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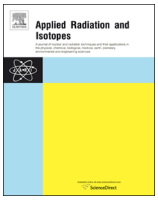

Basic detection property of an array-type CdTe detector for BNCT–SPECT – Measurement and analysis of anti-coincidence events

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HIGHLIGHTS

- We are investigating a BNCT-SPECT system.
- The BNCT-SPECT system is composed of a collimator and multiple gamma-ray detectors.
- We produced a two-element CdTe detector to confirm coincidence events.
- It was confirmed the S/N ratio could be improved by an anti-coincidence detection.

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ABSTRACT

Our research group is now investigating a BNCT–SPECT system with cadmium tellurite (CdTe) detectors, which can obtain a three-dimensional image of the BNCT treatment effect by measuring the 478 keV gamma-rays emitted from an excited state of the ^{7}Li nucleus generated by the $^{10}B(n,\alpha)$ reaction. The BNCT–SPECT system is composed of a collimator and an array-type CdTe detector.

In this study, we produced an array detector with two CdTe elements to test the basic detection property for anti-coincidence events. Our investigation confirmed that the detector offers an improved S/N ratio by the anti-coincidence detection. We also proposed an estimation method using the MCNP5 to analyze coincidence events in the detector.

1. Introduction

Boron neutron capture therapy (BNCT) is attracting attention as a new radiation therapy in medical fields worldwide (Forton et al., 2009; Kreiner et al., 2011), including Japan (Kobayashi et al., 2014; Kumada et al., 2014; Tanaka et al., 2014). Using an accelerator-based neutron source (ABNS) instead of nuclear reactors, the author group are planning to construct an ABNS-BNCT facility in Osaka University, Japan (Tamaki et al., 2015; Murata et al., 2015). BNCT can destroy tumor cells using the charged particles emitted by Eq. (1). Ranges of the emitted α and ^{7}Li particles are as long as the size of human body cells. Hence, if ^{10}B were accumulated only in tumor cells, it would be expected that only the tumor cells would be killed. Also, BNCT has an advantage that drugs containing boron compounds have already been developed, with which ^{10}B could be accumulated only in the tumor cells.

$$^{10}B + n \rightarrow \alpha + {}^{7}Li + 2.79MeV(6.1\%)$$

$$\rightarrow \alpha + {}^{7}Li^{*} + 2.31MeV + \gamma(478keV)(93.9\%) \qquad (1)$$

However, BNCT has some very serious unsolved problems. One of them is that the treatment effect (distribution of the local radiation dose to a tumor) cannot be determined during BNCT. We have thus been developing a single photon emission computed tomography (SPECT) system for BNCT to get the BNCT treatment effect in real time (Murata et al., 2011).

Fig. 1 shows the concept of the BNCT–SPECT system. The BNCT–SPECT system is composed of a collimator and multiple gamma-ray detectors (an arrayed gamma-ray detector). Promptly emitted 478 keV gamma-rays are collimated by the collimator, and measured by this array detector. A three-dimensional BNCT treatment

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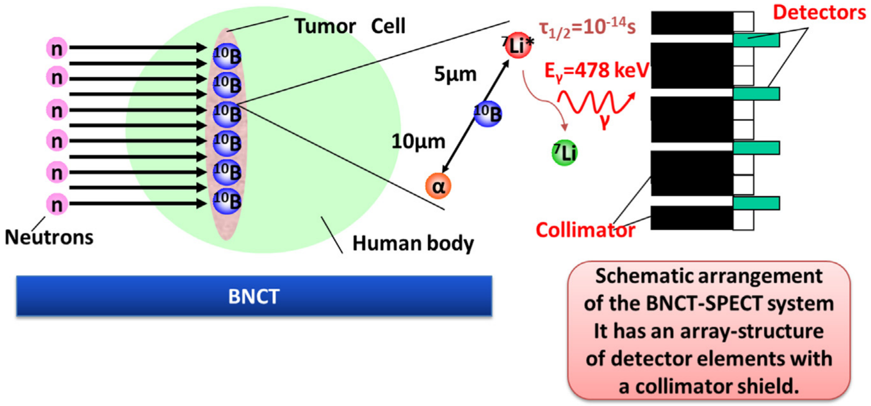

Fig. 1. Concept of the BNCT–SPECT system.

effect can be estimated from the obtained intensity distribution of 478 keV gamma-rays.

However, it is known to be very difficult to measure 478 keV gamma-rays for the following two reasons. Firstly, capture gamma-rays of 2.22 MeV re produced by the ^{1}H(n,γ)^{2}H reaction around a tumor and they cause a high and troublesome background field. Secondly, annihilation gamma-rays of 511 keV energy that are emitted via the pair production process can be detected just adjacent to the 478 keV gamma-rays to be measured.

We recently investigated feasibility of the BNCT–SPECT system that used CdTe crystals and a collimator (Manabe et al., 2015a). We found the estimated count rate of 478 keV gamma-rays was sufficiently large, being more than the target value of over 1000 counts/h. However, the S/N ratio did not meet the target value ($S/N > 1$) prescribed for the design. In a second study, we confirmed that deterioration of the S/N ratio was due to the influence of the Compton continuum formed by capture gamma-rays of hydrogen (Manabe et al., 2015b), and we started to improve the S/N ratio.

In the present study, to continue improvement of the S/N ratio, we focused on anti-coincidence detection by an arrayed detector. At first, we produced an arrayed detector with two CdTe elements to test anti-coincidence detection using two adjacent measurement elements. We then carried out an anti-coincidence measurement with a standard gamma-ray source to confirm possibility of reduction of noises formed by the Compton continuum. Also, we established a calculation method for the coincidence events using the MCNP5 (X-5 Monte Carlo Team, 2003) in order to compare measurement results to calculation results.

2. Materials and methods

2.1. Design requirements for the BNCT–SPECT system

As mentioned in the Section 1, the BNCT–SPECT system should be so designed that 478 keV gamma-rays can be measured in a very high background field. In addition, we should meet certain medical conditions pointed out by BNCT pioneers (Kato et al., 2004; Kobayashi et al., 2000) Taking into account the conditions, we set four design targets as follows:

①The spatial resolution should be less than 2 mm in an obtained SPECT image from the viewpoint of application to medical treatment and is as good as the resolution for PET.
②It is necessary to complete measurements in about 60 min, because the treatment time for BNCT is normally as long as one hour (Kato et al., 2004).
③The number of counts per unit detector should be more than 1000 counts so that the statistical accuracy can be kept within 4%.
④The energy resolution, full width at half maximum (FWHM), should be less than 33 keV, that is (FWHM of 478 keV+FWHM of 511 keV)/2 < 33 keV, so as to measure annihilation gamma-rays and 478 keV prompt gamma-rays separately. The value of 33 keV is based on the difference of the two energy peaks, 511–478 keV.

A group at Kyoto University (Kobayashi et al., 2000) first investigated the basic detection property of a SPECT system for BNCT. Based on their results, we decided to employ CdTe semiconductor detectors. Other research groups without our also have investigated similar researches (Minsky et al., 2009; Verbakel and Stecher-Rasmussen,1997). The details of the points we considered can be found elsewhere (Manabe et al., 2015b). We conducted basic research studies theoretically and experimentally for a one-element CdTe detector (Manabe et al., 2015a; Murata et al., 2014; Nakamura et al., 2012). The S/N ratio measured were less than unity (Manabe et al., 2015a). These results were obtained with just the one-element CdTe detector. Since the presently proposed BNCT–SPECT is an array-type detector, we expected that using the coincidence event measurement could improve the S/N ratio.

2.2. Development of the two-element CdTe detector

Fig. 2 shows the two-element CdTe crystals and the two-element CdTe detector produced in this study. The two-element CdTe crystals are used for the two-element CdTe detector. Schematic drawings of the two-element CdTe detector are shown in Fig. 3. One CdTe crystal (1st or 2nd layer of the two-element CdTe crystals) has 8 pixels divided horizontally as shown in Fig. 3(a). Gamma-rays are incident from the left hand side in Fig. 3(a) so that a high spatial resolution and good detection efficiency can be achieved simultaneously. As shown in Fig. 3(b), in one CdTe element 4 pixels are in the upper layer and another 4 are in the lower one. This complex structure can be applied to an array-type CdTe detector with a so-called ASIC (application specific integrated circuit). And this structure helps to carry out anti-coincidence detection easily. For bonding of the two crystal layers, gold wires are placed as GND lines between them. Finally the elements are surrounded by a guard ring of 1 mm thickness in order to decrease leakage current.

3. Coincidence event measurement

Before measuring the coincidence events, we first confirmed experimentally that the two-element CdTe detector met the

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