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A Dynamic Phantom Simulating Biokinetics for Nuclear Medicine Device Testing

In nuclear medicine, the development and validation of innovative detection systems and treatment strategies require rigorous testing under controlled conditions before clinical implementation. Traditionally, these evaluations rely on anthropomorphic phantoms, which aim to mimic the complexity of human anatomy and radiotracer distribution. However, most available phantoms are static, representing only a snapshot of the radiopharmaceutical distribution rather than the dynamic processes occurring within the body. This presents a significant limitation, as nuclear medicine treatments often involve time-dependent variations in radionuclide concentration due to both physical decay and biological clearance.
Biokinetics, the study of radiopharmaceutical distribution, metabolism, and excretion over time, plays a crucial role in optimizing personalized treatments, especially for theranostic applications where both diagnosis and therapy are integrated. The absence of phantoms capable of simulating biokinetic processes limits the ability to accurately test and refine new detection technologies, dosimetry models, and treatment planning methodologies. Without dynamic models, researchers must rely on theoretical simulations or in vivo studies, which can be costly, time-consuming, and ethically challenging.
Addressing this gap, the development of a dynamic phantom capable of replicating both the physical decay and biological washout of radionuclides is essential. Such a system would enable a more realistic evaluation of nuclear medicine devices, leading to improvements in imaging techniques, radiation dose optimization, and patient-specific treatment strategies. This study presents the design, implementation, and testing of a novel dynamic phantom, which incorporates a dilution mechanism to simulate organ clearance, allowing for a more accurate representation of physiological processes in nuclear medicine applications.
To test in realistic conditions the WIDMApp [Morganti et al. Med. Phys. 2021] detection system prototype for internal dosimetric study, a phantom mimicking biokinetic behaviours was realizied based on the NEMA-IEC body phantom. Two of the spheres were substituted with 3D-Printed modified spheres connected to a peristaltic pump. An Arduino-based system controlled the pump to vary the activity concentration in the spheres and to simulate biological clearance.
Tests were conducted with radionuclides used for nuclear medicine (177Lu and 99mTc) and varying the activity concentration with diluting speeds from a drop of water every 15s to a drop every few minutes. The WIDMApp sensors (p-terphenyl crystal and 2x2 C-series SiPM array, with the dedicated electronics), were tested in the monitoring photon emitted from the spheres by recording the particle detection rate from different spatial points. A Polimaster PM1610B dosimeter, used as reference, completed the experimental set-up.
Different decay constants were observed, resulting as the sum of the effects due to the physical decay and the emitting sphere's wash-out. The WIDMApp prototype proved to be effective: the results were comparable with the ones from the commercial dosimeter.
In conclusion, we have demonstrated that the development of a dynamic system that simulates both the physical decay and the biological organ wash-out is possible. Such a phantom could be used to test different nuclear medicine devices in realistic conditions.

Workshop topics

Applications

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