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Characterization of a radioactive ^{11}C beam by means of the associated particle technique

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This paper describes the results obtained for the production and characterization of a radioactive ^{11}C beam, by means of the in flight technique at the tandem laboratory of the National Institute of Nuclear Research, Mexico. The ^{11}C production technique described here, uses the well known Associated Particle Technique (APT) with the reaction $^2\text{H}(^{10}\text{B}, ^{11}\text{C})\text{n}$, in order to obtain a biunivocal correspondence between the radioactive ^{11}C particles and the associated neutrons. A discussion concerning the possible use of this ^{11}C beam in the study of the elastic scattering of protons is introduced.

Keywords: ^{11}C beam production; in flight technique.

Este trabajo describe los resultados obtenidos para la producción y caracterización de un haz radioactivo de ^{11}C usando la llamada técnica de separación “en-vuelo”, generado en el acelerador Tándem del Instituto Nacional de Investigaciones Nucleares en México. La técnica para producir el haz de ^{11}C usa la muy establecida Técnica de la Partícula Asociada con la reacción $^2\text{H}(^{10}\text{B}, ^{11}\text{C})\text{n}$, la cual aprovecha la correspondencia biunívoca existente entre el haz de ^{11}C y su neutrón asociado. Se presenta también una discusión sobre el posible uso de este haz de ^{11}C en el estudio de la dispersión elástica de protones por el mismo haz.

Descriptores: Producción de ^{11}C ; técnica de espectroscopía de iones “en vuelo”.

PACS: 25.45.-z; 29.30Ep

1. Introduction

As it is well known, that the associated particle technique (APT) when used with the reactions involving hydrogen isotopes, as $\text{D}(\text{d}, \text{n})^3\text{He}$ or $3\text{H}(\text{d}, \text{n})^4\text{He}$, can provide monoenergetic neutron beams of know flux and energy. The neutron beam characterization requires a clear identification of the associated helium particles in order that, by applying appropriate time of flight methods, the neutron flux can be determined through the helium recording. Many efforts were done in the past to identify the associated particle, which includes the use of solid state surface barrier telescopes with and without “veto detectors” [1,2] and, in a more sophisticated cases, the use of micro-channel plates are implemented [3]. The good results obtained, gave rise to the opening of many facilities providing monoenergetic neutrons supported in this method, used in applications to obtain neutron data, like total and differential cross sections, for most the elements useful in reactor design, for example.

In order to have a monoenergetic neutron facility using the APT technique, besides the associated particle unambiguous identification, the establishment of the technique requires actual neutron cone measurements by the use of an organic scintillator (NE213 or NE102A) as neutron detector which is moved, alternatively, across the neutron beam at the kinematics correlated angle in the horizontal and the vertical plane. As is discussed elsewhere [4], the neutron cone aperture is determined by the frontal slits which define the solid angle

subtended by the associated particle detector, and in the horizontal plane by the kinematics of the reaction involved.

The characterization of the neutron beam requires the measurement of the neutron time of flight which is accomplished by the use of a time to amplitude converter. Once the neutron time of flight is recorded, this signal can be used to gate linear signals from the AP detector or from the neutron detector.

As a result, the neutron and the associated particle are univocally tagged, and neutrons so defined can be used in any measurement of interest. An important point to be considered here is that both particles, helium and neutron, are tagged. This should be of interest if the reaction $\text{D}(^{10}\text{B}, ^{11}\text{C})\text{n}$ is to be considered, and look for tagging the neutron and the associated ^{11}C .

This paper reports the results obtained for the characterization of the tagged ^{11}C and neutron particles by using the $^{10}\text{B}+\text{D}$ reaction in inverse kinematics carried on at the 6.0 MV tandem accelerator facility of the National Institute of Nuclear Research (ININ) in Mexico.

2. Experimental details

2.1. Setup

A 10 MeV ^{10}B beam was directed towards home made deuterated polyethylene targets, films of 80 to 120 $\mu\text{g}/\text{cm}^2$ thick, located inside the scattering chamber schematically

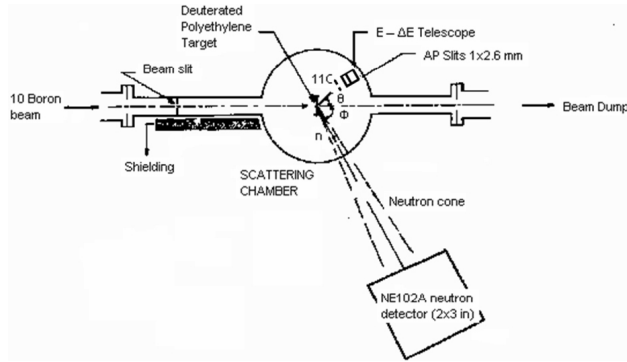


FIGURE 1. Schematic view of the experimental arrangement.

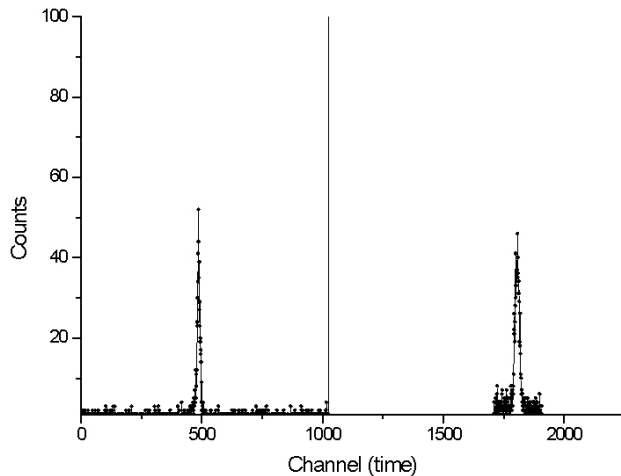
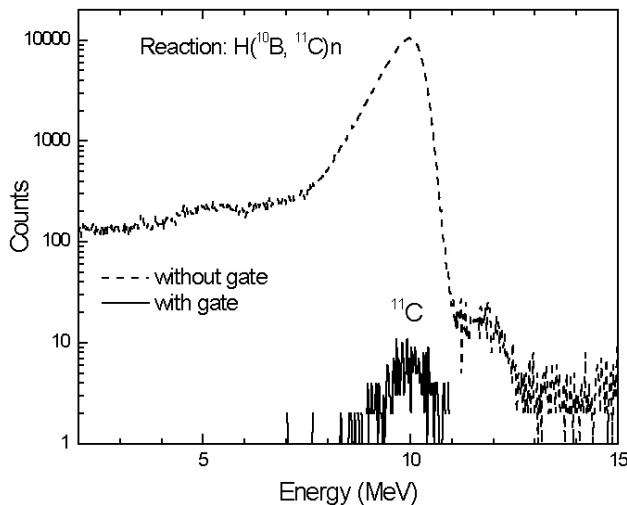

 FIGURE 2. Neutron detector versus ΔE detector time of flight spectrum (left side histogram) and, neutron detector versus E detector time of flight spectrum (right side histogram).


FIGURE 3. E detector linear spectra for: a) TOF Gated and b) non-gated conditions, as shown.

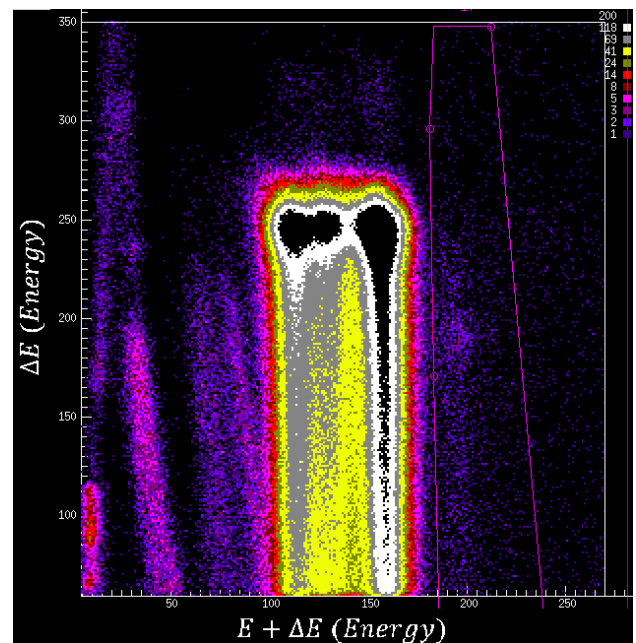
shown in Fig. 1 (whose characteristics are described elsewhere [5]). The Boron beam incident on the targets are collimated at the entrance of the chamber by a set of rectangular

slits, $1.5 \text{ mm} \times 2.5 \text{ mm}$, which produces a circular beam spot track if a rotating target assembly is used, described in Ref. 4. This rotating target assembly is adequate to avoid fast target deterioration. The ^{11}C radioactive beam was detected at 14.6 degrees by means of an $E+\Delta E$ telescope, which uses $2 \mu\text{m}$ thick, “ ΔE ”, and $75 \mu\text{m}$ thick, “E”, solid state surface barrier detectors. The neutrons were detected outside the chamber by means of a NE102A plastic scintillator (5 cm diameter \times 7.2 cm long), placed at the kinematically correlated angle (91 degrees), optically coupled to a 56 AVP photomultiplier. The neutron detector was mounted on a steel structure which can rotate around the center of the scattering chamber, where the target is located. The ^{11}C -neutron’s time of flight correlation was accomplished using a time to digital converter in the CAMAC event-by-event acquisition system used.

2.2. Measurements

The experiment using inverse kinematics with the $^2\text{H}(^{10}\text{B}, ^{11}\text{C})\text{n}$ reaction employs, as it was pointed out, a 10 MeV ^{10}B beam directed toward the deuterated polyethylene targets. The ^{11}C beam emerging from the target ($100 \mu\text{g}/\text{cm}^2$ thick) with an average energy of 9.04 MeV , is intercepted by a thin “ ΔE ” ($2.2 \mu\text{m}$ thick) surface barrier detector. A second, “E”, surface barrier detector $75 \mu\text{m}$ thick is located immediately behind the ΔE detector stopping the ^{11}C particles.

The energy of the ^{11}C radioactive beam in its path through the ΔE detector is reduced, mainly by electronic interactions, to an energy range from 6.4 to 7.1 MeV , averaging 6.75 MeV .


 FIGURE 4. CAMAC “E- ΔE ” map. As it can be appreciated, the different ion species are distinguished from one another.

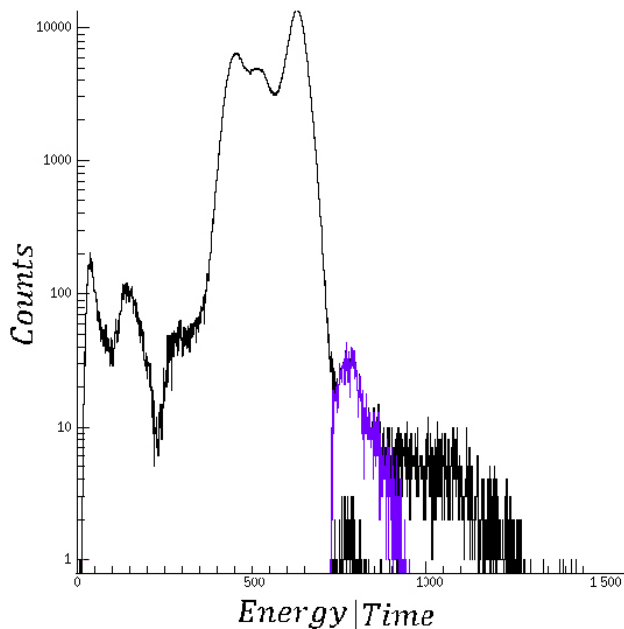


FIGURE 5. ΔE linear spectrum gated with ^{11}C events taken from an E- ΔE “banana”, and the time of flight spectrum between the ^{11}C signal and the neutron detector signal.

Initially, a time correlation of events between both surface barrier detectors and the neutron detector signal was searched for, obtaining time of flight spectra, as depicted in Fig. 2, once that the system was properly calibrated in time. The ΔE time of flight signal was then used to gate the linear signal of the E detector, and these results are illustrated in Fig. 3. As can be seen, the gated spectrum identifies the ^{11}C events unambiguously. However, as it was pointed out, the APT technique requires a clear separation of the associated charged particle (^{11}C ions); in order to do this, we use the signals coming from the ΔE and E detectors and the event by event CAMAC system, which uses the ΔE signal as main trigger, enabling the windows where the signals coming from the ΔE and E detectors and the neutron signals to be processed and eventually stored [6]. The CAMAC modules and controller

were programmed using LAB-VIEW (National Instruments Corp., USA) package version 8.0 [7].

Figure 4 shows an “E- ΔE ” histogram obtained from the CAMAC supported acquisition system. In this figure, we can appreciate all the ion species from the target originated by the incident ^{10}B beam. Moreover, the products from hydrogen to carbon are clearly displayed in this graph. A “banana” enclosing the carbon ions was selected by means of data analysis program “DAMM” from ORNL, Tenn., USA, and the interception of these events with those corresponding to the E detector is shown in Fig. 5. A clear identification of ^{11}C events is obtained.

In the same Fig. 5, a time of flight constriction was imposed to the ^{11}C carbon events, which shows up, again, an unambiguous identification of the radioactive ^{11}C ions.

These resolved ^{11}C ions could be used in nuclear reaction studies, once an adequate ^{11}C flux is guaranteed. The count rate recorded < 10 particles/s, is still low for the measurement of the elastic scattering of protons by ^{11}C , in order to study the lowest energy levels of ^{12}N by resonance scattering. However, the use of a deuteron gas jet as target instead of the deuterated polyethylene target is being looked for which, together with a microchannel plate detector, can improve the electronic count rate to handle as high as 10^6 counts/s.

3. Conclusions

The in-flight technique described in this work for the production of a radioactive ^{11}C beam, seems to be of importance in low energy nuclear spectroscopy studies with this nuclei as a projectile, if the ^{11}C flux can be improved above 1000 particles/s. Actually, one of our limitations was related with a rather low ($\sim 2\%$) neutron detector efficiency, which we plan to take care of, and with other improvements we plan to continue this development. The technique described could be used for the production of other ion species, like ^3H , if the $\text{D}(d,p)^3\text{H}$ is employed.

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