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A facility for production and utilization of radioactive beams

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Abstract

A radioactive ion beam facility, GIRAFFE, has been built at the CIAE HI-13 Tandem accelerator. The facility makes use of the inverse kinematics. A D-Q-Q type magnetic separation and focusing system was used in the beam line. This simple device is expected to yield some radioactive ion beams(A<20) near the β-stability line with the acceptable intensities(10^5-10^6 pps). The ion beams of ^{7}Be, ^{11}C and ^{17}F were delivered , and the ^{7}Be beam was applied for two experiments.

1. INTRODUCTION

The radioactive nuclear beams provide a new opportunity for studying nuclear structure and reactions in a wider degree of freedom of isospin. Since nuclear reactions that produce energy and synthesize new elements at various astrophysical sites in the cosmos often involve radioactive nuclei in their entrance channels, the nuclear data of the radioactive beam induced reactions are of the fundamental importance for nuclear astrophysics. The present paper describes the production of ^{11}C, ^{17}F and ^{7}Be beams and the application of ^{7}Be beam with a secondary radioactive beam facility (GIRAFFE).

2. GENERAL DESCRIPTION OF GIRAFFE

As an initial stage towards the studies with RNBs in CIAE, a simple facility to produce and utilize low energy beams of radioactive ions such as ^{6}He, ^{7}Be, ^{8}Li, ^{11}C, ^{12}B, ^{13}N, ^{15}O and ^{17}F has been constructed at CIAE HI-13 tandem laboratory[1]. It was designed for studying the elastic scattering of $T_z=\pm1/2$ mirror nuclei and some reactions of astrophysical interest. The general feature of the facility is schematically shown in Figure 1. It comprises a primary reaction chamber, a dipole magnet-quadrupole doublet beam transport system (D-Q-Q) and a secondary reaction chamber[2]. The basic parameters of the performance of the secondary beam line are listed in Table 1.

The primary beams of ^{7}Li, ^{11}B, ^{12}C, ^{14}N and ^{16}O ions from the tandem impinge on a hydrogen or deuterium gas cell in the primary reaction chamber, where some fractions of projectiles are converted to the desired radioactive ions via reactions in reversed geometries such as ^{2}H(^{7}Li, ^{8}Li)p and ^{1}H(^{7}Li, ^{7}Be)n. Use of the reversed geometries results in a kinematic compression of the reaction products of interest into a forward cone. Thus a large

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portion of the desired products can be transported and focused onto the secondary reaction targets, whereas the unwanted products are rejected, by the D-Q-Q system.

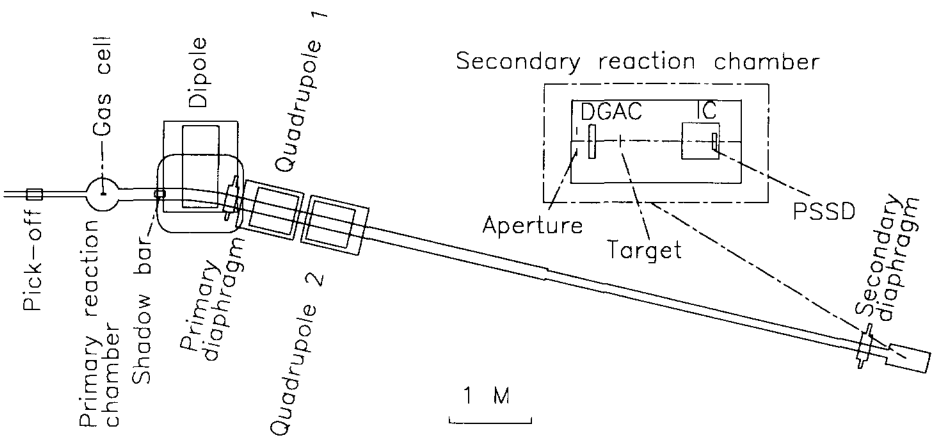

Figure 1. The layout of GIRAFFE.

Table 1. The basic parameters of the performance of the secondary beam line.

Maximum solid angle	$\Delta\Omega$ = 1.8 mSr ($\Delta\theta$ = ±16.4 mrad, $\Delta\phi$= ±34.8 mrad)
Maximum rigidity	$B\rho$ = 1.4 Tm
Total length	L = 9.8 m
Focal plane dispersion	$\Delta X/(\Delta P/P)$ = 0.47 cm/%
Spot size of RNB	ΔX = ±0.54 cm ΔY = ±0.92 cm
Acceptance angle	0°, 3°
Deflection angle	13°

The secondary beam profiles and timing are measured by a XY position sensitive double-grid avalanche counter prior to the secondary targets. The secondary beams and induced reaction products are detected and identified using a ΔE-E counter telescope, which consists of an ionization chamber with Frisch-grid or a thin Si (ΔE) detector and a 45×45 mm^2 XY position sensitive Si (E) detector.

3. PRESENT STATUS

3.1 Beam production

The ^{7}Be, ^{11}C and ^{17}F beams have been delivered so far[3]. The characteristics of the beams are summarized in Table 2. Figure 2 shows the horizontal profile of ^{11}C beam. Figure 3 illustrates the ^{7}Be energy spectrum. A shadow bar of 14 mm in diameter was installed between the gas cell and the dipole during the tuning of ^{11}C and ^{7}Be beams, which effectively eliminated the low-energy contaminants. As a result, the ^{11}C beam purity was enhanced from 6% to 14%. It is observed that the separation of the secondary beam from the primary beam contaminants strongly depends on the position deviation of the primary beam spot. Following the optimization of dipole and quadrupole fields, the meticulous adjustment of the beam spot positions was applied to the tuning of ^{11}C and ^{7}Be beams.

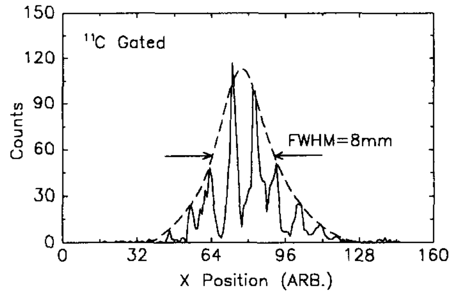

Figure 2. The horizontal profile of ^{11}C beam.

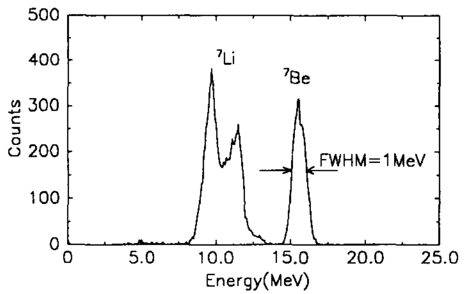

Figure 3. The ^{7}Be energy spectrum.

The ^{11}C and ^{7}Be beam intensities shown in Table 2 were determined by their Coulomb scattering on the Au targets.

Table 2. The summary of the experimental results for ^{11}C, ^{17}F and ^{7}Be beams.

RNB	^{11}C	^{17}F	^{7}Be
Production Reaction	$^{1}H(^{11}B,^{11}C)n$	$^{2}H(^{16}O,^{17}F)n$	$^{1}H(^{7}Li,^{7}Be)n$
RNB Energy(MeV)	41.0	68.0	15.5
Energy Resolution(MeV, FWHM)	1.5	2.5	1.0
Purity(%)	14	0.5	27
Intensity	1.2×10^{5}	--	1.0×10^{5}
Conversion Efficiency	5×10^{-7}	1×10^{-6}	9×10^{-8}

Notes: The pressure of gas cell was 1 atm.

3.2 Experiment

3.2.1 $^{2}H(^{7}Be,^{8}B)n$ reaction

This reaction is of interest in normal stellar hydrogen burning, particularly in the solar neutrino problem. A tentative measurement of $^{2}H(^{7}Be,^{8}B)n$ reaction cross section was carried out at ^{7}Be beam energy of 15.5 MeV. The reaction target was a $(CD_2)_n$ foil of 1 mg/cm^2 in thickness. The ΔE(IC)-E(PSSD) telescope was used for identifying the reaction product ^{8}B. Following the $(CD_2)_n$ target was an incident beam stopper to avoid the radiation damage of PSSD and pulse pile-up. In this case, the available CM angular range was 30°-150°. Unfortunately, it was found that the incident beam was not completely blocked, so that the ^{7}Li induced reactions in the window and gas of ionization chamber smeared the ^{8}B events. Further amelioration is being undertaken.

3.2.2 Experiment of ^{7}Be ion implantation into corn seed

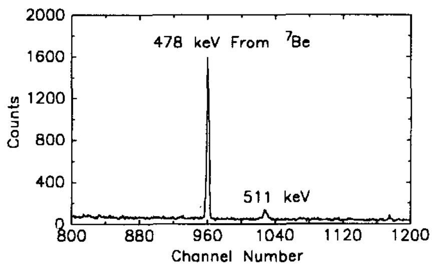

Figure 4. The ^{7}Be γ-ray spectrum.

The ^{7}Be isotope is thought to be one of the best species for tracing application to biology and material science because of its half-life (53.3 d) and detectable decay γ-ray. The ^{7}Be beam with energy of 33 MeV was used to implant into the corn seeds. The accumulated dose of ^{7}Be beam was about 10^9 ions/cm^2. The irradiated samples were off-line analyzed by detecting the 478 keV γ-rays from the ^{7}Be decay. A typical γ-ray spectrum for 4 grains of corn is shown in Figure 4. It is found that the γ-count ratio of the skin-stripped grains to those with skin is about 42 %. This means that only about half of ^{7}Be ions entered embryo of the seeds. No significant deviation from the well-known range-energy relation was observed. This conclusion is helpful to clarify the mechanism of the ion implantation. Some effects have been observed on the leaves of the corn from the irradiated seeds.

4. DISCUSSION

It can be seen from above experiments that while the low purity RNBs may be useful for the application to biology and material science, the RNBs with higher purity are needed for nuclear physics experiment. In order to enhance the beam purity, measures for improvement are being adopted. (1) Changing the acceptance angle of the beam line from 0° to 3° to avoid the primary beam prior to the dipole magnet. (2) Re-designing the gas target in the primary reaction chamber to minimize beam scattering. (3) Making TOF selection of the transmitted beams at upstream of the secondary target to trigger the events of interest on-line. It is expected that the radioactive beams with higher purity will make more experiments feasible.

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