CERN/PSCC/82-46
PSCC/P60
22 July, 1982

Proposal (experiment SC 86)

Studies of ^{18}O projectile residues at 0°

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Summary : We propose to use the electrostatic collection method to study the characteristics of light exotic nuclei. These nuclei are produced in interactions of ^{18}O with a thick carbon target. Magnetic and "atomic" separations are successively applied to perform a complete discrimination of each given specie. ^{15}B radioactive properties will be specifically studied.

Spokeman : A. FLEURY

MOTIVATIONS OF THIS EXPERIMENT

This proposal is the second facet of the SC 86 experiment. In the first one, cross sections and dynamical properties of heavy target residues produced in interactions with the SC ^{12}C beam have been studied using our new electrostatic collection device. The search for neutron deficient heavy new isotopes has not been successful but much new information has been obtained on the reaction mechanisms in this energy regime : momentum transfer, damping of the kinetic energy, mass distributions immediately after the first reaction step.

In the second phase of this experiment attempts to collect the projectile residues will be carried out. The goals of this experiment are multiple. We would like to investigate the reaction mechanisms at 0° in order i) to produce secondary beams for subsequent secondary reactions, ii) to produce and collect new exotic light nuclei for studies of radioactive properties and nuclear mass stability, iii) to study the range energy relations and compare the experimental results with the table we have recently published.

This experiment should be considered as a preliminary test of a new experimental collection device which will be widely used at GANIL and a test of the following experimental ideas for the studies of light new isotopes and secondary beams.

THE PRINCIPLE OF THE EXPERIMENT

The most severe limitation in the studies of many new exotic nuclei is more in the rapid and specific separation and collection of these nuclei than in the production possibilities. The most spectacular progress in this field during the last years have come from devices in which a rapid charge and mass selection can be performed. The role of solid state chemistry, as in the mass separator sources, has been, for instance,very well illustrated.

In this proposal the projectile residues are produced in a thick carbon target (between 0.1 and 2.5 g/cm^2) located before the first deflection magnet (MP 5) of the SC lines. A first magnetic separation is performed by this magnet and the selected ions are driven along the beam pipe into the experimental area. There, an "atomic" separation is performed using the range energy relation differences among the nuclei selected by the magnet. For each nuclear specie one can select an aluminium degrader (Fig. 1) so that this specie only is thermalised in the collection device. The other nuclei are trapped in the degrader or in the collector. The collection set-up is schematically drawn in Fig. 2. The ions thermalised in the gas are transported by a gas flow into the collection region. There a focusing field is applied and the ions are deposited on the surface of the particle detector. Correlations or anti-correlations can be made with a β or γ detector located close by.

In the next paragraph, the production and collection conditions will be analysed and the straggling problem will be particularly studied.

THE CONDITIONS OF THE EXPERIMENT

The nuclear physics background

For ^{18}O interactions the production rates of the projectile residues have not yet been measured, and the intensity of the secondary beam hardly can be estimated, especially as it depends on the $B\rho$ acceptance of the beam line. Using an intranuclear cascade code one can first calculate the total production cross sections of projectile residues in the interaction of ^{18}O at 86 MeV per nucleon on ^{12}C. For the emission of one to three protons one gets values for the conversion ratio (secondary intensity divided by the primary one) of $4\ 10^{-4}$ for ^{17}N, 10^{-4} for ^{16}C and 10^{-5} for ^{15}B.

For the dynamical properties of this reaction one can use the results of similar reactions. In the case of ^{12}C at the same energy the angular distributions are forward peaked and the telescope measurements close to 0° performed by Mougey et al. and Lynen et al. have shown that in the forward direction the fragment velocities are very similar to the projectile velocity.

Two examples of the energy dispersion around this average value are shown in Fig. 3 and 4 for ^{12}C at 86 AMeV and ^{40}Ar at 213 AMeV. The Ar results obtained at Berkeley are well reproduced by the Goldhaber formula $\sigma^2 = \sigma_0^2 \frac{F(A-F)}{A-1}$ where σ_0 = 95 MeV/c, F and A are the mass numbers of the residue and the projectile respectively.In the case of ^{12}C ions obtained at CERN the distributions are much wider and the fit can be obtained only when an additionnal term is used : $\sigma^2 = \sigma_0^2 \; F(A-F)/(A-1) + \gamma^2F^2/A^2$ with γ = 160 MeV/c. This greater width in the energy or momentum distribution can be explained by the nature of the ^{12}C ion in which the α clustering is large or/and by the lower energy. For the subsequent calculation, in the case of ^{18}O, we have used the most unfavorable results obtained with the ^{12}C beam.

The atomic physics ingredients

The large target thickness introduces a new straggling effect due to the differences between the stopping power of the incident ion and the produced nuclei. In Fig. 5 are shown the extreme energies E_1 and E_2 obtained for secondary carbon ions produced in ^{18}O interactions on a 1 200 mg/cm^2 thick carbon target. E_1 and E_2 stand for nuclear reactions occuring in the first and last layers of the target material respectively. The results have been obtained using the new F. Hubert et al. table. The secondary ion velocity is supposed to be the velocity of the projectile when the nuclear reaction takes place. For the heaviest carbon isotopes this straggling is very severe and the energy dispersion of the "secondary beam" is close to 30 %. A large fraction of these ions will be lost in the transport line to the experimental area depending upon the admittance of this line. On the other hand, the E_1-E_2 difference decreases when the mass of the carbon isotope decrease unto ^{10}C where the straggling is very small.

A secondary atomic straggling effect comes from the statistical nature of the slowing down process. Using the theory of Sigmund and Winterbon one can shown that the angular straggling is very small. For instance 80 % of the ions are found in a 6 mrad cone when ^{12}C ions at 86 AMeV go through a 1 g/cm^2 carbon target. Similarly the energy straggling calculated in the same case using the Schmidt and Bocking formula is only 1 MeV.

The separation possibilities

Using the atomic and nuclear straggling and the dynamics of the nuclear reaction it is therefore possible to analyse the separation possibilities of the various species produced in interactions of ^{18}O at 86 AMeV on ^{12}C targets.

In Fig. 6 are shown the Bρ dispersion obtained for each secondary ion produced when a 300 mg/cm^2 ^{12}C target is used. For sake of clarity the results have been split so that on each line are shown the Bρ dispersions for the various isotopes of a given element. For each Bρ value the separation is not complete and several isotopes are transported simultaneously into the experimental area. On the same figure is shown for a selected Bρ value (3.165 T.m.) and a given admittance of the line (1 %) the transported nucleus ranges in an aluminium catcher. In this case a complete separation is performed among ^{18,17}N, ^{15}N, ^{13,12}B. For instance using a degrader of 2 500 mg/cm^2 and a 200 mg/cm^2 Al collector or the same equivalent thickness of gas, it is therefore possible to collect specifically ^{15}C. ^{18,17}N are stopped in the degrader and ^{13,12}B in the catcher.

In Fig. 7 are shown the results obtained when a 2 250 mg/cm^2 ^{12}C target is used. In this case the ^{18}O primary beam is stopped in the target. The Bρ dispersion is now very large and for each ion is extended to zero. These very large dispersions would be limited if the evolution of the production rates with the incident energy were introduced in the calculations. For a Bρ value of 3.154 ± 0.03 one gets a clean separation of ^{14,12}Be, ^{9}Li but ^{11}Li and ^{15}B are still superimposed. The ^{11}Li desintegration properties are well known and it is therefore possible to use this method to study ^{15}B for which no desintegration characteristics are known.

BEAM TIME REQUIREMENT

For this experiment including the verifications of the preceeding calculations and some tests of the experimental device we would require a run of 9 eight-hour shifts.

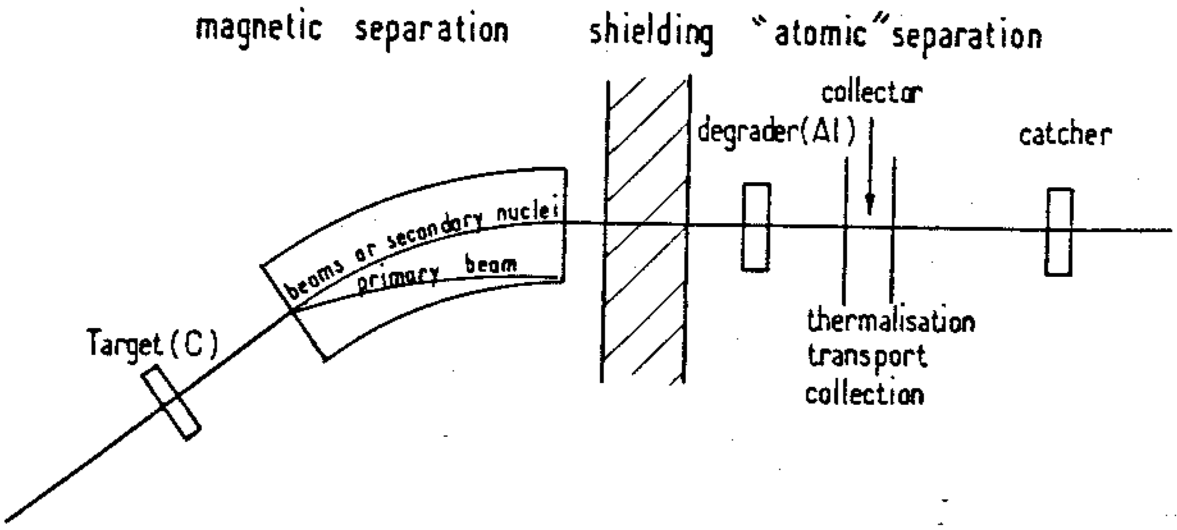

Fig. 1 : Schematic drawing of the separation principle

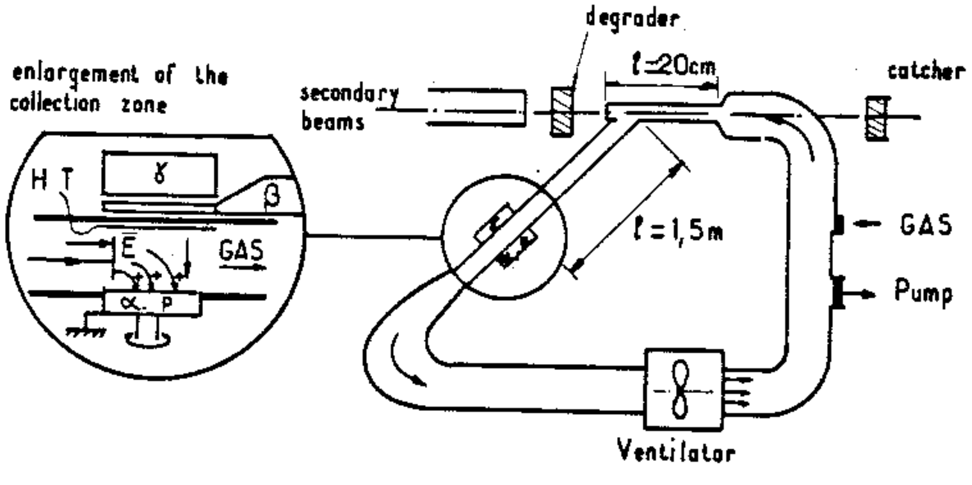

Fig. 2 : Design of the collection device

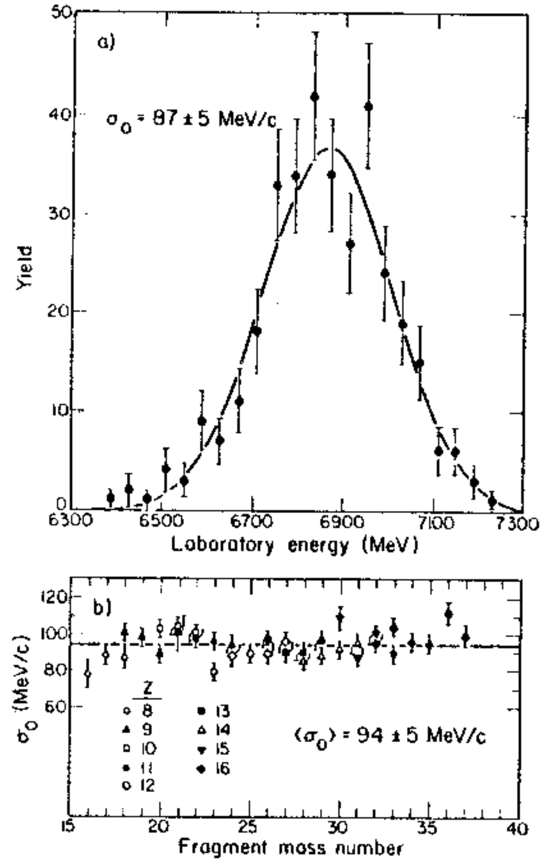

FIG. 1. (a) Measured energy spectrum of ^{34}S at 1.5° from fragmentation of 213-MeV/nucleon ^{40}Ar on a carbon target. The solid line corresponds to a fitted Gaussian momentum distribution. (b) Values of σ_0 for the fragments in the mass range 16 to 37. (For each fragment, the weighted mean of σ_0 obtained from the energy spectra at many angles is shown.)

Fig. 3 : From Y.P. Vigori et al. :
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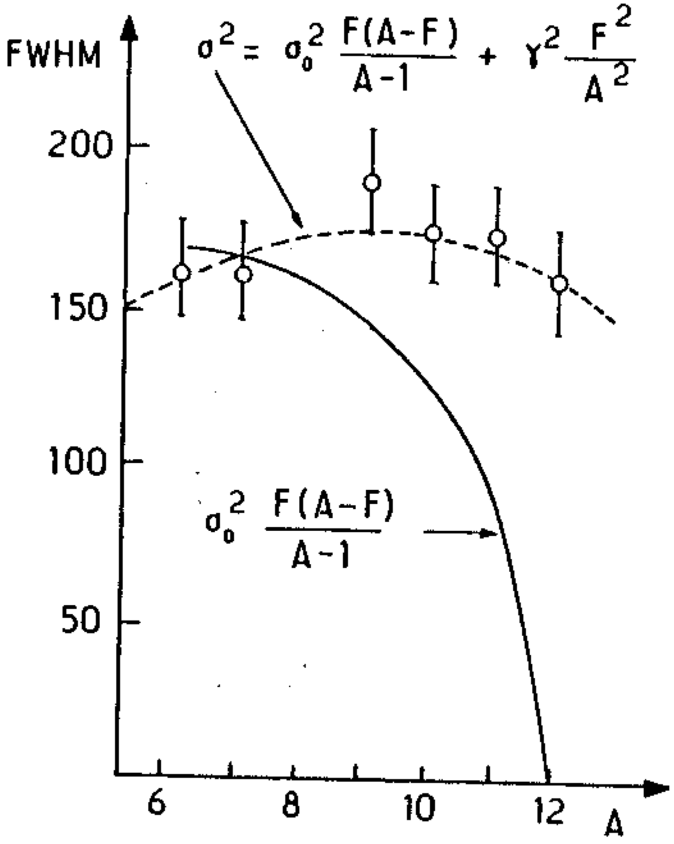
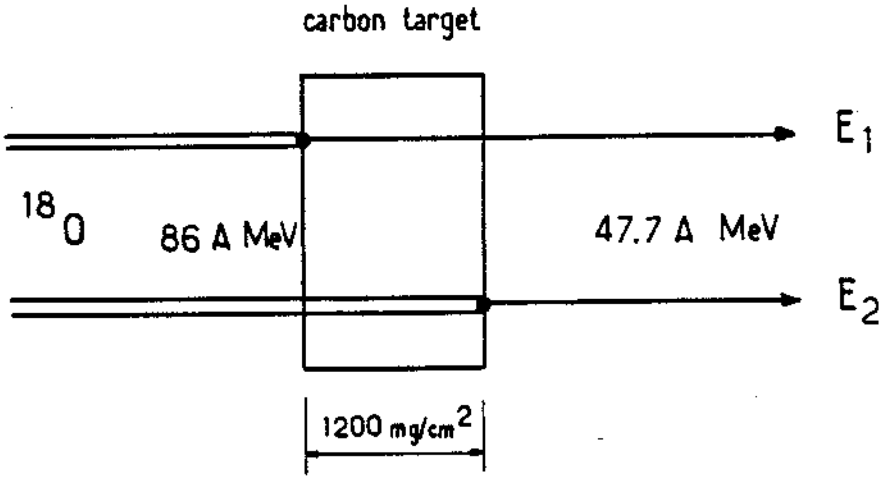


Fig. 4 : Values of the FWHM of the momentum distribution in 86 AMeV ^{12}C interaction on a light target : (from Mougey et al.)



	^{9}C	^{10}C	^{11}C	^{12}C	^{13}C	^{14}C	^{15}C	^{16}C
E_1	379	478	574	667	758	849	939	1027
E_2	430	471	524	573	620	659	716	763

Fig. 5 : Energy dispersion of secondary carbon beams produced in 86 AMeV ^{18}O interaction with a thick ^{12}C target

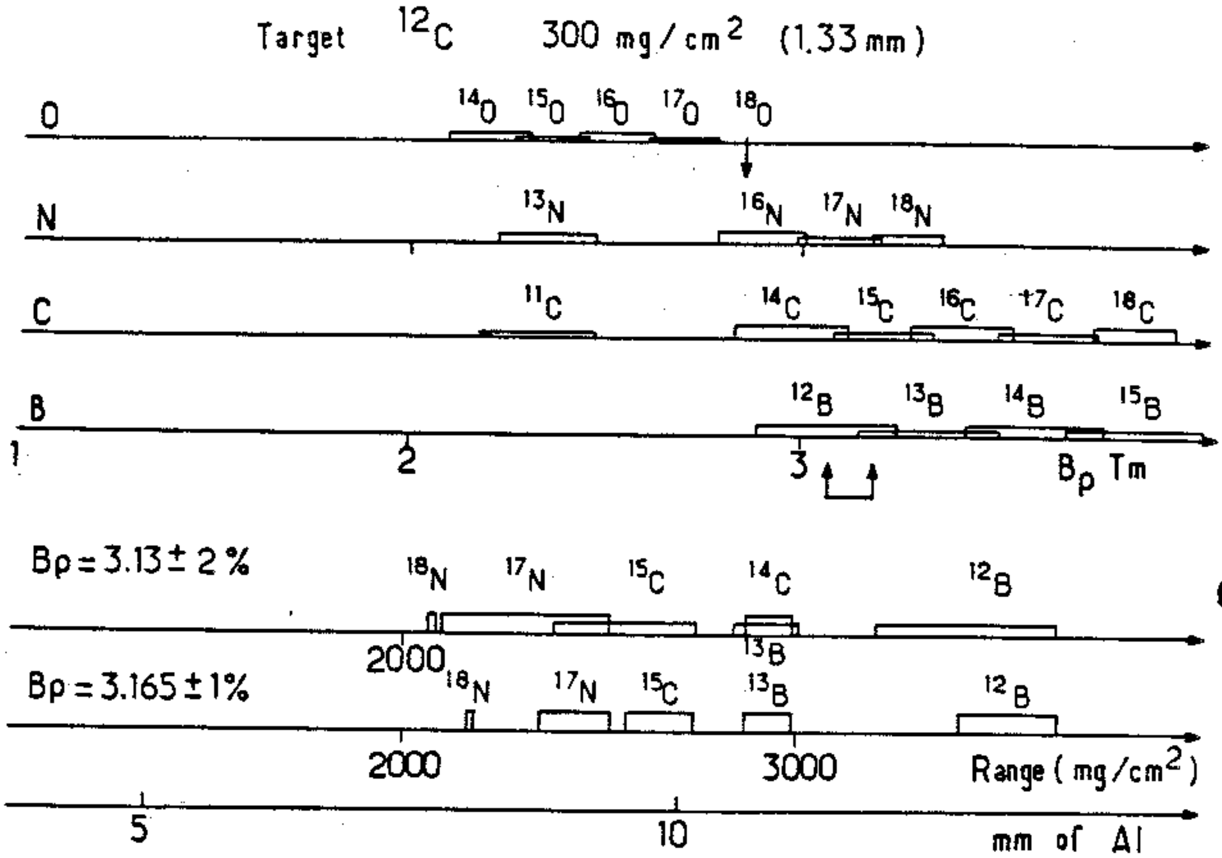


Fig. 6 : Complete separation of ^{18,17}N, ^{15}N, ^{13,12}B using the device shown in Fig. 1 (see text)

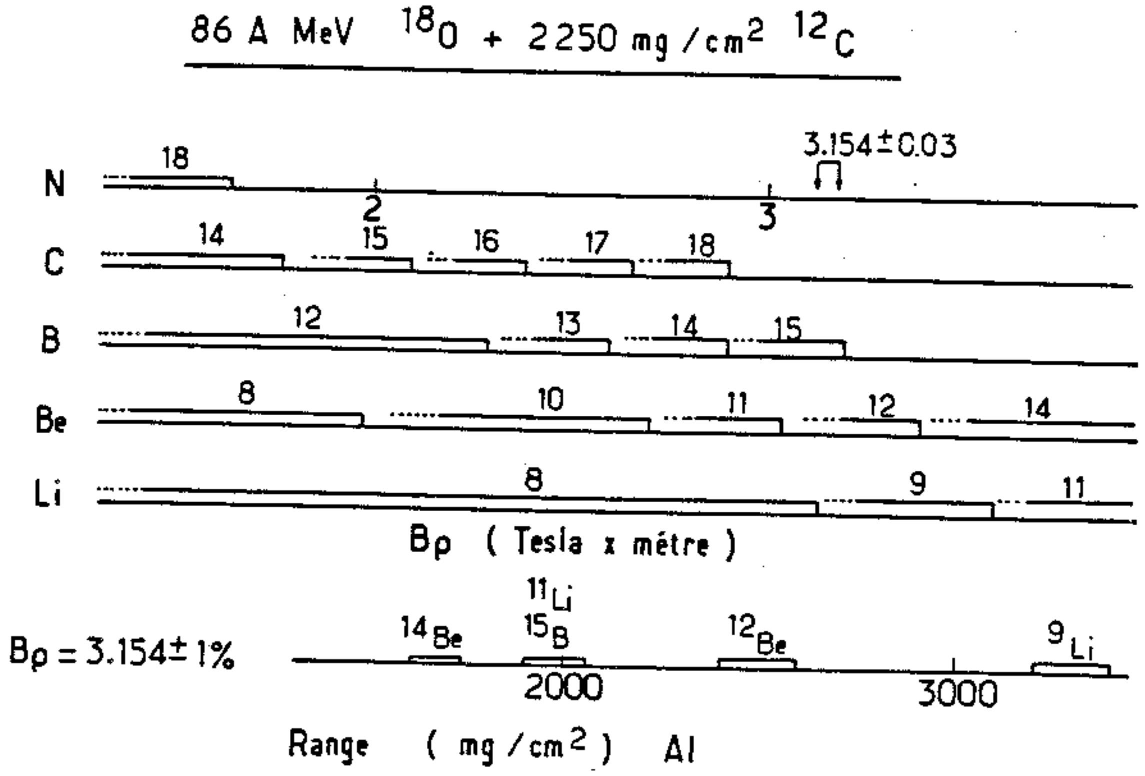


Fig. 7 : Possibilities of ^{15}B radioactive property studies after magnetic and atomic separation (see text)