A1－6

# Particle-based simulation of proton therapy for QA

Kiyoshi Yasuoka
Proton Medical Research Center
University of Tsukuba

**Abstract**
We present a method of quality assurance (QA) for dose and dose distribution anticipated in treatment planning at proton therapy using a particle-based simulation method.

## INTRODUCTION

It is one of the important issues in the proton therapy to verify quality assurance (QA) for dose and dose distribution anticipated in treatment planning and irradiated into a patient. There are some ideas making direct measurements of dose distribution using Positron Emission Tomography (PET)[1] technique in the proton therapy as well as developed in a conventional radiotherapy or a heavy ion radiotherapy. They would be good methods of QA if they are developed with good resolution. The resolution, however, may not be satisfied as good enough in a treatment due to statistics. Thus development of different ways is meaningful in the proton therapy. Recently, simulation studies using GEANT3.21 Monte Carlo code[2] have been performed in application to treatment planning.[3] In this paper we present an indirect method of QA for dose and dose distribution in the proton therapy.

## METHOD

The GEANT3.21 is applied to the simulation in the proton therapy. It is a particle-based full simulation code including nuclear interaction. A beam of 250-MeV protons is fully simulated with full structure of the horizontal beamline (Fig.1) and a beam phase space measured at a scatterer of 3-mm thick lead plate at the Proton Medical Research Center (PMRC). A patient structure is constructed with voxels, whose properties are determined by CT data. In the proton therapy, the simulation requires an atomic number Z and an atomic mass A of the material in each voxel. Thus an electron density in the CT data should be converted into Z and A in the proton simulation. Effective atomic number $Z_{eff}$ and atomic mass $A_{eff}$ are defined as:

$$Z_{eff} = \sum \omega_i Z_i,\ A_{eff} = \sum \omega_i A_i,\quad \omega_i = P_i A_i / \sum P_i A_i\ ,$$

where $P_i$ is a number weight of the i'th component in a material. They are expressed as a function of the CT data using calibration curves in Fig.2, where phantom data[4] are fitted.

## RESULTS AND DISCUSSION

A measurement of dose distribution in a water phantom was simulated using the bolus and the collimator for the patient (Fig.3). A block of 4-cm thick bolus made from mixed-Dp and a 10-cm thick brass collimator are set in front of the water phantom placed at Z=0-30 cm. For convenience, no energy deposits into the air are shown in the plot although the simulation was fully performed in the air as well. The results were in good agreement with phantom data measured using the radiation field analyzer scanning a silicon detector (SSD) in 3D. The simulation of irradiation into the patient is in progress. The particle-based simulation with GEANT has many advantages in precise simulation because of realistic secondary-track simulation with appropriate scattering cross sections including nuclear scattering process. The simulation code is applicable to many purposes; studying of hot or cold spots in a patient, an effect of edge scattering at the collimator surface and bolus surface, and proton radiography planned at the new proton therapy facility[5)] in PMRC, where particle counting technique will be available.

## CONCLUSION

The particle-based simulation method using the GEANT code has been developed to make the QA studies for dose and dose distribution in the proton therapy at PMRC. The basic part has been accomplished and available for basic studies. The simulation of irradiation into the patient is in progress.

**References**


1) D. W. Litzenberg, "On-line monitoring and PET imaging of the positron-emitting activity created in tissue by proton radiotherapy beams.", Ph.D thesis, Univ. of Michigan, USA, 1997.

2) CERN Application Software Group, GEANT version 3.21, Detector description and simulation tool, CERN, Geneva, 1994.

3) R. Ragona, V. Rorando, and A. Solano, "Treatment planning of proton beams using the GEANT Monte Carlo," Advances in Hadrontherapy, edited by U. Amaldi, B. Larsson, and Y. Lemoigne, Excerpta Media, International Congress Series 1144, 1997, 706-711.
H. Paganetti, "Monte Carlo method to study the proton fluence for treatment planning", Med. Phys. **25**, 1998, 2370-2375.

4) Uwe Schneider and Eros Pedroni, "Proton radiography as a tool for quality control in proton therapy", Med. Phys. **22**, 1995, 353-363.

5) See, for example, Proceedings of 8$^{th}$ Workshop for Medical Proton Accelerator (in Japanese), edited by Y. Takada, 1996, PMRC, Tsukuba. Proceedings of 9$^{th}$ Workshop for Medical Proton Accelerator (in Japanese), edited by Y. Takada, 1997, PMRC, Tsukuba.

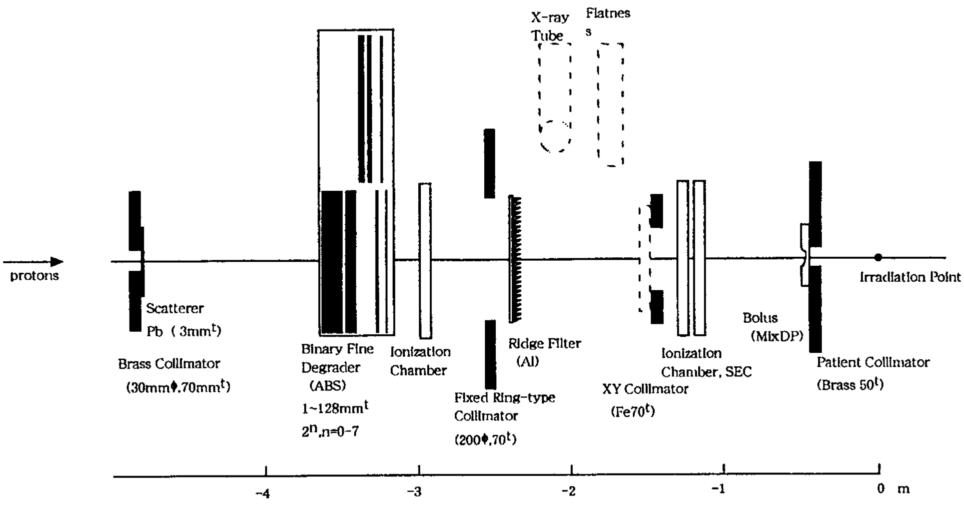


Fig. 1 A schematic view of the horizontal beamline at PMRC.

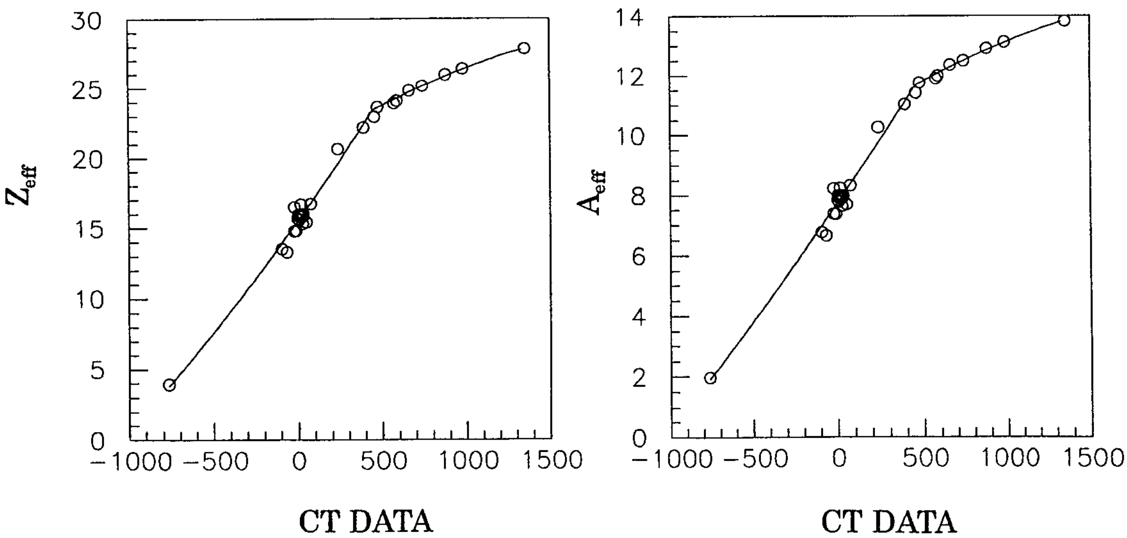


Fig. 2 a)An effective atomic number and b)an effective atomic mass.

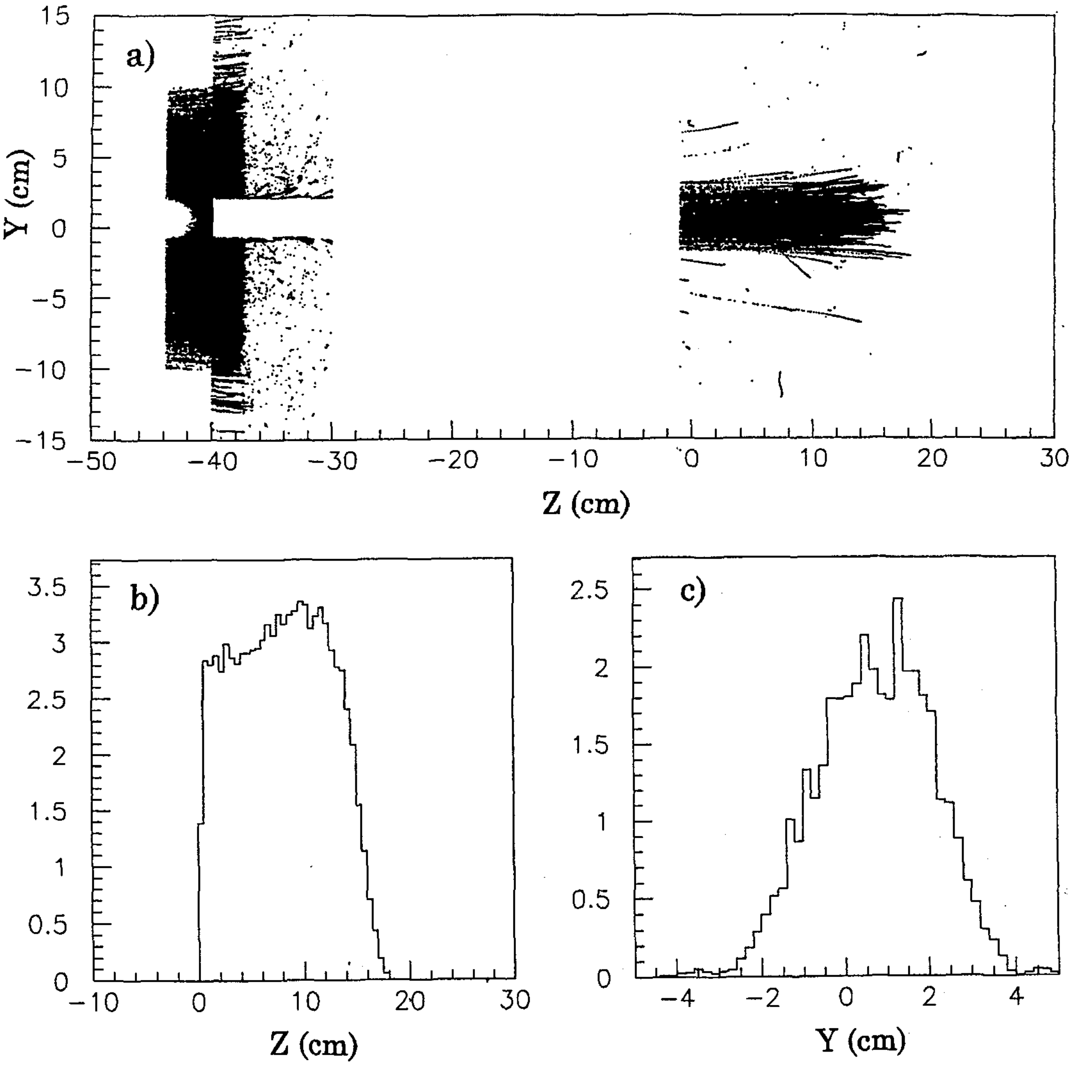


Fig. 3 A simulation of dose distribution for protons passing through a patient-dedicated bolus and collimator, and stopping inside a water phantom. a)An image of energy deposition by initial protons and secondary particles, b) depth-dose distribution on the beam axis, and c)lateral-dose distribution at the Bragg peak.