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A modular Geant4 framework for rapid beam shaping assembly design for neutron capture therapy

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Accelerator-based neutron sources (ABNS) are reviving interest in neutron-capture therapy (NCT) for cancer treatment. However, each facility needs a custom beam-shaping assembly (BSA) to tailor the neutron spectrum, flux, spatial profile and gamma contamination. We have developed a modular, macro-driven Geant4 framework that accelerates BSA prototyping and adaptation across facilities.

Our framework allows users to configure beam components - reflector, moderator, filter and collimator - at run-time from declarative macros. Facility-specific source terms (energy, current, reaction and phase-space files from dedicated target simulations) are used to define injected primaries. Built-in scorers report standard NCT beam-quality indicators - epithermal/thermal flux, fast-neutron and contamination at phantom entrance, beam uniformity.

We follow a validation-then-adapt workflow: (1) reproduce published BSA geometries that meet IAEA-style beam criteria to establish baseline fidelity; (2) substitute site-specific source terms for two systems: ANSTO's ANTARES 10 MV tandem accelerator and an RFQ linac driven lithium neutron source at Brookhaven National Laboratory; and (3) iteratively adjust geometry under facility constraints (footprint, shielding, available materials) to approach target figures of merit. We will present preliminary designs and sensitivity analyses for both sites, together with a roadmap for experimental characterisation.

By making geometry, physics lists and scoring fully declarative, the framework improves reproducibility, shortens design cycles and provides a common basis for cross-facility comparison of NCT beam options.

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