HEAVY ION SECONDARY BEAMS

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Abstract : The possibility of producing secondary beams of radioactive nuclei is an interesting application of medium and high energy heavy ion beams. After a first attempt at CERN (1), two experiments have been performed at GANIL, using 44 MeV/u ^{40}Ar (2) and 65 MeV/u ^{18}O projectiles. This paper recalls the results of the Ar experiment, and presents new data obtained with the ^{18}O beam.

1. EXPERIMENTAL TECHNIQUE

The radioactive nuclei are produced in a thick target of a light element through projectile fragmentation or transfer. The products emitted at zero degree are separated from the primary beam using a magnetic spectrometer of large angle and energy acceptance (LISE). The secondary beam is transported over 18 m and refocused in a spot of diameter less than 15 mm. The spectrometer is composed of two dipoles and 10 quadrupoles. It is described in ref. (3). Beam diagnostics make it possible to visualize the beam profiles in several points. A solid state detector telescope (ΔE,E) is placed at the achromatic focus in order to analyse the isotopic composition of the secondary beam. Details about the experimental procedure can be found in ref. (2).

2. EXPERIMENTAL RESULTS

2.1. ^{40}Ar beam

Secondary beams of masses around 40 and energies around 34 MeV/u have been produced using a 99 mg/cm² Be target. The yields I/I_0 (secondary/primary beam intensity) obtained (2) for these beams are given in table 1.

Primary beam	Target	S.B.	I/I_0	S.B.	I/I_0	S.B.	I/I_0
44 MeV/u ^{40}Ar	99 mg/cm² Be	^{41}K	5.10^{-5}	^{38}Ar	10^{-4}	^{39}Cl	10^{-4}
				^{39}Ar	3.10^{-4}	^{38}S	$0.6.10^{-5}$
65 MeV/u ^{18}O	567 mg/cm² Be	^{18}N	2.10^{-6}	^{16}C	2.10^{-6}	^{13}B	$1.5.10^{-6}$
		^{17}N	$\sim 10^{-4}$	^{15}C	4.10^{-6}	^{12}B	10^{-6}
		^{16}N	$\geq 10^{-4}$	^{14}C	10^{-4}	^{11}B	$\gtrsim 5.10^{-6}$
65 MeV/u ^{18}O	1026 mg/cm² Be	^{17}N	5.10^{-6}	^{16}C	$0.5.10^{-6}$		

Table 1 : Production yields (I/I_0) for various secondary beams (S.B.) obtained from ^{40}Ar and ^{18}O primary beams.

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2.2. ^{18}O beam

2.2.1. Production of 50 MeV/u secondary beams

Using a 567 mg/cm² Be target, various secondary beams of about 50 MeV/u have been produced in the mass range 10-18. An example of the beam profiles observed at the achromatic focus is given in fig. 1a. The emittance of a ^{16}C secondary beam has been measured using the beam profiles in two different positions, and is equal to 30 ± 6 π mm.mrad.

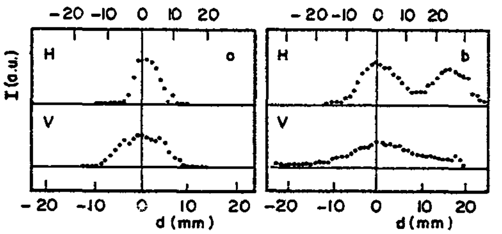

Fig. 1 : Horizontal (H) and vertical (V) beam profiles observed at the LISE achromatic focus. The intensity collected on each wire is plotted versus the wire position d. Note that the wire spacing is equal to 1 mm for vertical profiles and to 1.5 mm for the horizontal ones.

a. Non purified ^{16}C beams produced in a 567 mg/cm² or in a 1036 mg/cm² Be target (similar profiles are observed for both targets).
b. Secondary beams produced in a 1036 mg/cm² Be target and purified with a 150 mg/cm² Al degrader. The horizontally centered peak contains almost pure ^{16}C, the peak on the right is a mixture of several components, the main ones being ^{15}C and ^{13}B.

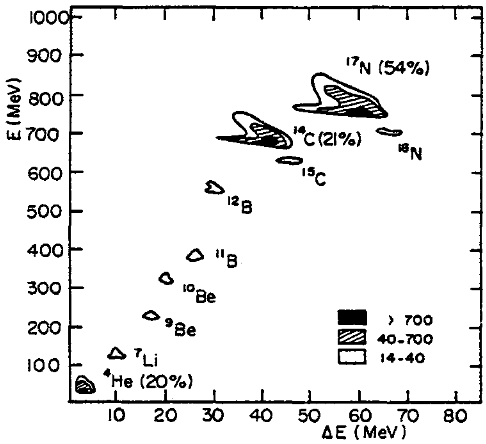

Fig. 2 : Bidimensional plot showing the isotopic composition of a secondary beam obtained in the following conditions : 65 MeV/u ^{18}O + 567 mg/cm² Be ; Bρ = 2.44 Tm ; ΔBρ/Bρ = ± 0.17 %. The abundances of the main components are given in parenthesis.

The isotopic composition of a secondary beam optimized for ^{17}N production is shown in fig. 2. Such bidimensional plots, associated with primary beam intensity measurements are used to determine the production yield for each isotope, and for each value of the magnetic rigidity Bρ. The resulting curves are presented in fig.3, and the maximum production rates, deduced from these curves, are given in table 1.Note the relatively high yields for $^{16-17}N$ and ^{14}C, and also the odd even effects in the production of the couples ^{15}C-^{16}C and ^{12}B-^{13}B. The significant yield for ^{18}N is interesting to remark,firstly because it is a relatively exotic nucleus, and secondly because it can be produced only through a transfer (charge exchange) reaction.

2.2.2. Production and purification of 34 MeV/u secondary beams

Secondary beams have been produced around 34 MeV/u from the 65 MeV/u ^{18}O beam using a 1036 mg/cm² Be target. Due to the increase in target thickness, the Bρ distribution for each isotope is now much broader. As a consequence, the individual yields for a given Bρ value are lower than with the 567 mg/cm² target (see table 1). The influence of the target nature was studied using 1138 mg/cm² Al and 1350 mg/cm² Ni targets which lead to the same energy for secondary beams. This study showed that Be targets are more efficient by a factor 2.5 relative to Al and 5 relative to Ni targets for the production of secondary beams of masses not very far from the projectile one. These numbers correspond to almost equivalent cross sections in the three targets.

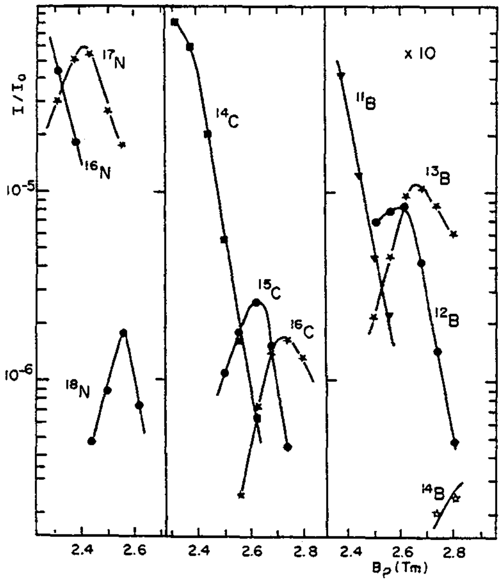

Fig. 3 : Variation of the production ratio I/I_0 of secondary beams with the magnetic rigidity Bρ, for a Bρ acceptance of ± 1.67% (65 MeV ^{18}O + 567 mg/cm² Be).

With such thick targets, a beam obtained for a given Bρ value is now composed of a large number of nuclides, as can be seen in fig. 4a. An efficient purification can be performed by using a wedge degrader (achromatic) placed between the two dipoles. After going through this degrader, secondary beams are dispersed by the second dipole according to their new magnetic rigidity. This can be seen in fig. 1b where a beam profile obtained at the focus in these conditions is displayed. By setting the proper value of the second dipole magnetic field, a spectacular purification of ^{16}C is achieved, as shown in fig. 4b. This is made with negligible intensity loss for ^{16}C. Another tuning of dipole 2 selects a mixture of beams corresponding to the same magnetic rigidity after going through the degrader (see fig. 4c).

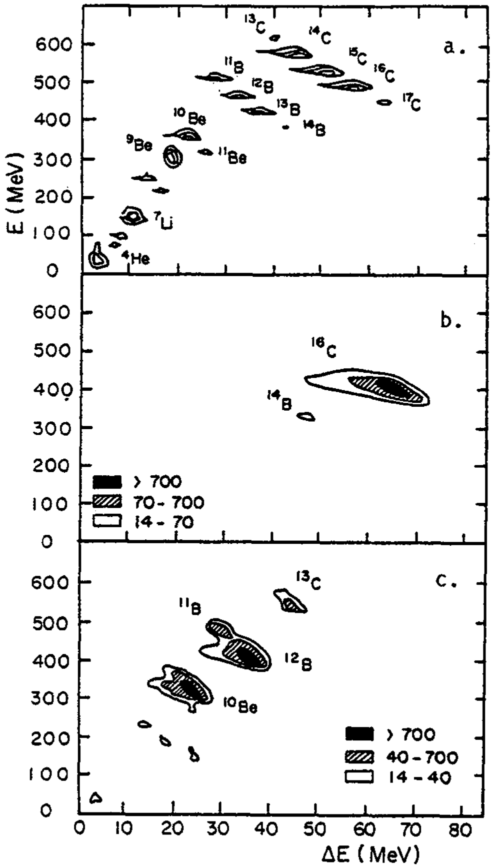

Fig. 4 : Same as fig. 2 for a 1036 mg/cm² Be target
a. unpurified beam ($B_1\rho$ = 2.248 Tm, $\Delta B\rho/B\rho$ = ± 0.22 %)
b. ^{16}C purified beam (same $B_1\rho$, 150 mg/cm² Al intermediate degrader, $B_2\rho$ = 2.114 Tm, $\Delta B\rho/B\rho$ = ± 2.78 %)
c. secondary beam obtained with the same $B_1\rho$ and $\Delta B\rho/B\rho$ values, and $B_2\rho$ = 2.154 Tm.

This study shows that the best purification of a given secondary beam can only be obtained by a careful selection of target thickness, magnetic field in first dipole, Bρ acceptance, degrader thickness and magnetic field in second dipole.

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