Estimation of Nuclear Interaction for ^{11}C Cancer Therapy

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ABSTRACT

Cancer therapy using high-energy ^{12}C ions is successfully under way at HIMAC, Japan. An alternative beam to ^{12}C is ^{11}C ions. The merit of ^{11}C over ^{12}C is its capability for monitoring spatial distribution of the irradiated ^{11}C by observing the β^+ decay with a good position resolution. One of the several problems to be solved before its use for therapy is the amount of nuclear interaction that deteriorates the dose concentration owing to the Bragg curve. Utilizing the dedicated secondary beam course for R&D studies at HIMAC, we measured the total energy loss of ^{11}C ions in a scintillator block that simulates the soft tissue in human bodies. In addition to the total absorption ^{11}C peak, non-negligible bump-shaped contribution is observed in the energy spectrum. The origin of the bump contribution can be nuclear interaction of the incident ^{11}C ions with hydrogen and carbon atoms. Further studies to reduce the ambiguity in dose distribution are mentioned.

Keywords: Heavy ion, Cancer therapy, ^{11}C ions, β^+ decay, Nuclear interaction

1. INTRODUCTION

R/D study for cancer therapy using ^{11}C is being done at HIMAC, Japan. The merit of ^{11}C over ^{12}C is its capability for monitoring spatial distribution of irradiated ^{11}C ions. The ^{11}C nucleus loses its kinetic energy by the ionization loss in matter, and the beam makes a Bragg peak just before its termination. This mechanism is similar to the case of the ^{12}C beam. While the ^{11}C nucleus decays into the ^{11}B nucleus and a positron with maximum energy of 0.96 MeV in a half-life of 20 m. Further, the positron annihilates into two photons. Utilizing this mechanism, a precise range measurement of the ^{11}C in phantom has been carried out by Kanazawa et al.[1] on the secondary beam course for production and transportation of the ^{11}C beam from HIMAC. By using their positron cameras[2] of NaI(Tl) on the beam course, they successfully measured the position resolution[3] of the annihilation positrons coming from ^{11}C to be 6mm.

In order to promote the plan, we have examined possible hindrance to the future cancer therapy using ^{11}C. One is the contamination of other nuclear species in the ^{11}C beam, and the other is possible deterioration in dose concentration due to contamination of nuclear fragments in the ^{11}C beam. The fragments are produced by nuclear interaction of incident ^{11}C in matter. As for the nuclear fragments, our measurements using the E–ΔE method of plastic scintillation counters has been completed. The results obtained in the beam energy range 100~355 MeV/n are discussed.

2. MATERIALS AND METHODS

2.1. Experimental equipment

^{11}C ions are produced through nuclear fragmentation processes in the Be target by bombarding primary ^{12}C ions from the HIMAC Synchrotron. They are momentum analyzed in the secondary beam course, and incident on the counters placed at around the isocenter as shown in Fig. 1. The energy was adjusted by changing the thickness of the range shifter made of PMMA. The ΔE counter of 0.5 cm in thickness measured stopping power for particle identification of the incident beam, and the E counter measured total energy deposit in 30-cm depth. Nuclear interactions in the E counter cause energy reduction.

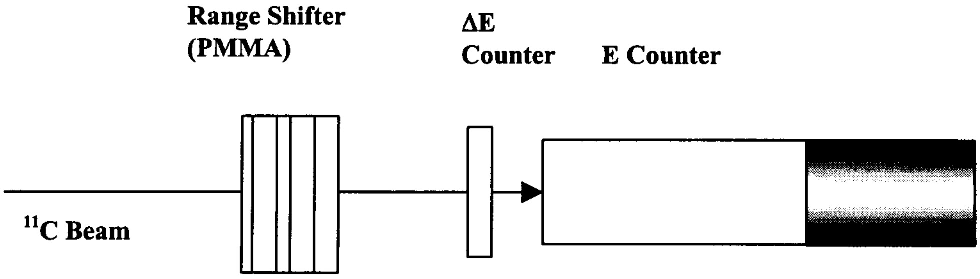

Fig. 1 Experimental Layout

2.2. Purity of the ^{11}C beam

The purity of the beam was measured at the energy of 355MeV/n by analyzing the pulse height in the ΔE counter. One can identif ^{4}He and ^{7}Be besides ^{11}C as seen in Fig. 2.

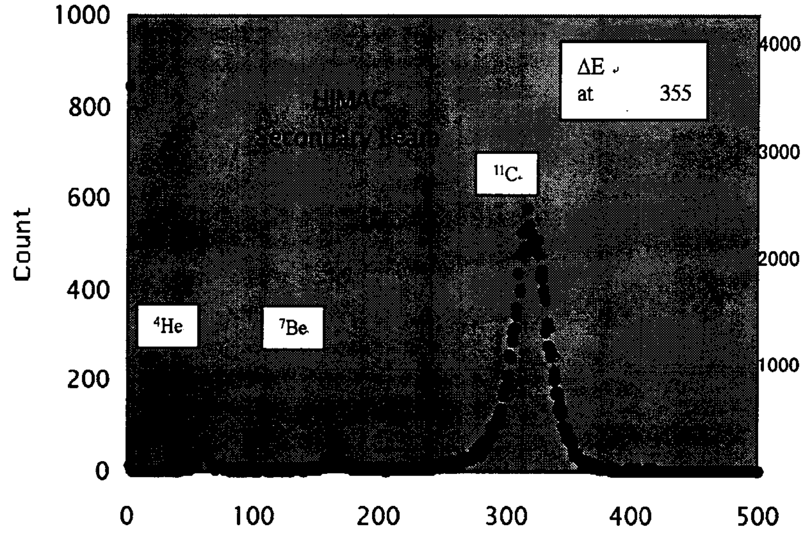

Fig. 2 Pulse height spectrum of the ΔE counter. Three types of nuclei ar fragmentation products in the Be target. Each background contribution which can be subtracted in dose calculations, is no more than 5%.

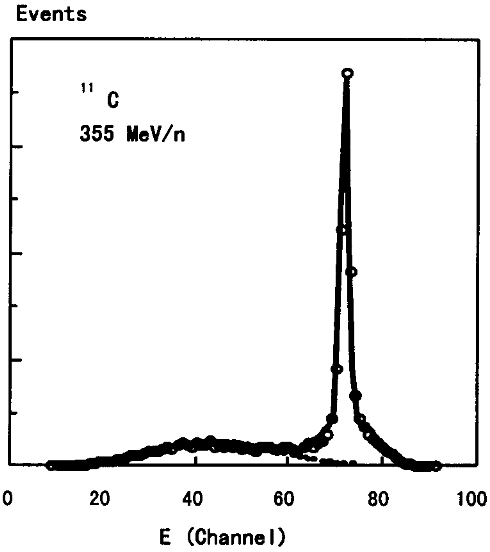

Fig. 3 A peak at around 70 channel is ^{11}C.

3. RESULTS

^{11}C were selected by the use of ΔE. Figure 3 shows the pulse height spectrum of the E counter, which is the total energy deposit in the scintillator. A sharp peak corresponds to the stopped ^{11}C, which transfer the total kinetic energy to the scintillator, and this means that the energy deposit along the path can be represented by the Bragg curve. While, a bump structure observed in the region below the peak channel indicates another energy loss mechanisms than the Bragg curve of ^{11}C. This can be caused by the nuclear interactions. Lower energy contribution comes from energy losses due to nuclear interaction. The shape of the peak can be represented by a superposition of two gaussians, and the bump is also reproduced by a gaussian with a broader width. Fitting parameters are listed in Table 1. Integrated numbers of events in both regions are 63% and 37%, respectively, i.e. 37% of ^{11}C suffer from nuclear interactions in the 30-long plastic scinchillator before its termination. In order to compare with the above data, we measured the loss of ^{11}C in PMMA as a function of its thickness as shown in Fig. 4. A straight line can reproduce the increase.

4. DISSCUSION AND CONCLUSION

In order to estimate the amount of nuclear interactions that suffered in the course of ionization loss of ^{11}C, our detection system used the total absorption technique. Those ^{11}C that do not suffered from nuclear interactions loses energy by ionization only, and the total energy deposit can be a peak with a width that reflects the detector resolution and the ^{11}C struggling in the scintillator. Our data shown in Table 1 indicate that the detector resolution is 1.2%, and that the energy struggling in the scintillator results in the energy spread of 7.6%. While, those suffered from nuclear interactions lose energy according to the reaction mechanisms that we do not have enough knowledge, and those make the bump structure in Fig. 3. In the case of ^{11}C, we conclude that 37% of incident ^{11}C are lost before making the Bragg peak in a block of plastic scintillator. Our data of plastic scintillator are supported by the thickness dependence of ^{11}C loss in PMMA. It gives a linear increase as shown in Fig.4. It is worth noting that the nuclear interaction length in plastic scintillator of 82.0 g/cm^2 is very close to that in PMMA of 83.6 g/cm^2. It is important to identify the mechanism of the loss. Our next measurements are to estimate the cross section of the nuclear interaction of ^{11}C in comparison with ^{12}C. For the experiment to be carried out this fall, charged particle detectors to observe nuclear interaction products surround the E counter. Another method to estimate the contribution to the dose distribution is to simulate the behavior of the produced particle in detail. It will be desirable to use accumulating basic data for the estimation of the dose distribution in human bodies in near future.

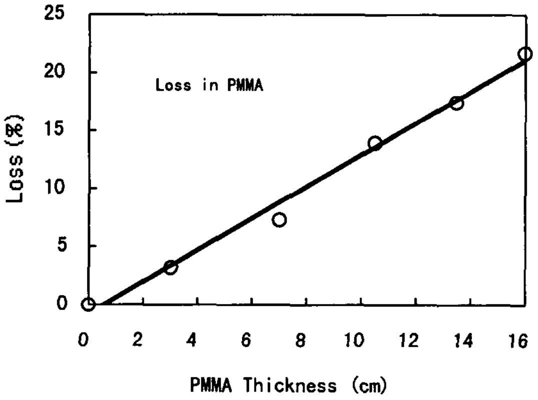

Fig. 4 Loss of ^{11}C ions is measured as a function o PMMA thickness. Data are reproduced by a straigh line or by an exponential function.

Table 1 Parameters used in the fitting of Fig. 3.

Type	*Peak channel*	*σ/peak (%)*
^{11}C	72	1.2%
		7.6%
Bump	44	31 %

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