Designing a liquid Fricke dosimeter for boron neutron capture therapy: performance assessment in contrast to the method of prompt gamma-ray spectrometry

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In recent years, boron neutron capture therapy (BNCT) has been undergoing active development and gradual transition from the experimental stage to clinical application. A distinctive feature of this method, fundamentally differentiating it from conventional radiation therapy, is the complex structure of radiation exposure comprising four independent components: boron dose, thermal neutron dose (or nitrogen dose), fast neutron dose, and gamma-ray dose [1]. Modern technological advancements have overcome the fundamental limitation that existed a decade ago - the inability to measure the first three dose components.

For measurement of total dose in the study was applied the method of chemical dosimetry based on Fricke iron sulfate solutions. Used two variants of solutions: standard and modified by addition of sodium tetraborate. Composition of both types of dosimeters underwent optimization. For this purpose was introduced xylenol orange, which performed the function of complexing additive. The calibration procedure of the measurement system was performed using spectrophotometric methods.

The developed Fricke dosimeter combined with prompt gamma-ray spectrometry was applied in the treatment of a domestic cat with a spontaneous tumor. This comprehensive approach enabled determination of the absorbed dose in both tumor and healthy tissue. Irradiation was performed using the VITA accelerator-based neutron source [2].

For total dose measurement, a modified Fricke liquid dosimeter was used. After irradiation, the solution was analyzed using a spectrophotometer. Linear approximation of spectrophotometric data allowed determination of the total equivalent dose, which was 35 Gy-eq.

Simultaneously, prompt gamma-ray spectrometry was performed: during cat irradiation, an HPGe gamma-ray spectrometer measured the energy spectrum of photons emitted from the irradiated object. The detector registered 478 keV photons produced by the $^{10}B(n,\alpha)^{7}Li$ reaction, enabling evaluation of boron concentration in tumor and healthy tissues.

In the total Fricke dosimeter dose of 35 Gy-eq, the presence of boron at 26 ppm resulted in a dose of 26 Gy-eq, while the remaining 9 Gy-eq were from the other three dose components. Considering the relative biological effectiveness (RBE) coefficients of 3.2 for fast neutrons, 3 for thermal neutrons, and 1 for photons, the dose from non-boron components was 6.5 Gy. Prompt gamma-ray spectrometry revealed decreasing intensity of the 478 keV line during irradiation, indicating reduction of boron concentration in tissues. Based on the number of registered fundamental $^{10}B(n,\alpha)^{7}Li$ reactions and the assumed 3:1 ratio of boron concentrations in tumor versus healthy tissue [1], dose components were calculated. In tumor tissue, the boron dose was 16.4 Gy, with other components contributing 6.5 Gy. The total equivalent dose was 23 Gy. In healthy tissue, the boron dose was 5.5 Gy, with other components contributing 6.5 Gy. The total equivalent dose was 12 Gy.

The combined application of Fricke dosimetry and prompt gamma-ray spectrometry demonstrated good consistency in assessing absorbed dose during BNCT, leading to the conclusion about the feasibility of their joint use for treatment planning and evaluation of BNCT results.

References

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