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THE BEAM-STRIPPER INTERACTION STUDIES FOR GANIL

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Abstract

A series of experiments on angular and energy straggling of heavy ions traversing carbon foils was carried out on the MP Tandem at Strasbourg, along with foil lifetime studies. An adaptation of the results and of the already available knowledge applicable to the GANIL mass and energy range is presented.

1. Introduction

The GANIL beams which have to be stripped between the two separated-sector cyclotrons SSC1 and SSC2 range from 6 to 92 in atomic number, from 0.37 to 7.4 MeV/nucleon in energy and from 10^{10} to 10^{14} p.p.s. in intensity[1]. In order to predict the beam qualities at the exit of SSC2, it was necessary to evaluate the effects caused by the stripper on this wide variety of beams extracted from SSC1: multiple scattering leading to an increase of the angular divergence and of the energy spread, and energy loss. Conversely, whenever a solid stripper is used, its average lifetime under heavy-ion bombardment had to be estimated. Under these circumstances, a series of experiments was performed in collaboration with a Strasbourg team on their MP Tandem [2 3 4 5]. Our results, added to the previous ones obtained in several other laboratories around the world, led to the conclusions presented here. Although some GANIL beams may be stripped by a gas stripper (for mass numbers < 40), we present only results related to solid (mostly carbon) strippers.

2. Foil thickness

The estimates of the three above-mentioned stripper effects on the beams requires first of all knowledge of the optimum foil thickness to be used. Since in most cases the highest charge states of the distributions are requested at a given energy, the criterion will be the "equilibrium thickness" x_∞ which is defined as the minimum thickness above which the distribution no longer changes. In addition to the fact that the asymptotic character of this definition makes x_∞ rather imprecise, no study of its eventual dependence on the atomic number Z_p of the projectile exists. Despite this lack of knowledge, existing values of x_∞ were plotted versus the energy W, regardless of Z_p, for light solid strippers (Fig. 1). The appreciable scattering of the data probably has several origins:

a) Z_p might be a parameter, although no systematic dependence could be discerned.

b) Authors sometimes do not indicate the accuracy with which the thicknesses were measured.

c) x_∞ is either defined by the thickness after which the proportions of all charge states become constant, or by the asymptotic value of the mean charge $\bar{q}$.

Rather than choosing a x_∞ versus W function that would go through the highest points of the diagram (which would probably guarantee the maximum proportions of the highest charge states, but would in turn lead to a beam loss due to an excessive multiple scattering), we preferred to fit all the data by a simple analytical function (least-squares fit) given by:

$$x\ (\mu g/cm^2) = 5.9 + 22.4\ W - 1.13\ W^2 \qquad (1)$$

where W is in MeV/nucleon (see curve on Figure 1). As a consequence of this choice, we will give, in the three following sections, estimates of the angular and energy spread and of the energy loss as functions of the energy W, each value of W being linked to unique value of x, given by equation (1), regardless of Z_p.

3. Energy loss

3.1 Determination of the energy loss

Many experiments allow the prediction of the stopping power $\frac{dE}{dx}$ of heavy ions in carbon in the energy range considered here. Knowing the stripper thickness x, it is easy to calculate the energy loss ΔW of a beam of in-

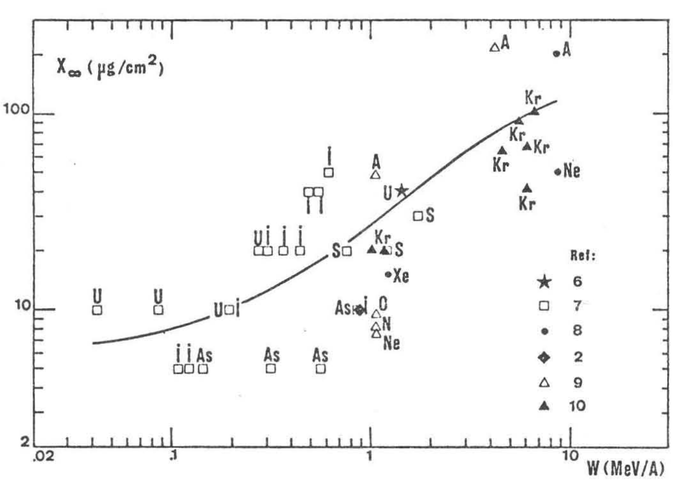

Figure 1 Stripper equilibrium thickness versus beam energy. The projectiles are indicated.

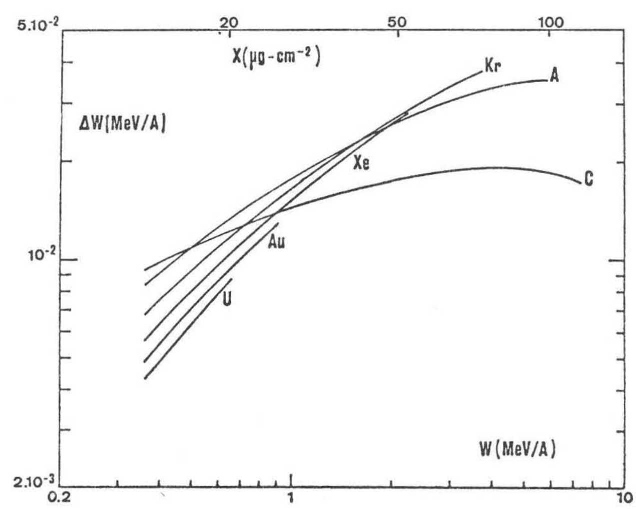

Figure 2 Energy loss of various ions in a carbon foil with equilibrium thickness versus energy.

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coming energy W and mass number A_p,

$$\Delta W = \frac{x}{A_p} \left(\frac{dE}{dx} \right) , \qquad (2)$$

through existing tables or computer codes. In figure 2, we illustrate the expected ΔW in a carbon stripper with the help of the tables computed by Northcliffe and Schilling [11] for C, A, Kr, Xe, Au and U ions.

3.2 Energy loss compensation

Due to the fact that, for RF frequency reasons, the velocities of the beam extracted from SSC1 and of the beam injected into SSC2 must match exactly, one way of compensating the energy lost in the stripper is to raise the foil to a positive d.c. potential V with respect to the beam pipe; in this way, the total energy gain of the particle having an incoming charge q_1 and an outgoing charge q_2 is given by

$$\Delta E = V \, (q_2 - q_1) \qquad (3)$$

and can be made equal to the energy loss. Such a system would require a maximum voltage of about 150 kV. It should be mentioned that, if parasitic phenomena like changes in foil thickness should occur during its lifetime, the method of readjusting the velocity by variation of a d.c. voltage is particularly simple.

4. Angular Scattering

Many groups [4 12 13 14 15 16 17] have established the validity of Meyer's theory [18] which allows one to calculate the width $\Theta_{1/2}$ (HWHM) and the shape of the quasi-gaussian angular distribution of an initially parallel beam after traversing a foil of a given thickness and material. The width $\Theta_{1/2}$ generated by the carbon stripper for the GANIL beams is represented in Figure 3 as a function of energy for different projectiles.

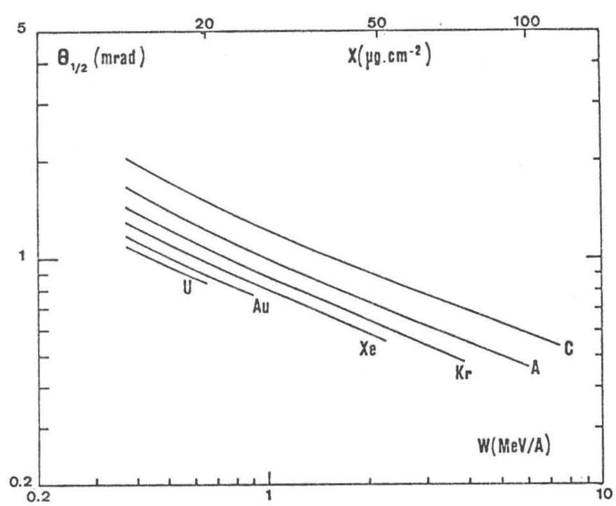

Figure 3 Calculated width (HWHM) of the angular distribution of various ion beams traversing a carbon foil with equilibrium thickness versus energy.

5. Energy spread

No theory exists for predicting the spread δW of an initially monoenergetic heavy ion beam after traversing matter. We performed a few experiments at Strasbourg with Ni, I and Au ions in carbon (Fig. 4), with results which differ substantially from what can be drawn from Tschalär's work [19]. It seems that, in the GANIL energy range, we can estimate the half-width at half-maximum of the energy distribution through a formula similar to that of Bohr [20],

$$\underset{(\text{MeV/A})}{\delta W} = \pm\, 0.462 \; \left(\frac{Z}{A}\right)_p \sqrt{\left(\frac{Z}{A}\right)_t \cdot x} \quad (x \text{ in g/cm}^2) \qquad (4)$$

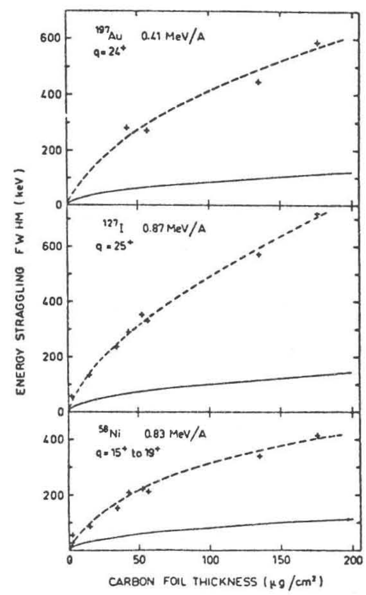

Figure 4 Experimental width (FWHM) of the energy distribution of Au, I, and Ni ions after traversing a carbon foil. From reference (4).

where indices p and t refer to projectile and target, respectively, the Z's and the A's being the atomic and mass numbers. This energy- independent empirical formula does not claim an accuracy better than 35%. The expected values of the relative energy spread for the GANIL beams are plotted on Figure 5.

6. Carbon foil lifetime

Among the numerous possible causes for foil breakage under bombardment by heavy ions (thickening, sputtering, thermal and mechanical stresses, etc....), it seems increasingly more certain that a re-ordering of the originally amorphous carbon structure makes the foil thinner. Therefore, it appears reasonable to take into account the number of displaced atoms in the crystal in order to establish a theory of foil destruction. We thus have made the following assumption: the foil life T comes to an end when each of its carbon atoms has suffered a given average number of displacements. This number can be obtained, for instance, from Seitz's theory [21], and the lifetime may be put in the form,

$$T = C \cdot \frac{W}{Z_p^2 \cdot \bar{\nu} \cdot j} , \qquad (5)$$

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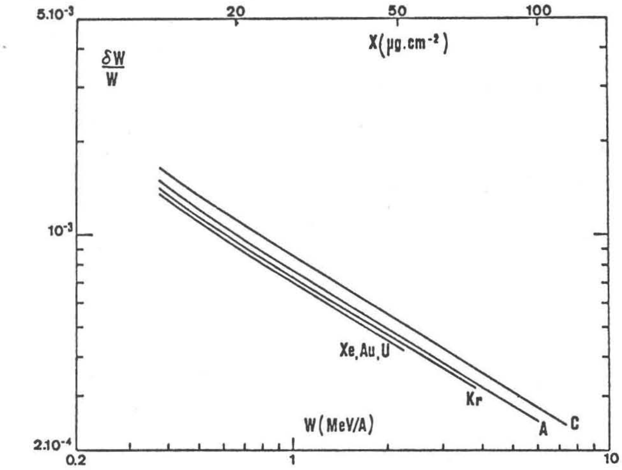

Figure 5 Estimated relative energy spread (HWHM) of various ion beams passing through an equilibrium thickness of carbon.

where J is the beam current density, and $\bar{\nu}$ the average number of atoms displaced by a carbon atom having suffered a collision with a beam ion ($\bar{\nu} \sim 5$ to 8 in the cases considered here). We have fitted expression (5) to both our own results for iodine ions (3) and the results obtained in several other laboratories. It turns out that, in many cases, the constant C takes the value:

$$C = 3.6\ 10^4\ \text{h - p}\mu\text{A - cm}^{-2}\ (\text{MeV/nucleon})^{-1} \quad (6)$$

Figure 6 shows the foil lifetime T plotted versus energy W for different ion species and with J=1 pμA - cm^{-2}. The low T values foreseen for very heavy ions can be increased, if these beams are too intense, by expanding the beam spot size or by moving the foil across the beam.

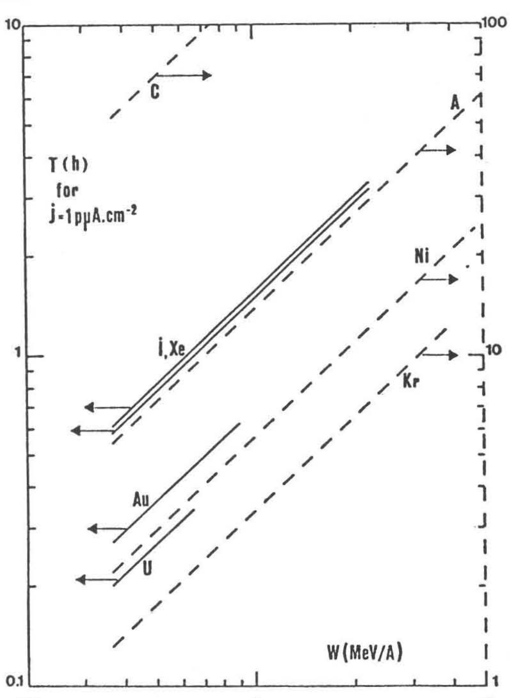

Figure 6 Estimated carbon foil average lifetime under bombardment by various 1 pμA — cm^{-2} ion beams.

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