Validation of Geant4 Fragmentation for Heavy Ion Therapy

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Introduction: ^{12}C ion therapy has had growing interest in recent years for its excellent dose conformity. However at therapeutic energies, which can be as high as 400 MeV/u, carbon ions produce secondary fragments. For an incident 400 MeV/u ^{12}C ion beam, ~70% of the beam will undergo fragmentation before the Bragg Peak (BP). The dosimetric and radiobiological impact of these fragments must be accurately characterised, as it can result in increasing the risk of secondary cancer for the patient as well as altering the relative biological effectiveness. This work investigates the accuracy of three different nuclear fragmentation models available in the Monte Carlo Toolkit Geant4, the Binary Intranuclear Cascade (BIC), the Quantum Molecular Dynamics (QMD) and the Liege Intranuclear Cascade (INCL++). The models were benchmarked against experimental data for a pristine 400 MeV/u ^{12}C beam incident upon a water phantom [1].

Materials and Methods: Using version 10.2p02 of Geant4 a mono-energetic ^{12}C 400MeV/u pencil beam with an energy sigma of 0.15% and a FWHM of 5 mm was incident upon a variable thickness of water with an area of 50×50 cm^2 and thicknesses of: 59, 159, 258, 279, 288, 312 and 347 mm.

Results: Fragment yields are shown in figure 1, it can be seen that the models vary significantly from one another for each element. QMD-F (QMD with frag option enabled) was seen to give the best overall agreement with experiment for lighter elements with it performing the best for H and He, BIC reproduced the best for Li and B while QMD reproduced Be the closest. Example angular and energy distributions are shown in figure 2, QMD-F is not included since they did not differ from the default QMD results. INCL++ was seen to reproduce experimental angular distributions the best with the exception of H, where QMD performed the best. For energy distributions INCL++ was seen to perform the poorest of the three models with it routinely having energy distributions shifted to lower energies compared to the other models. BIC and QMD were seen to perform very similar to one another for both the angular and energy distributions, with QMD performing slightly better out of the two. QMD-F again did not differ for energy distribution compared to QMD.

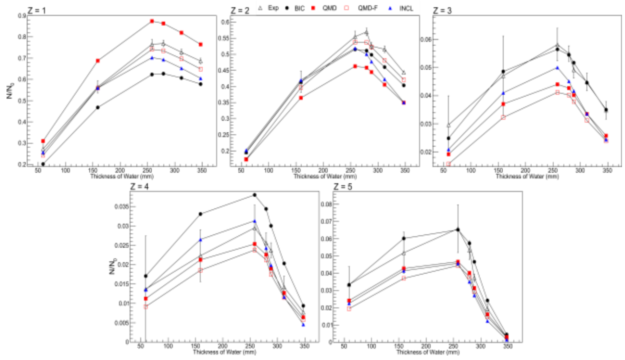

Figure 1: Fragment yields for the different models

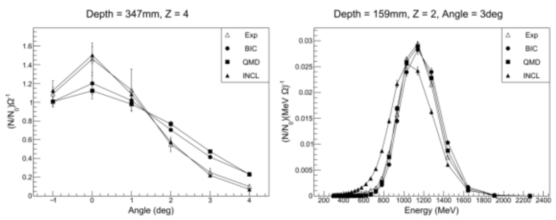

Figure 2: Left: An example angular distribution of the fragments. Right: An example energy distribution of the fragments.

Conclusion: Using Geant4.10.2p02, fragmentation of a mono-energetic 400MeV/u ^{12}C beam in water was benchmarked using the: BIC, QMD and INCL++ models. Fragment yields were seen to vary significantly from model to model, with QMD-F giving the best overall agreement. Angular distributions was best reproduced with INCL++ and energy distributions were worst using the INCL++, BIC and QMD performed similar to one another for the angular and energy distributions, with QMD performing slightly better.

Acknowlegdments: This research is supported by an Australian Government Research Training Program (RTP) Scholarship.

References:

[1] E. Haettner et al., "Experimental study of nuclear fragmentation of 200 and 400 MeV/u 12 c ions in water for applications in particle therapy," *Physics in Medicine and Biology*, vol. 58, no. 23, p. 8265, 2013.