In-Body Stray Neutrons Produced in Carbon and Proton Radiation Therapy

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Abstract— *It has been revealed that a significant amount of secondary neutrons are produced during carbon and proton radiation therapy. Thus, the study of secondary neutrons due to their high linear energy transfer can be considered as of vital importance. Therefore, the objective was to study the secondary neutrons production just from the patients (water phantoms) for ^{12}C and proton beams. Furthermore, the study ventures to discover the manner in which the stray neutron equivalent dose per therapeutic dose (H/D) vary with distance for different energies for ^{12}C and the possibility of identifying a simple relationship to calculate H/D at different distances for different energies. Although there is no simple dependence of H/D Vs Depth inside the body, a higher H/D from ^{12}C beams compared to Proton beams was discovered. This particular study was conducted utilizing FLUKA Monte Carlo simulation package.*

Keywords— Carbon Therapy, Proton Therapy, Stray Neutrons, FLUKA

I. INTRODUCTION

Carbon radiation therapy and proton radiation therapy are intensively investigated areas in medical physics. A large number of people are benefiting from these two treatment methods, and yet, they are still in their early stages of development (especially carbon therapy). The study secondary neutron production from these two treatment methods has been considered recently (Zheng *et al* 2007) as a high priority because of the large linear energy transfer of neutrons, thus affect adversely on healthy tissues and organs. There are also suspicions that these stray neutrons might increase the risk of secondary cancers (Rui Zhang *et al* 2010, Chaudhri *et al* 2007, 2006). Although several studies of the stray neutron are already available (Phillip J Taddei *et al* 2009, Newhauser *et al* 2009, Fontenot *et al* 2008, Gunzert-Marx *et al* 2008), the secondary neutron production from the patient himself has not been thoroughly investigated (Basit S Athar B and Harald Paganetti 2009, Phillip J Taddei *et al* 2009). This study is mainly concerned with the stray neutron dose equivalent per therapeutic dose (H/D) from the patient himself, and with the comparison of H/D encountered in ^{12}C and proton radiation therapies.

II. METHOD AND MATERIALS

Monte Carlo simulations were carried out using FLUKA code (FLUKA). The first part of this study compares the H/D values from ^{12}C and proton inside and outside the water phantom. An annular energy beams with a radius of 7.5 mm was used. The geometry of the water phantom used was $20 \times 20 \times 30$ cm^3 (X, Y, Z respectively) (G Martino *et al* 2010). Previously, it has been found that for protons the highest neutron dose equivalent occurs along the beam axis (Dowdell *et al* 2009, Yuanshui Zheng *et al* 2009). Our goal was also to find the maximum H/D. Therefore our calculations were carried out along the beam axis (Z axis). Inside the phantom measurements were taken every 5 cm from 2 to 27 cm depths. Outside the phantom, measurements were taken at 35, 50, 75, 100, 150, and 200 cm (figure1). These measurements were taken from the beginning of the water phantom. The sensitive volumes were $5 \times 5 \times 10$ mm^3. Outside the phantom the material considered was air (N_2, O_2, Ar, C).

To calculate the energy deposited form the neutrons, we used the “AUXSCORE” card combined with “USRBIN” card in the FLUKA code. The “AUXSCORE” card will filter the energy scoring of the “USRBIN” card to only the energy that is deposited by neutrons. To obtain the fragmentation tail from ^{12}C, we used “HADROTHE” default and we included the “PHYSICS” card with

“SDUM = EVAPORAT”, and FLUKA code was linked to DPMJET library.

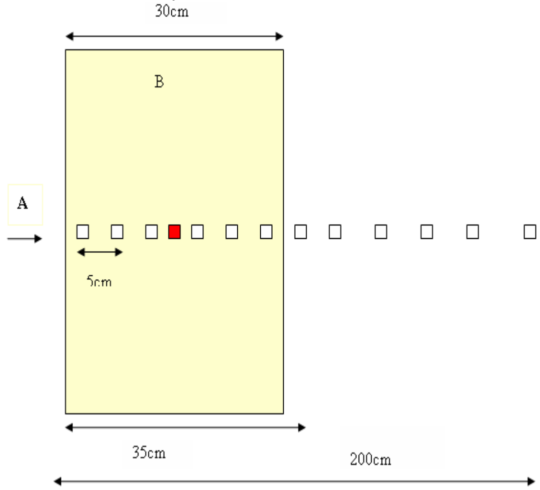

Figure1. Simulation Design to calculate neutron H/D (note, the diagram is not to scale): A) pencil beam, B) water phantom. The small boxes denote the detectors and the red box is the location of the iso-center.

III. RESULTS

To verify the computer simulation from FLUKA, the simulated results were compared with experimental results obtained by GSI Darmstadt, Germany. The results of our computer simulations are shown in Figure 2. They seem to agree very well with the analog experimental results of Schardt *et al* 2010. Simulated results for ^{12}C exactly tally with the experimental result, giving a Bragg peak at 12.6 cm. However, for protons, the simulated Bragg peak from 131.46 MeV/u (the energy used in Schardt *et al* 2010) occurs at 12.4 cm. Therefore, to get a one to one comparison, we had to use a proton beam with energy 133MeV/u.

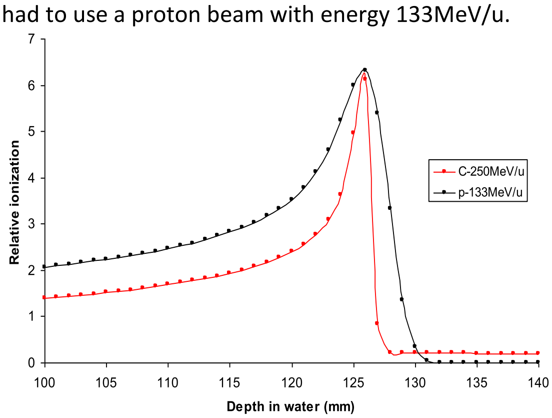

Figure 2. Comparison of simulated Bragg curves for protons and ^{12}C ions (normalized to the same peak height).

It was found from computer simulations that protons with 200 MeV/u and ^{12}C with 384 MeV/u have the same range in water (25.6cm). Calculations were carried out using these two energies for protons and ^{12}C to compare H/D. It was clear from the results that a slightly higher neutron dose equivalent per therapeutic dose occurs during ^{12}C therapy as compared to proton therapy. Figure 3 shows the H/D vs. depth inside the water phantom, and figure 4 shows the H/D vs. depth outside the water phantom. Although there is no obvious relation between H/D vs depths inside the phantom, Figure 4 clearly shows a linear dependence in log-log scale of H/D vs. depth outside the water phantom, indicating a power law.

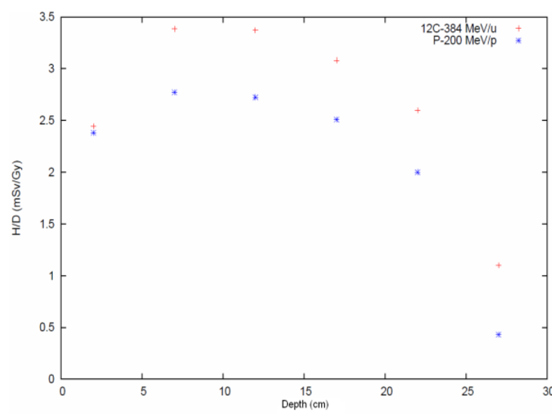

Figure 3. H/D as a function of depth inside the water phantom along the axis of the beam for ^{12}C and proton beams.

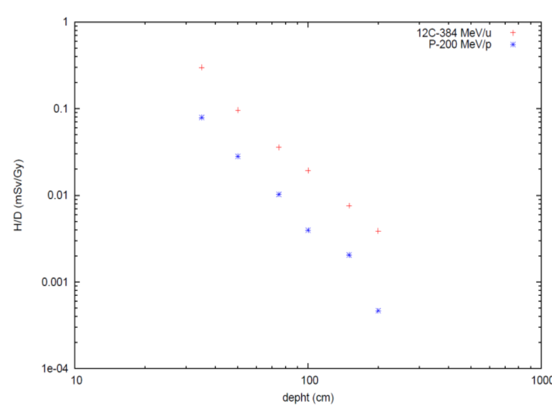

Figure 4. H/D as a function of depth outside the water phantom along the axis of the beam for ^{12}C and proton beams (in log-log scale).

IV. CONCLUSION

For this project we used the Monte Carlo simulation package FLUKA to simulate the effects of ^{12}C and proton beams in water phantoms. We found that the results of the FLUKA simulations for ^{12}C and proton Bragg peaks agree well with the experimental results. Our simulations for beams of ^{12}C and protons beams that create Bragg peaks at the same depth show that ^{12}C beams generates higher neutron H/D compared to the proton beams, when only the stray neutron produced from the patient itself are considered.

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