Proton Radiography study using a passive scattered beam

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The use of high-energy proton beams enables to delivering high doses to target volumes, while sparing organs at risk compared to X-ray radiotherapy. However, the protons advantages cannot be fully exploited because the range (i.e the stopping powers) of protons in matter is not accurately known. Indeed, the proton stopping powers are obtained by an empirical conversion of X-CT Hounsfield Units that leads to systematic errors in proton range calculation. Several publications demonstrated that proton imaging was feasible and could be used to directly obtain proton stopping powers. However, the main drawback of p-CT or proton radiography (p-RG) is the limited spatial resolution, induced by the multiple Coulomb scattering of protons with nuclei.

We investigate a first approach in proton-radiography with our “low”-energy proton beam (65 MeV) passing through a small phantom (2.2 x 2.2 x 2.2 cm\textsuperscript{3}). An EBT3 radiochromic film perpendicular to the beam axis was used as a detector system to acquire a projected image of the phantom.

The first method consists in modulating the proton beam energy using a modulator wheel, to obtain a well-defined depth dose curve (DDC). When the polyenergetic beam crosses the phantom, the film detector measures a dose map. The dose response of the detector system was calibrated as a function of beam penetration depth that enables a correlation with the protons water equivalent path length to be obtained. Initially proposed by Koehler et al. in 1975, this method consists in modulating the beam energy in such a way that a linearly decreasing signal dose versus depth of penetration was produced in the detector system. Adjusting the depth dose curve to the water equivalent path length of the phantom allows to provide a higher contrast resolution, which is induced by the steeper slope of the DDC. This technique requires knowing “a priori” the size and the composition of the phantom, which are generally unknown.

The new proposed method consists in performing several monoenergetic radiographies, in a large range of energies, and analyze the set of measured images to build a resultant radiography with a maximized contrast. This method is defined as a “dynamic mode”, and is very different from the “integrated mode” explained above. Indeed, in the “integrated mode”, all the monoenergetic radiographies are “imprinted” on the detector and produce a integrated dose map.

In this work, we will use the Monte Carlo code MCNPX v2.5 to simulate the performance of our imaging device and to compare the calculated radiography with the measured radiography of our different imaging methods. The study is particularly focused on the image parameters: calculated/measured water equivalent path length traversed by the protons, spatial resolution, and contrast.

This work aims at highlighting the potentiality and feasibility of p-RG, and later p-CT, based on the available low-energy proton beam in Nice (France), with the MEDICYC machine as preliminary study. The study will be extended at high energy and for a pencil beam scanning delivery when the 230 MeV IBA/PROTEUS-ONE accelerator will be available at the Centre Antoine Lacassagne in Nice.