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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 ⁴⁰Ar (2) and 65 MeV/u ¹⁸O projectiles. This paper recalls the results of the Ar experiment, and presents new data obtained with the ¹⁸O 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. ⁴⁰Ar 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/I₀ (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/cm ² Be	41K	5.10 ⁻⁵	38Ar	10 ⁻⁴	39Cl	10 ⁻⁴
				39Ar	3.10 ⁻⁴	38S	0.6.10 ⁻⁵
65 MeV/u ¹⁸ O	567 mg/cm ² Be	18N	2.10 ⁻⁶	16C	2.10 ⁻⁶	13B	1.5.10 ⁻⁶
		17N	~ 10 ⁻⁴	15C	4.10 ⁻⁶	12B	10 ⁻⁶
		16N	≥ 10 ⁻⁴	14C	10 ⁻⁴	11B	~ 5.10 ⁻⁶
65 MeV/u ¹⁸ O	1026 mg/cm ² Be	17N	5.10 ⁻⁶	16C	0.5.10 ⁻⁶		

Table 1 : Production yields (I/I₀) for various secondary beams (S.B.) obtained from ⁴⁰Ar and ¹⁸O primary beams.

2.2. 180 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 ¹⁶C secondary beam has been measured using the beam profiles in two different positions, and is equal to $30 \pm 6 \pi$ mm.mrad.

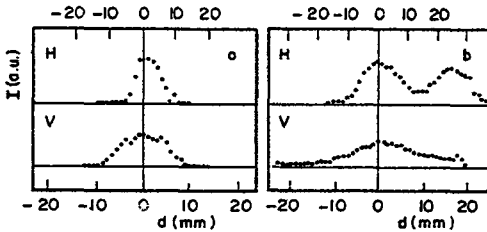


Fig. 1 : Horizontal (H) and vertical (V) beam profiles observed at the LISE achromatic focus. The intensity collected on each wire is plotted versus the wire position d . Note that the wire spacing is equal to 1 mm for vertical profiles and to 1.5 mm for the horizontal ones.

- Non purified ¹⁶C beams produced in a 567 mg/cm² or in a 1036 mg/cm² Be target (similar profiles are observed for both targets).
- 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 ¹⁶C, the peak on the right is a mixture of several components, the main ones being ¹⁵C and ¹³B.

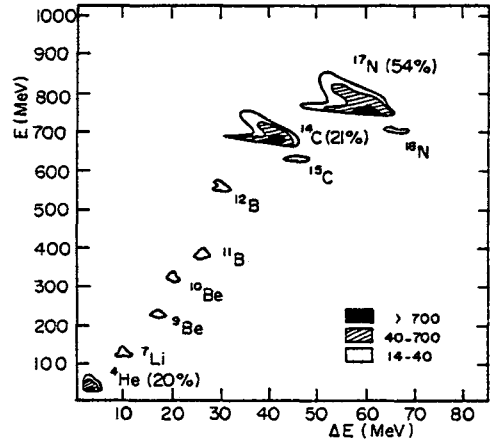


Fig. 2 : Bidimensional plot showing the isotopic composition of a secondary beam obtained in the following conditions : 65 MeV/u ¹⁸O + 567 mg/cm² Be ; $B\rho = 2.44$ Tm ; $\Delta B\rho/B\rho = \pm 0.17$ %. The abundances of the main components are given in parenthesis.

The isotopic composition of a secondary beam optimized for ¹⁷N 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 $B\rho$. 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 ¹⁶-¹⁷N and ¹⁴C, and also the odd even effects in the production of the couples ¹⁵C-¹⁶C and ¹²B-¹³B. The significant yield for ¹⁸N 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 ¹⁸O beam using a 1036 mg/cm² Be target. Due to the increase in target thickness, the $B\rho$ distribution for each isotope is now much broader. As a consequence, the individual yields for a given $B\rho$ 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.

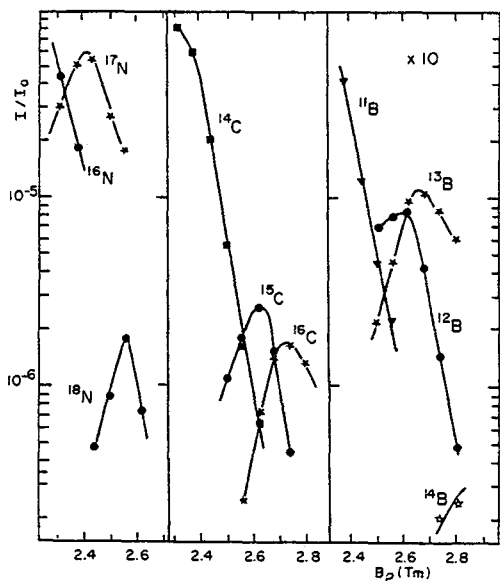


Fig. 3 : Variation of the production ratio I/I_0 of secondary beams with the magnetic rigidity B_ρ , for a B_ρ acceptance of $\pm 1.67\%$ (65 MeV $180 + 567$ mg/cm² Be).

With such thick targets, a beam obtained for a given B_ρ 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).

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, B_ρ acceptance, degrader thickness and magnetic field in second dipole.

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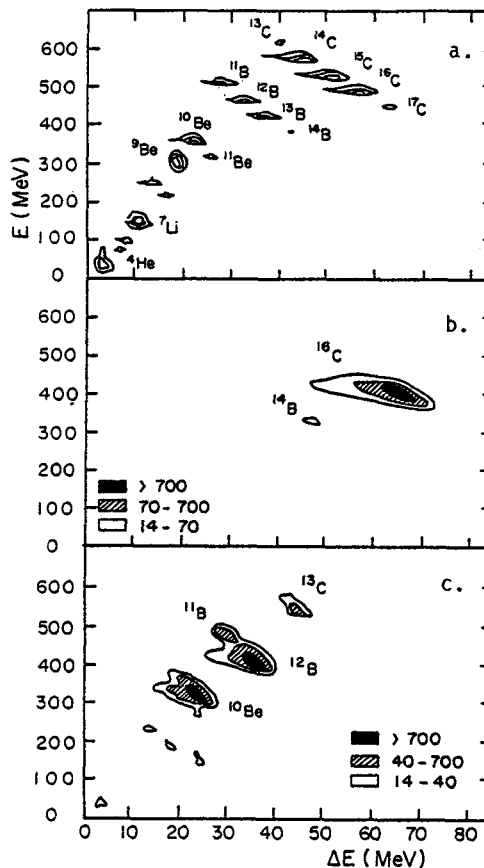


Fig. 4 : Same as fig. 2 for a 1036 mg/cm² Be target
 a. unpurified beam ($B_{1\rho} = 2.248$ Tm, $\Delta B_\rho/B_\rho = \pm 0.22\%$)
 b. ^{16}C purified beam (same $B_{1\rho}$, 150 mg/cm² Al intermediate degrader, $B_{2\rho} = 2.114$ Tm, $\Delta B_\rho/B_\rho = \pm 2.78\%$)
 c. secondary beam obtained with the same $B_{1\rho}$ and $\Delta B_\rho/B_\rho$ values, and $B_{2\rho} = 2.154$ Tm.