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BEAM FOIL INTERACTION STUDIES FOR THE FUTURE STRIPPER OF GANIL

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Summary

The GANIL 3 - cyclotron accelerator complex is to be upgraded in 1989 by increasing the beam energy at the stripper. In view of this modification, the effect of carbon stripper foils of various thicknesses (from 50 to 250 µg/cm^2) on the energy spread of Ar, Kr, Xe and Ta beams was measured using the analysing section of the 270° spectrometer. Energies ranging from 3.2 to 6.5 MeV/A (i.e. corresponding to the future energy range) were used, and intensities of several hundreds of electrical nanoamperes were concentrated over a few mm^2 spot.

Unusually large values of the additional energy spread are reported. In addition, charge state distributions of the 6.48 MeV/A Xe and 4.81 MeV/A Ta beams were measured as a function of the carbon thickness, in order to be able to choose how close to the equilibrium thickness the stripper should be, while keeping the energy spread of the outgoing beams within reasonable limits.

1) Introduction

The energy spread δW generated by the carbon stripper foils on the GANIL heavy ion beams may, if too large, lead to particle losses in the third stage of acceleration SSC2. Measurements performed with the MP tandem at Strasbourg$^{(1)}$, and a compilation of experimental values available at the beginning of the GANIL operation had led to the semi-empirical formula for the carbon foils :

$$\delta W/W = \pm 0.5.10^{-3}\frac{(1.206+0.25\ \mathrm{Log}\ W)}{W(\mathrm{MeV/A})}(Z/A)_p\sqrt{(Z/A)_t x(\mu g/cm^2)} \qquad (1)$$

where δW is the HWHM value, x the foil thickness, Z and A the atomic and mass numbers, the indices p and t respectively referring to projectile and target. However, since then, the day-to day operation of the accelerator revealed δW values higher than expected through (1). In addition, the machine modification to be undertaken at the end of 1988 in view of increasing the energy of the"medium heavy"-to-"very heavy" ion beams ("O.A.E" project$^{(2)}$) is based on energies at the stripper much higher than the present ones (figure 1) and therefore, thicker targets will be required to reach equilibrium for the charge state distributions ; scarce values collected in different laboratories indicate that we should expect up to 300 (or even 500 µg/cm^2) equilibrium thicknesses, to be compared to the present 80 µg/cm^2 value. Figure 1 also shows that ion species above xenon will be accelerated and stripped at energies where poor data exist on charge state distributions P(Q) as a function of carbon thickness. We therefore had to refine our knowledge on these two parameters : δW and P(Q).
Moreover, the energy loss ΔW caused by these thicker foils can no longer be compensated by a polarisation of the stripper, and this has to be taken into account in the design of the SSC2 injection system ; a precise knowledge of the required range of thickness is necessary.

In view of this, we carried out a series of measurements of δW versus carbon thickness with 3.24 MeV/A Ar, 7.53 MeV/A Kr, 6.48 MeV/A Xe and 4.81 MeV/A Ta beams ; the charge state distributions were measured only with the Xe and Ta beams.

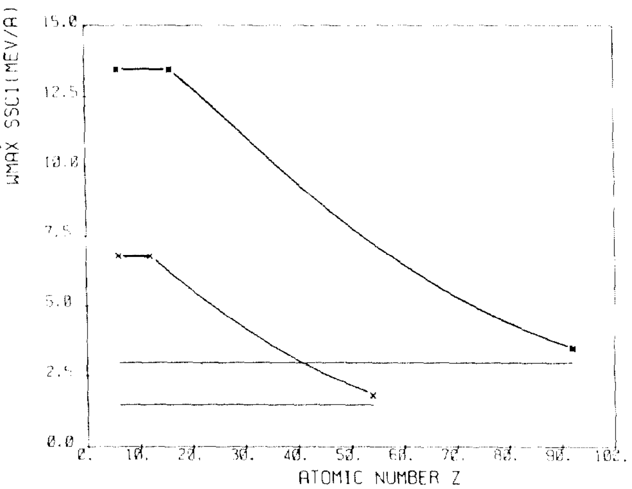

Figure 1. GANIL energy range at the stripper : present (X) and future (*)

2) Experimental method

2.1. Apparatus

We used the 135° analysing section of the high energy monochromator following SSC2 ; ion beams accelerated by SSC1 were directed to the objet focal point where the width Δx_o was measured either by movable slits, or by a beam profile monitor ; the dimension Δx_i at the image point was similary measured by a beam profile monitor (total width : 47 mm ; distance between wires : 1 mm).

The relative energy spread (HWHM) is then calculated by :

$$\delta W/W = \pm\frac{2.10^{-3}}{C_d}\sqrt{\Delta x_i^2 - \Delta x_o^2} \qquad (2)$$

where C_d is the dispersion coefficient of the analyser (6.96 mm/‰ momentumwise), and the energy spread of the unstripped beam is substracted by quadratic difference. The charge state distributions were measured using merely two Faraday cups located at the SSC1 output and at the image point of the analyser, each measurement on one cup being followed immediately by the corresponding one on the other cup for monitoring.

The target thicknesses were measured by energy difference, using the newly-calculated stopping power tables$^{(3)}$, with a 2 to 3 µg/cm^2 accuracy.

2.2. Targets

Two possible reasons for δW values larger than could be predicted were considered :

- foils could be inhomogenous from the start ; we therefore tried strippers from five different origins: three laboratories (ISN Grenoble, CRN Strasbourg and Faculté des Sciences Nantes) and two commercial firms$^{(*)}$;
- inhomogeneity could develop during the modification of the carbon structure under bombardment by intense heavy ion beams ; to check for this, one test (with tantalum) was carried out using first a reduced intensity and then the full beam (factor 10 to 15).

(*) Arizona Carbon Foil Co and Micromatter Co.

3) Results

3.1. Energy spread

The results are presented on figures 2a to 2d ; it can be seen that :

- the results are always higher than predicted by formula (1) (thin line) sometimes by a factor of 2 or 3,
- even for targets originating from the same manufacturer, the measured values do not show a smooth variation as a function of the thickness ; for example, the 70 - to - 100 μg/cm ^{2} Grenoble targets may generate a δW value comparable to the 140 - to - 180 μg/cm ^{2} ones (figures 2c),
- no target make seems to be better than the others,
- some targets give wild results (see the 212 and the 255 μg/cm ^{2} points on figure 2d).

Figure 3 shows the results of two series of measurements with foils bombarded first by a reduced (10^9 pps) Ta beam, then by the full intensity ($1.6.10^{10}$ pps) ; although there is a definite growth of the δW value for each target, the initial value is always much larger than could be predicted by formula (1).

In order to have a rough approximation for the energy spread to be expected after the "O.A.E" modification, all the experimental results were least-square fitted, giving the formula :

$$\delta W/W = \pm 0.5.10^{-3} \frac{1.866+1.57 \text{ Log } W}{W} (Z/A)_p \sqrt{(Z/A)_t . x} \qquad (3)$$

(see the thick lines on figures 2a to 2d), but the accuracy is not better than 50%.

3.2. Charge state distributions

The distributions were measured for the Xe and Ta beams with 5 and 4 different thicknesses respectively; they are presented in Table 1a and 1b, with the mean value $\bar{Q}$ and the standard deviation $\underline{d}$. For comparison, the last column shows the distribution as we usually calculate it (for equilibrium thickness and W > 1.3 MeV/A), i.e by the formulae $^{(4)}$:

$$\bar{Q} = Z_p \left(1 - \exp\left(-\frac{83.28\,\beta}{Z_p^{0.447}}\right)\right), \quad \beta = v/c \qquad (4)$$

$$d = 0.5 \sqrt{\bar{Q}\left(1 - (\bar{Q}/Z_p)^{1.667}\right)} \qquad (5)$$

(formula (5) gives $\underline{d}$ as predicted by V.S Nikolaev and I.S. Dmitriev)$^{(5)}$. It is to be noted that the apparently too high calculated $\bar{Q}$'s might be due to the fact that in neither case, the equilibrium thickness is reached, as shown by figure 4.

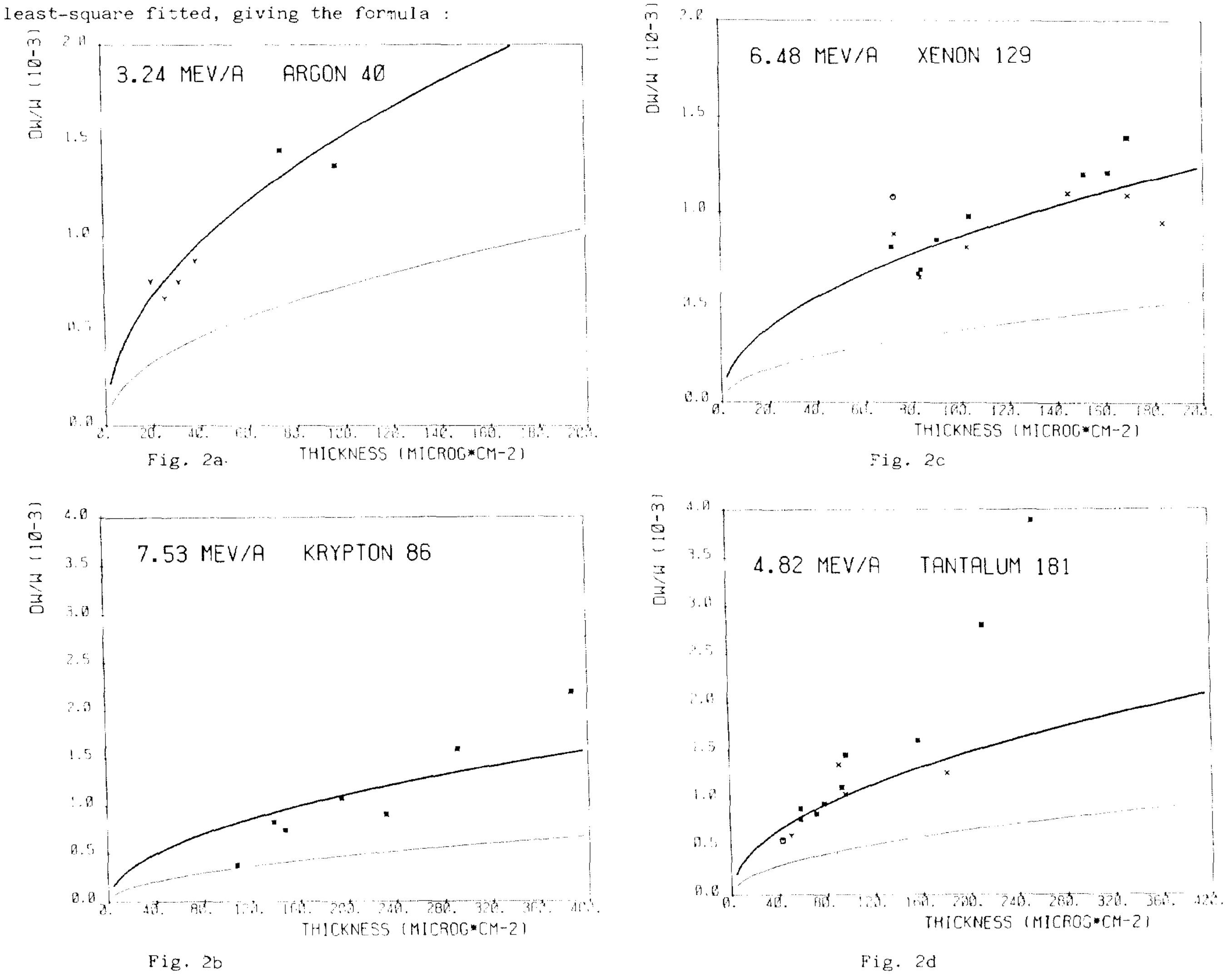

Fig. 2a

Fig. 2c

Fig. 2b

Fig. 2d

Figure 2. Relative energy spread (HWHM) generated by carbon foils on various beam. Foil origins : Strasbourg (□), Nantes (O), Grenoble (X), Micromatter (Y) and Arizona (*).
The thin and heavy lines represent expressions (1) and (4) respectively.

3.3. Choice of the stripper thickness for the "O.A.E" modification (Example)

The nominal injection energy into SSC2 can be lowered by at most 2% to account for the energy lost in the stripper ; in the cases considered here, this corresponds to foil thicknesses of 230 $\mu g/cm^2$ for Xe and 150 $\mu g/cm^2$ for Ta and, although equilibrium is not necessarily reached, the required charge states (44 + and 51 + respectively) are very close to the maximum probability.

This choice would then lead to an additional energy spread $\delta W/W = \pm 1.3\ 10^{-3}$, according to formula (3). If this last figure were unbearable for a safe acceleration in SSC2, a reduction of the quoted thicknesses by a factor of 2 would bring $\delta W/W$ down to $\pm 0.9.10^{-3}$ while reducing the intensities by only 30%.

4) Conclusions

The energy spread generated by thick carbon foils on heavy ion beams can be estimated. The charge state distributions are fairly well predicted if close to equilibrium and the measurement of their evolution as a function of foil thickness allows to find a good compromise to satisfy the injection and acceleration constraints of SSC2.

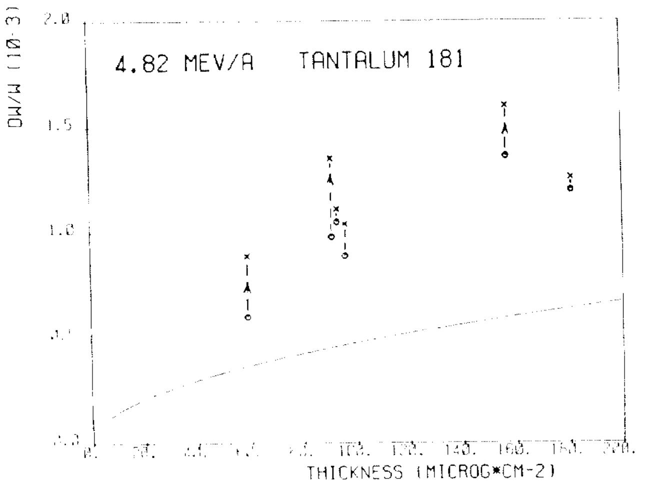

Figure 3. Relative energy spread generated by carbon foils on a 4.82 MeV/A Ta beam with reduced (O), then full (X) intensity.
The solid line represents expression (1).

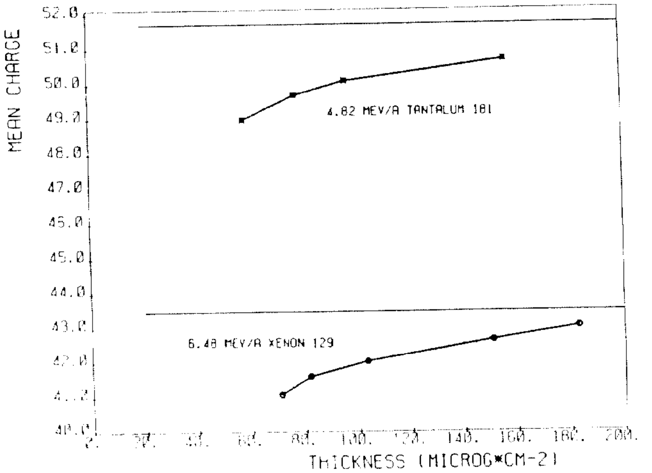

Figure 4. Mean charge $\bar{Q}$ as a function of foil thickness for the Xe and Ta beams. The values calculated by (4) are shown as horizontal lines.

Table 1
Charge distribution (%) as a function of foil thickness.

The column noted (5) gives the prediction as calculated with formulae (4) and (5) using the exit energy of a 183 $\mu g/cm^2$ foil for Xe and of a 157 $\mu g/cm^2$ foil for Ta.

Charge State	Thickness ($\mu g/cm^2$) 71	82	102	151	183	(5)
36	0.46					
37	1.96	0.72	0.38			
38	5.27	2.80	1.62	0.60	0.66	0.25
39	11.13	7.32	4.72	2.35	1.60	1.12
40	18.20	14.98	11.37	7.15	4.71	3.70
41	22.41	21.79	19.08	14.51	10.94	8.98
42	18.67	22.16	22.97	20.98	18.10	16.11
43	13.02	16.77	19.86	23.15	23.19	21.35
44	7.25	10.39	14.53	20.28	24.19	20.90
45	1.39	2.63	4.24	8.14	11.47	15.12
46	0.25	0.42	1.11	2.36	4.11	8.07
47			0.12	0.49	1.03	3.19
$\bar{Q}$	41.07	41.59	42.02	42.62	43.00	43.43
d	1.78	1.68	1.67	1.62	1.64	1.82

a) W = 6.48 MeV/A Xe Q = 17+

Charge State	Thickness ($\mu g/cm^2$) 59	78	97	157	(5)
43	0.19				
44	0.93	0.28			
45	2.89	1.38	0.72	0.28	0.36
46	6.90	4.03	2.62	1.16	1.06
47	12.64	8.94	6.71	4.00	2.60
48	18.18	14.94	12.78	9.02	5.35
49	19.82	18.92	17.45	13.45	9.24
50	16.27	19.18	19.35	19.49	13.38
51	11.71	15.37	17.68	20.20	16.24
52	7.00	9.86	12.55	16.13	16.52
53	2.61	4.68	6.55	9.53	14.09
54	0.82	1.75	2.68	4.68	10.07
55	0.15	0.55	0.77	1.70	6.03
56			0.12	0.34	3.03
Q	48.94	49.52	49.99	50.51	51.60
d	1.99	1.97	1.96	1.93	2.38

b) W = 4.82 MeV/A Ta Q = 20+

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