*Transactions of the Korean Nuclear Society Spring Meeting*
*Pyeongchang, Korea, May 27-28, 2010*

# Effect of Phantom Geometry on Measured Prompt Gamma Distribution for 150 MeV Proton Beam

Chul Hee Min, Han Rim Lee, Chan Hyeong Kim*
*Department of Nuclear Engineering, Hanyang University, 17 Haedang-dong, Seongdong-gu, Seoul, 133-791, Korea*
**Corresponding author: chkim@hanyang.ac.kr*

## 1. Introduction

Accurately determining the distal dose edge, where the dose decreases to 80% of its peak dose directly after the Bragg peak in the patient, is very important not only for successful treatment, but also for the safety of the patient in proton therapy. Recently it is proved that the proton dose distribution has clear relationship with the distribution of the prompt gammas, generated from the proton-induced nuclear reactions in the passage of the proton beam [1-4].

A proof-of-principle measurement system, which could measure the prompt gammas distribution by scanning method with a single CsI(Tl) scintillation detector and a single-slit collimation system, showed that the location of the distal dose edge or the proton beam range in the water phantom can be accurately determined despite the high level background of neutrons and neutron capture gammas [2,3]. However, the prototype measurement system developed only to prove the principle cannot be used in real clinical situations, principally due to the very large and heavy (160 cm x 100 cm x 82 cm; 500 kg) scanning system. Moreover, the scanning process used in the study is not suitable for "spot scanning" or any other scanning techniques, because the spot of the proton beam continuously moves during treatment.

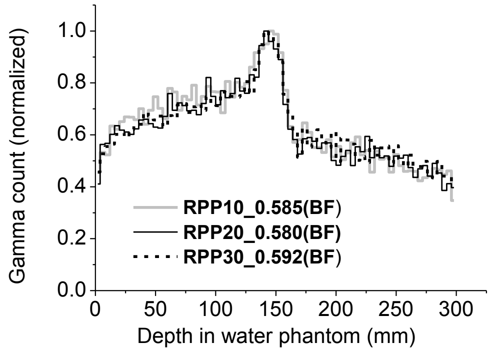
For the clinical purpose, a small, array-type prompt gamma detection system incorporating a linear array of multiple CsI(Tl) scintillation detectors, a multi-slit collimation system, and multi-channel DAQ is under development to obviate the problematic scanning process [4]. It is also fundament for the clinical application to assess the prompt gamma distribution according to the phantom size, material, shape, and location (considered the human characteristics) in proton therapy for the accurate determination of the distal dose edge. In the present study, the prompt gamma distributions according to the phantom-to-phantom variation were assessed based on the background fraction, indicating the distribution index as the ratio of the average background gamma counts to the peak gamma counts, by MCNPX code using the Monte Carlo method. The computational burden with the repeated calculation with the various phantoms was reduced with the employment of the parameterized source term and with the use of the 97-node computer cluster.

## 2. Methods and Results

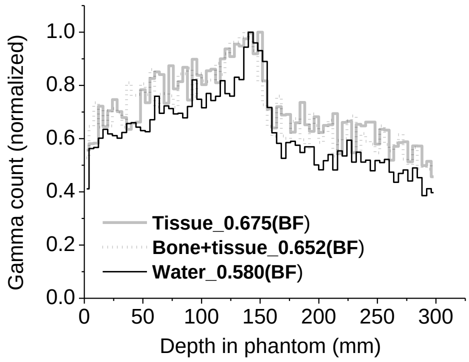
Protons of 150 MeV were delivered to a 20 cm x 20 cm x 40 cm phantom with the MCNPX code, after which a 'ptrac' file (~2 gigabytes) was generated for 2 x $10^8$ incident protons using the particle tracking option in the MCNPX code. Then, the distribution of the secondary particles generated from the proton-induced nuclear reactions was divided at 1 mm intervals along the beam passage (in the Z direction), and subsequently the X and Y positions, directions, and energies of the secondary particles were divided at 2 mm, 7.2°, and 0.1 MeV intervals (2 MeV intervals for neutrons), respectively. Finally, the generation probability of the secondary particles was determined as a function of position, direction, and energy, to be used as a source generator in the subsequent Monte Carlo simulations to assess the prompt gamma distribution according to the phantom-to-phantom variation.

The parameterized sources were repeatedly used with the phantom variation of (1) the size of 5x5x40, 10x10x40, and 20x20x40 $cm^3$ (width x height x depth), (2) the material of tissue, bone (1-cm-depth) + tissue, and water, (3) the shape of a sphere (5- and 10-cm-radious), a right circular cylinder (10-cm-diameter with 40-cm-depth), and a rectangular parallelepiped (20x20x40 $cm^3$), (4) the central location of -5 cm, 0 cm, and 5 cm from the proton beam passage (distance from the proton beam passage to the center of the phantom). To reduce the computing time, a cluster computer (96-node Pentium-4 processors) also was used.

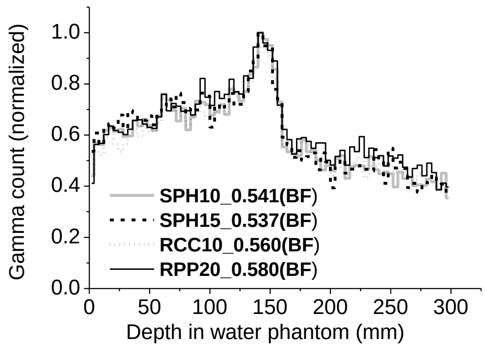
Figure 1 shows the variations of the prompt gamma distribution and the background fraction (BF) according to the phantom size, material, shape, and location. The background fractions were 0.585, 0.580, 0.592 with the phantom size of 10x10x40, 20x20x40, and 30x30x40 $cm^3$, respectively; that is, the results show the prompt gamma distribution is not much influenced by the phantom size. The background fractions with the variation of the phantom shape and location also fluctuated within 4 %. As results of the size, shape, and location, it could be considered that the change of the phantom-penetration-length, from the generation location of the prompt gammas to the exiting (phantom) surface, do not affect the distribution of the prompt gammas measured with detection system. However, the background fraction is affected by the phantom material. The background fractions with the tissue, the bone (1-cm-thickness from the beam entering surface) + tissue, and the water phantoms were 0.675, 0.652, and 0.580 respectively. It is recognized that every element has a unique characteristics in generating the secondary particles with the nuclear interaction.



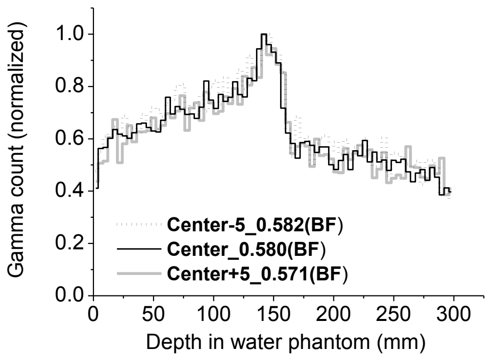

(a)




(b)




(c)




(d)

Fig. 1. Prompt gamma distributions and the background fraction (BF) according to (a) the phantom size, (b) the phantom material, (c) the phantom shape, and (d) the phantom location with the proton beam of 150 MeV.

### 3. Conclusions

In the present study, the prompt gamma distribution according to the phantom variation was assessed with the Monte Carlo method. Our results show that the phantom dimension do not practically affect on the measurement of the prompt gamma distribution, while the phantom material variation show the alteration in prompt gamma distribution. For the clinical application, it is expected that the prompt gamma distribution would be significantly considered in the body of the considerable disparity in element composition (the tissue, lung, bone etc.).

### ACKNOWLEGMENT

This work was supported by the Nuclear R&D Program in Korea through KINS and BAERI. This work was also supported by Korean Ministry of Knowledge Economy (2008-P-EP-HM-E-06-0000)/Sunkwang Atomic Energy Safety Co., Ltd.

### REFERENCES

[1] F. Stichelbaut, Y. Jongen, “Verification of the Proton Beam Position in the Patient by the Detection of Prompt γ-Rays Emission,” Meeting of 39th Particle Therapy Co-Operative Group, San Francisco, USA, 26-29 Oct., 2003.

[2] C. H. Min, C. H. Kim, M. Y. Youn, J. W. Kim, Prompt Gamma Measurements for Locating the Dose Fall-off Region in the Proton Therapy, Appl. Phys. Lett., vol.89, 183517, 2006.

[3] C. H. Min, J. W. Kim, M. Y. Youn, C. H. Kim, Determination of distal dose edge location by measuring right-angled prompt-gamma rays from a 38MeV proton beam, Nucl. Instr. and Meth. A, Vol.580, p.562-565, 2007.

[4] C. H. Min, J. G. Park, C. H. Kim, Preliminary Study for Determination of Distal Dose Edge by Measuring 90-deg Prompt Gammas with an Array-type Prompt Gamma Detection System, Nuclear Technology, Vol.168, p.89-92, 2009.