CALCULATED FINITE EMITTANCE AND DEE-GAP CROSSING EFFECTS ON HEAVY-ION TRAJECTORIES OF ION INJECTION INTO THE OAK RIDGE ISOCHRONOUS CYCLOTRON FROM A 25 MV TANDEM ELECTROSTATIC ACCELERATOR

Gregory S. McNeilly, K. N. Fischer
Computer Sciences Division
at Oak Ridge National Laboratory
Union Carbide Corporation, Nuclear Division*
Oak Ridge, Tennessee

Summary

The present calculational results are part of a continuing study to assist in optimizing the geometry and flexibility of the ORIC injection system.[1] The calculated effects of finite emittance and dee-gap crossings during ion injection on beam size and quality at the stripper foil are presented.

Introduction

A general discussion of energy boosting of heavy-ions using the ORIC is presented elsewhere in these proceedings.[2] Central ray trajectories for a variety of heavy-ions and some details of the calculations are presented within the above paper. This paper will present the results obtained when beams of *finite-size* heavy-ions are injected into ORIC. For finite-emittance studies, the perimeter of an appropriate phase-space area was outlined by a "packet" of particles or rays with differing initial conditions. The evolution in time of this packet of particles allowed the study of finite-size beams of heavy ions.

Finite Beam Studies

Injection

The 25 MV tandem electrostatic accelerator proposed for the heavy-ion facility at Oak Ridge,[3,4] using gas-stripping, will have a characteristic emittance of 19π mm-mrad $(\mathrm{MeV})^{1/2}$. The propagation of this finite-size beam through the various injection elements of ORIC (see Figure 3 in Reference 2) to a 1 × 5 mm beam spot (radial by axial dimensions) at the ORIC stripper-foil, should be accomplished if possible with no loss of beam intensity due to beam clipping. The calculations presented here investigate the region between the inflection magnet and the ORIC stripper-foil. The calculations include the effect of crossing through the slot cut in the ORIC dee-stem (see Figure 4 in Reference 2). For the phase acceptance of ORIC (±3 rf-degrees) the effect of passing through the dee-stem slot has been found to be negligible.

Table I gives the radial (i.e., bending plane) widths of various heavy-ion beams at the horizontal mid-line crossing point just after the exit from the inflection magnet on an injection path into ORIC. Determination of beam parameters preceding this point in the tandem-ORIC injection beam line, including the inflection quadrupole and inflection magnet are presently underway using the TRANSPORT code.[5,6] However, worst case estimates indicate the beam to be at most a factor of two larger than the tabulated values within the inflection quadrupole. Including the factor of two, the tabulated beams fill about 70% or less of the quadrupole bore.

*Prime contractor for the Energy Research and Development Administration.

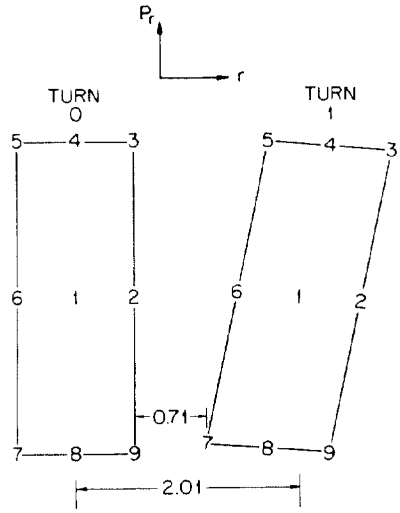
Table I. Radial Beam Widths
Tandem Emittance — 19π mm mrad $(\mathrm{MeV})^{1/2}$
Beam Spot at Foil — 1 mm × 5 mm

Injected Beam	Radial Beam Width (cm)	Crossing Point (cm)
^{12}C $3^+ \rightarrow 6^+$	3.11	203.6
^{35}Cl $9^+ \rightarrow 16^+$	2.04	182.4
^{79}Br $8^+ \rightarrow 27^+$	1.32	212.5
^{127}I $8^+ \rightarrow 34^+$	1.24	235.8
^{158}Gd $8^+ \rightarrow 37^+$	1.02	216.6
^{181}Ta $8^+ \rightarrow 38^+$	1.02	214.5
^{208}Pb $7^+ \rightarrow 38^+$	1.14	231.4

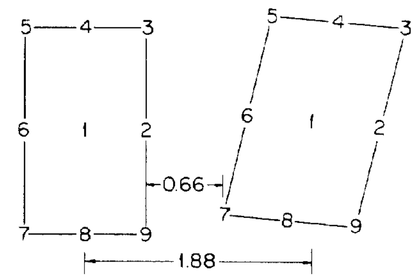
Table II gives axial widths for the same set of heavy-ion beams. Two widths are given: (1) the axial width at the horizontal mid-line crossing point, and (2) the maximum axial width within the dee walls (the walls are 2.4 cm apart). As can be seen, all cases are well within acceptable limits, and in fact, for some cases (notably ^{79}Br) a waist in the axial direction occurs near the inflection quadrupole-inflection magnet location.

Table II. Axial Beam Widths
Tandem Emittance — 19π mm mrad $(\mathrm{MeV})^{1/2}$
Beam Spot at Foil — 1 mm × 5 mm

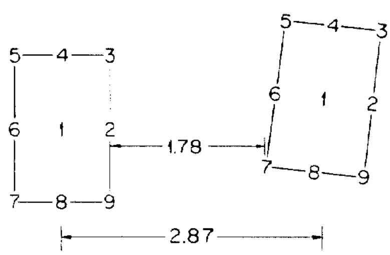
Injected Beam	Maximum Width Within Dee Walls (cm)	Crossing Point Width (cm)
^{12}C $3^+ \rightarrow 6^+$	0.70	0.86
^{35}Cl $9^+ \rightarrow 16^+$	0.58	0.77
^{79}Br $8^+ \rightarrow 27^+$	0.61	0.16
^{127}I $8^+ \rightarrow 34^+$	0.61	0.33
^{158}Gd $8^+ \rightarrow 37^+$	0.61	0.41
^{181}Ta $8^+ \rightarrow 38^+$	0.61	0.42
^{208}Pb $7^+ \rightarrow 38^+$	0.60	0.45



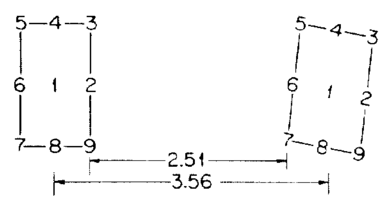
$^{12}C^{6+}$; 80 MeV Equilibrium Orbit Injection.



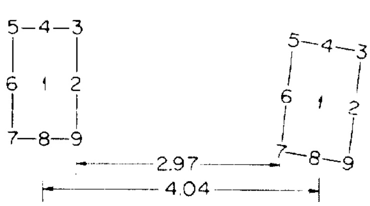
$^{35}Cl^{16+}$; 250 MeV Equilibrium Orbit Injection.



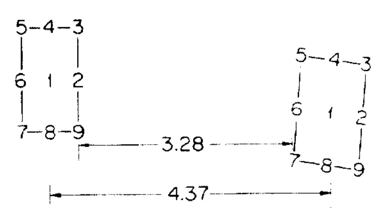
$^{79}Br^{27+}$; 225 MeV Equilibrium Orbit Injection.



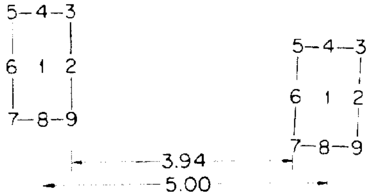
$^{127}I^{34+}$; 225 MeV Equilibrium Orbit Injection.



$^{158}Gd^{37+}$; 225 MeV Equilibrium Orbit Injection.



$^{181}Ta^{38+}$; 225 MeV Equilibrium Orbit Injection.



$^{208}Pb^{38+}$; 200 MeV Equilibrium Orbit Injection.

Fig. 1. Calculated Turn Separations for Various Heavy-Ions (mm).

Acceleration

Turn Separation. The separation of an injected beam (turn 0) from the location of turn 1 must be sufficient to allow clearance of the foil-stripper mechanism; otherwise, a portion of the accelerated beam will be lost in a second encounter with the stripper-foil. Figure 1 presents calculations for the first two turns of a variety of heavy-ions. As can be seen, the turn separation (given in mm) is smallest for the lighter ions. Since the foil-holder will project about 0.5 mm beyond the foil, the clearance is ample for the heavier ions, but quite close for ^{12}C and ^{35} Cl.

Stripper-Foil Scattering. Small-angle scattering and energy loss of the heavy-ions in the ORIC stripper-foil increase the phase-space area of the beam. In particular, the transverse divergence of the beam is increased and a spread in energy is introduced. Only the transverse divergence change is addressed here. Following Meyer,[7] small-angle scattering has been calculated for the heavy-ions shown in Table III. For a carbon stripper-foil 10 $\mu g/cm^2$ thick, the table shows the per-cent increases in transverse beam divergences after stripping in ORIC. The per-cent increases shown would contain 90% of the beam. Since the beam-spot size in the axial direction is five times larger, the per-cent increases for the axial cases are five times the Table III values.

Focusing to a smaller beam-spot size on the stripper-foil would reduce the effect of the small-angle scattering. However, this would be accomplished at the expense of (1) increased beam width up-stream in the injection beam-line, and (2) possibly decreased stripper-foil lifetime due to the increased current density of the smaller beam-spot size. Since the ORIC admittance is much larger than the emittance from the tandem, even including the small-angle scattering, foil-scattering is not a serious problem.

Table III. Foil Scattering

Tandem Emittance — 19π mm mrad $(MeV)^{1/2}$

Beam Spot at Foil — 1 mm × 5 mm

Carbon Foil — 10 $\mu g/cm^2$

Injected Beam	Per-cent Increase Transverse Divergence
$^{12}C\ 3^+ \rightarrow 6^+$	4.7
$^{35}Cl\ 9^+ \rightarrow 16^+$	6.7
$^{79}Br\ 8^+ \rightarrow 27^+$	15.1
$^{127}I\ 8^+ \rightarrow 34^+$	21.9
$^{158}Gd\ 8^+ \rightarrow 37^+$	23.2
$^{181}Ta\ 8^+ \rightarrow 38^+$	27.4
$^{208}Pb\ 7^+ \rightarrow 38^+$	32.1

References

1. Bulletin of the American Physical Society, Series III, Vol. 19, No. 10, 1974.

2. R. S. Lord, et al., Proceedings of this conference.

3. W. T. Milner, et al., ibid.

4. J. K. Bair, et al., ibid.

5. K. L. Brown, et al., SLAC-91, Revision 1, 1974.

6. R. O. Sayer, private communication.

7. L. Meyer, Phys. Stat. Sol. (B) 44, p. 253, 1971.