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Scintillation Detector System for Heavy Ion CT

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ABSTRUCT

We have developed a new heavy ion CT detector system for the use of a fan beam. The system consists of two sets of a position sensitive detector and an energy detector. The calibration runs were carried out using a ^{12}C beam of 1mm in diameter with the energies of 290 MeV/u, 254.5 MeV/u, and 215.8 MeV/u. The spatial resolution of 1.1 mm and the energy resolution of about 1% were achieved.

INTRODUCTION

In order to achieve the radiotherapy more precisely using high energetic heavy charged particles, it is important to know the distribution of electron density in a human body, which is highly related to their range. From heavy ion CT image, we can obtain the 2-D distribution of electron density of a sample directly. We have already shown the feasibility of heavy ion CT using a pencil beam of 1 mm in diameter and a sample with a rotation symmetry [1]. However, it takes too much time to scan the sample by such a narrow beam to improve the spatial resolution. In order to decrease the total amount of dose and to shorten the measuring time, it is essential to use a fan beam by only rotating the sample. Therefore we have developed a new detector system consisted of two sets of a position sensitive detector (PSD) and an energy detector. Two PSDs are placed in front of and behind the sample to monitor the position of heavy ion beam and the energy detector measures the residual beam energy in coincidence with these PSDs. Each detector is a plastic scintillator coupled photomultiplier tubes (PMT) to both ends. The position and the residual energy of the beam are calculated from the PMT outputs. The performance of the system will be reported in this presentation.

METHOD

(a) Principle [2]

The schematic layout of a PSD is shown in Fig.1. If we consider the interaction of a heavy ion at a distance of x from the mid-point of the detector element having length L and if the attenuation of the light is exponential, then the signals E1 at tube PMT1 and E2 at PMT2 are

$$E1 = \frac{\Delta E}{E_0} \cdot P \cdot \exp\{-\alpha({}^{L}\!/_{2} + x)\} \qquad (1)$$

$$E2 = \frac{\Delta E}{E_0} \cdot P \cdot \exp\{-\alpha({}^{L}\!/_{2} - x)\}, \qquad (2)$$

where α is the light attenuation coefficient per unit length, P is the total probability that a photon produced at one end will generate a photoelectron in the nearby photomultiplier tube, E_0 is the energy needed to emit light quanta from a scintillator, ΔE is the energy lost in the detector by the interacting heavy ion. Hence from eqs.(1) and (2), the position of an event is given by

$$x = \ln({}^{E1}\!/_{E2}) \cdot \frac{1}{2\alpha}, \qquad (3)$$

and the energy deposited in the detector is

$$\Delta E = \sqrt{E1 \cdot E2} \cdot \frac{E_0}{P} \cdot \exp(\frac{L}{2}\alpha). \qquad (4)$$

(b) Detector design

A detector system is required to have following characteristics: monitoring the position of the heavy ion beam and measuring the residual beam energy. To achieve a high counting rate, an NE102A plastic scintillator was adopted to the PSD. The size of the scintillators for PSD is 2 mm in thickness, 10 mm in height and 300 mm in width. The value of α is needed to be large for the purpose of a high spatial resolution. Many reflections of the light during propagation in a scintillator attain large α. Therefore we made their thickness as small as 2 mm. So did the height and 10 mm was the tolerant minimum value in mechanics. The width of 300 mm was determined from the high sensitive area of the PSDs and a sample size. An NE102A plastic scintillator is also used for the E-detector to achieve a high counting rate. Its size is 200 mm in thickness, 50 mm in height and 300 mm in width. The thickness of 200 mm is longer than the range of ^{12}C beam of 290 MeV/u.

(c) Detector calibration

All experiments were carried out at the secondary beam course of the HIMAC. As the first step, it is needed to obtain a response function which depends on the position by using a well collimated pencil beam. A ^{12}C beam of 290 MeV/u, which can be regarded as a diameter of 1 mm was used for the calibration. The calibration runs were carried out by changing the position of the incident beam at energies of 290.0 MeV/u, 254.5 MeV/u, and 215.8 MeV/u. The detector outputs were processed with ADCs of a CAMAC system. Figure 2 shows the outputs of the PSD as a function of the beam position.

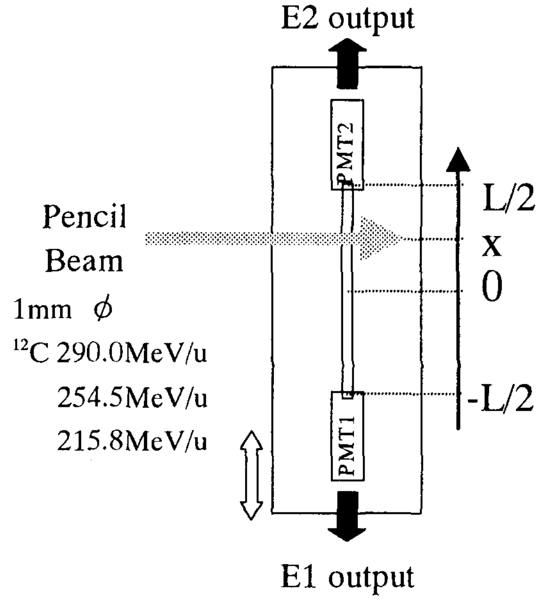

Fig.1 Schematic layout for detector calibration

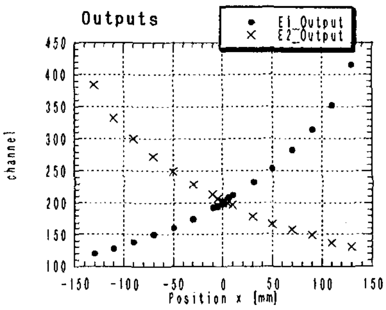

Fig.2 Position response of E1 and E2

(d) Experimental method

Figure 3 shows the experimental arrangement to obtain a CT image by using a fan beam. Even in an asymmetric sample, we can obtain the projection data for reconstruction by only rotating the sample.

RESULTS

Figure 4 shows the calibration curve of the PSD at an energy of 290 MeV/u. The spatial resolution of 1.1 mm was achieved. The calibration curves at the other energies are almost identical to that in Fig.4. Figure 5 shows the calibration curve of the E-detector. When operated under this condition, the energy resolution of about 1% will be obtained.

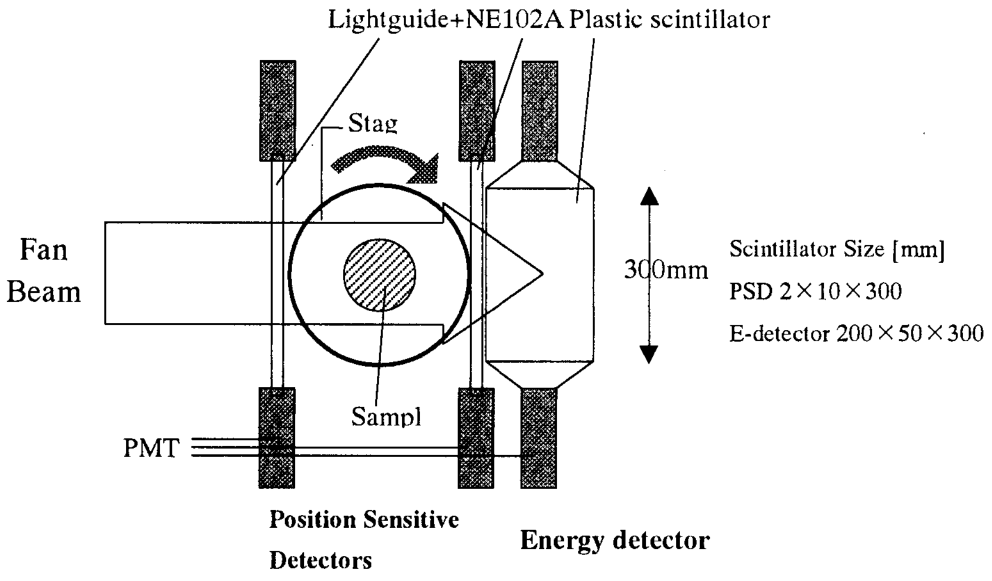

Fig.3 Experimental arrangement of detector system

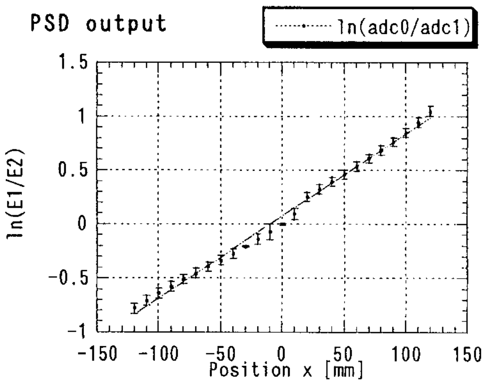

Fig.4 Calibration curve of PSD

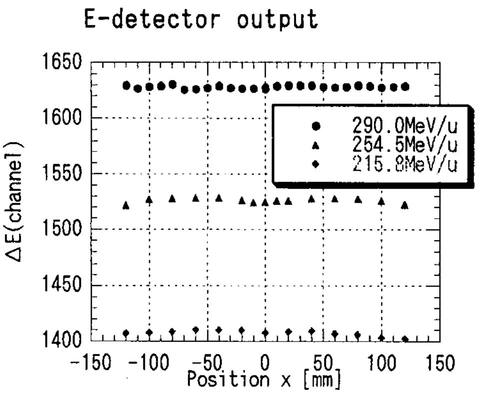

Fig.5 Calibration curves of the E-detector

REFERENCES

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[2] J. N. Carter et al, Nucl. Instr. and Meth. 196 (1982) 477