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Validation of Geant4 fragmentation for broad beam heavy-ion therapy

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Heavy-ion therapy (HIT) is a growing cancer treatment modality due to its dose sparing and high biological effectiveness. However, a major challenge in heavy-ion therapy is nuclear fragmentation, where primary ions break into smaller particles, resulting in complex secondary radiation fields. Monte Carlo simulations are commonly used to study the secondary radiation field, such as to estimate secondary cancer risk for healthy tissue, making it crucial to know how Monte Carlo models perform against experimental measurements. Several comparison studies have been performed for HIT, though these have mainly focused on narrow-beam geometries, however, clinically the treatment area of the beam will typically be much larger, which may result in a significant difference in Monte Carlo models.

This study compared experimental 12C and 20Ne ion broad beams, with 100 mm diameter, against the Monte Carlo toolkit Geant4. Additionally, a 12C ion pencil beam, ~ 2 mm sigma, was also compared to see if any systematic differences occur between the two beam sizes for the models. The models evaluated in Geant4 against experimental measurements were the: BIC, INCL, QMD and LiQMD.

For the 12C ion broad beam, the LiQMD model agreed the best with experimental measurements, achieving a mean percentage error of less than 20% for all secondary fragments, except for lithium. Similarly, the LiQMD physics constructor also performed the best for the 20Ne beam with the exception of the lithium, carbon and nitrogen fragments. For the 12C narrow beam, the fragmentation models produced smaller mean percentage errors with experimental data than the broad beams. This discrepancy was primarily due to the model's difficulties in accurately replicating the angular distributions of the fragments. Notably, the LiQMD constructor exhibited the lowest percentage errors in modelling the angular distributions for the narrow beam, therefore confirming the importance of angular distributions in broad beam simulations.

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