Formation of a Spread Out Bragg Peak at the Vertical Beamline ◇

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1. Introduction

Radiobiological research with proton beams is very important to obtain information for optimizing the treatment modality such as to induce highest injury in human tumors with maximum healthy tissue sparing.
In Italy a study has started to investigate the response of pigmented skin melanoma of mice to photodynamic therapy (PDT) and boron neutron-capture therapy (BNCT). This animal model appears to be well suited to study proton-treatment effects too. The study aims at assessing the dose range needed to induce the disappearance of the tumor by means of morphologic, biochemical and cell-kinetic analysis.
An experiment is planned, in which B16 melanoma cells are inoculated under the skin of mice. After a five-day growing period the tumor will be irradiated with doses up to 25 Gy in a single session. The tumor growth is measured every day and compared to non irradiated control mice. Histological and biochemical analysis of the tumor and control tissue will be performed at the University of Florence.

2. Depth-dose distribution

For such experiments a beam modification has to ensure that the entire tumor volume will be irradiated uniformly. This means that the Bragg peak has to be spread out. In a usual passive beam modulation technique the transformation of a sharp Bragg peak into an SOBP (Spread Out Bragg Peak) is accomplished using absorbing material in the beam path.

Accurate depth-dose measurements in water are very difficult due to the short range of protons with $E_{max} \approx$ 26 MeV of about 6 mm . In order to get reliable depth-dose distributions for these relatively low energies, a Monte Carlo program was written, based on the data published in [1]. In addition a program was developed which is based on an analytical approximation of the Bragg curve recently published in [2].

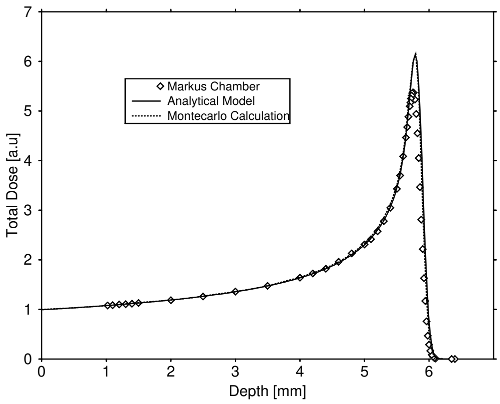

Fig. 1: Comparison of Monte Carlo simulation, analytical model and experiment. Each curve is normalized to the plateau value at $E_0 = 23.85$ MeV

To verify our calculations experimentally we used a watertight commercial ionisation chamber, which is in clinical use as a standard dosimeter. A comparison between calculations and measurement is given in fig. 1. The agreement between the calculations and the experimental data is very good for the whole plateau region. The experimental underestimation of the calculated dose at the distal falloff of the Bragg peak region can be understood taking into account the finite size of the cylindrical ionisation chamber (6 mm diameter, 2 mm high). Further experiments with different beam properties are in progress.

3. Design of the range modulator

To obtain a given SOBP in a water phantom, an initial set of semimonoenergetic proton beams were combined by minimizing the following expression for N data points:

$$\sum_{j=1}^{N} \left[\sum_{k=1}^{M} D_k(z_j) \cdot \gamma_k - D_{mod}(z_j) \right]^2 = \min$$

where $D_k(z)$ are the calculated doses in a water phantom at deph z, for M individual proton beams entering the phantom. γ_k are the sought weighting factors for the individual dose distributions to form the SOBP $D_{mod}(z)$.

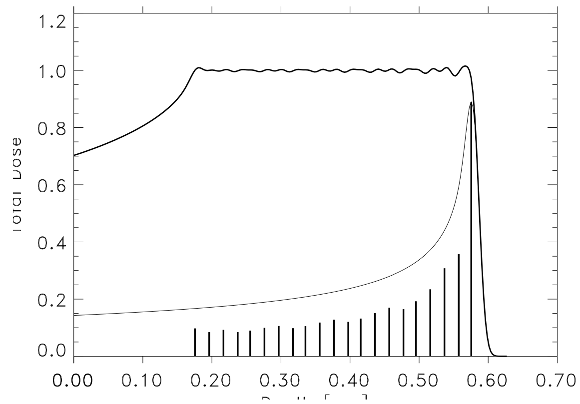

Fig. 2: Calculated curve for a 4 mm flat-top range modulator (normalized to unity). The thin line shows the unmodulated Bragg curve. The thick line shows the modulated curve. Also shown are the weightings of the shifted Bragg curves.

An example of a calculation is shown in fig. 2. For this particular case, 20 shifted peaks were employed using 0.2 mm spacing, corresponding to the waterequivalent thickness of Plexiglass. In practice we want to use a rotating, fan-shaped, stepped absorber to sweep the Bragg peak through the extended target volume. The weighting factors correspond to the opening angle of each step. A modulator wheel is under construction.

References

[1] International Commission on Radiological Units and Measurement. Stopping Powers and Ranges for Protons and Alpha Particles. ICRU Report 49, 1993

[2] T. Bortfeld, *An analytical approximation of the Bragg curve for therapeutic proton beams*, Med. Phys. **24** (1997) 12

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