# Carbon beam dosimetry in bony tissue inhomogeneties: TRiP98 validation with experimental measurements

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Recent Measurements of the attenuation of a therapeutical carbon beam in bone-like materials [1] showed that the experimental values are slightly higher than the theoretical predictions obtained with a simple density scaling of measurements in water. In TRiP98, the heavy ion treatment planning system developed at GSI [2], the interaction between primary radiation and tissue is modeled from experimental data measured in water and rescaled to all other biological materials. As the attenuation experiment showed, this approximation is not accurate enough for materials whose elemental composition besides density deviates significantly from water.

The influence of this discrepancy on the dose profile has to be investigated in order to assess the accuracy of the treatment planning. The dose inhomogeneity predicted by TRiP98 at the interface between water and bone targets was investigated and measured at the Heavy Ion Therapy center (HIT) in Heidelberg, Germany. The inhomogeneity region is obtained by shooting the beam in a composite target so that the particles pass partly directly through water and partly through a layer of bone before entering water. The dose spikes are induced by two different effects: a macroscopic one due to the finite size of the pencil beam and in addition a microscopic one due to the scattering of the particles at the interface. How exactly the latter influences the dose inhomogeneities is not completely understood yet and a further investigation is needed.

## Experimental setup

For the experiment, a water phantom was exposed to a carbon beam for irradiating a tumor volume of 5x3x3 $cm^3$ placed at a depth of 10 cm. A scheme of the experimental is shown in Fig. 1.

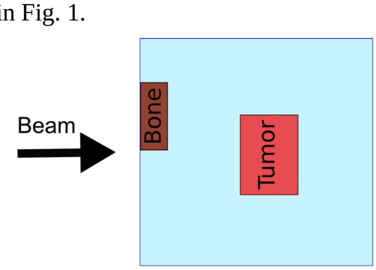


Figure 1: Scheme of the experimental setup.

The 3D treatment plan was optimized by TRiP98. The inhomogeneity region was obtained by equipping the water phantom with different bone targets at beam entrance channel. The measurements were repeated with two types of target: 1 cm thick compact bone (Gammex RMI 450) and a multilayer composed by 2 pieces of compact bone, 1 cm each, separated by 1 cm of spongious bone (Gammex RMI 456). Measurements without bone target were collected as a reference. The dose profile was measured with thermoluminescence detectors of the type TLD-700 ($^7$LiF:Mg), Pin-Point Ionization Chambers and X-ray dosimetric films (Kodax X-Omat V). The detectors were placed at several depths along the beam direction and in the perpendicular plane to understand the dose contributions over the whole treatment area, especially nearby the critical areas, i.e the bone target and the tumor volume.

## Results

The lateral and depth-dose profiles measured with the Pin-Point Ionization Chambers show differences when compared to the values predicted by TRiP98 (Fig. 2). Two effects can be identified in the comparison. First of all, only the data points measured in the pure water pathway fit perfectly to the TRiP98 calculation. The values collected in the region containing the bone target are smaller than the predicted data, which is in agreement with the trend showed by the attenuation measurements. The other effect is the presence of dose spikes at the interface between the bone target and water. This effect is patently reproduced by TRiP98 and can be clearly seen in Fig. 2.

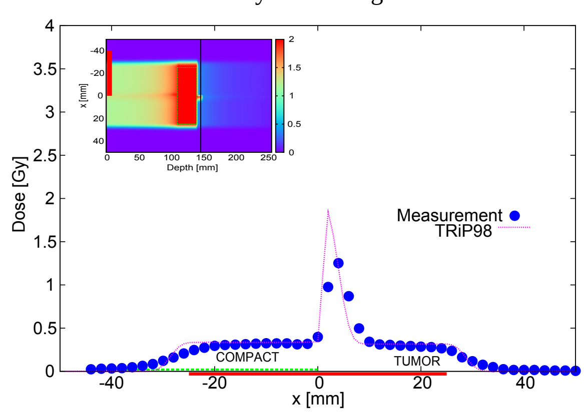


Figure 2: Dose distribution measured with the Pin-Point Ionization Chambers at a water depth of 146.3 mm directly behind the tumor volume (Longitudinal cut-line shown in the coronal plot inset

## References

[1] A. Eichhorn et al., GSI Scientific Report (2011)
[2] M. Krämer et al., Phys. Med. Biol. 45, 3319 (2000)