropriate Beam Shaping Assembly (BSA) it can provide a suitable neutron beam for the treatment of deep-seated tumours. The design of the irradiation room requires also environment dosimetry and radioprotection evaluations. Preliminary studies in this context included experimental measurements on powders of the BSA material, and simulations of neutron activation and dosimetric quantities in the treatment room. New studies developing the previous research are here presented, concerning the effect of irradiation on the BSA material, its resistance to radiation damage, and the time evolution of induced activity. From the point of view of the patient activation during a treatment, the distribution of dose-rate around its body and how it evolves over time was estimated. Furthermore, new simulations were performed to evaluate the dose absorbed in the principal organs of the patient in different treatment positions.

Materials and Methods

Samples of densified aluminium fluoride (AlF_3), the main BSA constituent, were created by sintering process at University of Pavia, and irradiated at the research nuclear reactor TRIGA Mark II. Simulations of the treatment room were carried out with the Monte Carlo codes MCNP6 and FLUKA. The simulations were repeated changing the composition of the walls of the treatment room, to study the effect of the different materials on the quantities of interest. The BSA activation due to a clinical irradiation was simulated using the AlF_3 composition experimentally determined, and the time evolution of the residual activity was estimated. To study the absorbed dose in the patient, irradiations were simulated implementing an anthropomorphic geometrical model (MIRD phantom) with head, chest or knee in front of the beam-port. Particular attention was dedicated to the dose absorbed by the heart, due to the risk of radiation-induced cardiovascular diseases. Concerning the patient activation, a simplified geometrical phantom was simulated and the time-evolution of the dose around the patient due to residual radioactivity was evaluated.

Results

Aluminum fluoride has been fully characterized from the point of view of the response to radiations. The time-evolution of the BSA activity due to its activation has been thus estimated. From the dosimetric results, borated concrete is confirmed as the most appropriate material for the walls composition in the treatment room. This result is confirmed also when considering the activations induced by the treatments.

Conclusion

When designing a BNCT facility from accelerator, the optimization of the shieldings, the evaluation and minimization of the dose received by the organs outside the treatment area, and the control on the activation of the irradiated materials are closely interconnected. All these aspects are critical not only to design the facility but also to manage it during its operation. The beam is first designed based on the clinical optimization, but the tailoring must be done taking into account also the factors presented in this work.