© 1975 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

ENERGY BOOSTING OF A TANDEM BEAM WITH THE OAK RIDGE ISOCHRONOUS CYCLOTRON*

R. S. Lord, J. B. Ball, E. D. Hudson
M. L. Mallory, J. A. Martin, S. W. Mosko
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830
and
R. M. Beckers, K. N. Fischer,
Gregory S. McNeilly, J. D. Rylander
Union Carbide Nuclear Division, Oak Ridge, Tennessee 37830

Summary

The energy of heavy ion beams from the 25 MV "folded" tandem now being acquired[1,2] will be increased by additional acceleration in the Oak Ridge Isochronous Cyclotron (ORIC). Beams of ions up to A = 160, with energy sufficient to overcome the Coulomb barrier on lead, will be produced. The beams will enter the cyclotron through the dee stem, be directed by a magnet through the fringe and main fields to a stripping foil which lies on the appropriate orbit for acceleration. A stripping foil holder, an injection magnet, and beam transport elements will be required in addition to modifications of the ORIC rf system. Central ray data for several beams are presented. An analysis of the effects of finite beam size and emittance are presented elsewhere in these proceedings.[3]

Energy and Intensity Performance

We are in the process of procuring a 25 MV "folded" tandem electrostatic accelerator. This machine will be used as a stand-alone heavy ion accelerator and also to inject into ORIC for further energy boosting. The energy performance for the most abundant charge states is shown in Fig. 1. Somewhat higher energies can be achieved at the sacrifice of intensity by accelerating ions that are off the equilibrium charge state. The maximum energy increase achieved in the cyclotron is about a factor of 4 with gas stripping in the terminal of the tandem and foil stripping inside the cyclotron.

The maximum energy gain of the tandem-cyclotron combination when compared with operation of the tandem alone with gas stripping in the terminal *and* foil stripping in the high energy tube is a factor of ∿ 2. In this mode of operation the intensities of the tandem and the tandem-cyclotron combination are comparable. A typical beam intensity from the tandem with only gas stripping in the terminal will be ∿ 1 particle-microampere (pμA) with ∿ 60% of the beam bunched to ± 3 rf degrees. With the design pressure of 5×10^{-7} torr in the injection line more than 95% of this beam will be transmitted to the cyclotron. About 20% of the beam passing through the stripping foil in the cyclotron will be in the charge state required for acceleration. Of this beam, 95% will survive to extraction radius if the average pressure in the cyclotron is 1×10^{-6} torr. Because of the low emittance (19 π mm mrad) and the narrow phase width of the injected beam, virtually all of the beam that reaches full radius will be extracted. When these losses are accounted for, the expected intensity is ∿ 0.1 pμA for most beams.

Injection System

The principal items of equipment that must be added to ORIC for beam injection are: (1) a conventional beam transport line (Fig. 2) extending ∿ 36 meters from the tandem to ORIC and equipped with the appropriate beam bending, focusing and diagnostic devices, (2) a movable inflection magnet located in the dee stem (Fig. 3), and (3) a foil positioner which will be supported from a modified radial ion source support tube. A "magazine" of several foils (5 in the present design) will be mounted on the positioner so that individual foils can be quickly changed without breaking vacuum. Complete foil magazines will be replaceable in ∿ 30 minutes--also without breaking vacuum. In addition, the dee and trimmer of the rf system must be redesigned to allow passage of the injected beam through slots in their peripheries (Figs. 3, 4). In typical operation, as shown in Fig. 3, beam from the tandem (225 MeV $^{127}I^{8+}$ in this example) enters the cyclotron parallel to the axis of the dee stem. The beam passes through the quadrupole, the inflection magnet, and is bent by the cyclotron magnetic field to the injection point where it is focused to a small spot (∿ 1 x 5 mm) on a thin (∿ 10–20 mg/cm^2) carbon foil. The foil is positioned so that after changing charge the desired charge state (in this example I^{32+}, ∿20%) is in an orbit suitable for acceleration.

Central Ray Trajectories

Calculations for a variety of heavy-ions have been made to determine the location and characteristics of the new devices mentioned above. The trajectories were obtained from a computer code based on the original general orbit code (GOC).[4] The original GOC has been the basis for several codes which have evolved in different directions for different uses.[5,6,7] The present code (evolved from the Hopp version) emphasizes injection and extraction studies with, of course, special attention to the peculiar requirements of ORIC. The details of this code will be reported elsewhere.[8]

The trajectories were obtained by defining the beam at the foil-stripper position and then integrating the equations of motion forward for in-machine studies, or integrating the equations of motion backward with the pre-stripped charge state to obtain injection trajectories. Finite emittance injection studies are reported elsewhere in these proceedings.[3]

Figure 4 shows trajectories for a variety of initial conditions. The ORIC field strength for all calculations shown is for an energy constant of E_0 = 90 MeV. Gas-stripping in the tandem terminal followed by foil-stripping in ORIC is assumed. All charge states used represent the peak of the post-stripping charge state distribution (excepting carbon, which is two units of charge lower than the predicted equilibrium charge state after tandem gas-stripping.)[9]

Several design constraints are satisfied by the calculated trajectories shown. (1) The foil stripper is located between the dee and the horizontal mid-line, i.e., within the second quadrant. (2) The injection paths miss the extractor mechanism, shown schematically in Fig. 3. (3) The range of motion of the center of the inflection magnet is restricted to the range 2.34 to 3.55 meters, measured from the center of ORIC, and (4) The maximum field required for the inflection magnet is 15 kG.

*Work supported by the US ERDA under contract with the Union Carbide Corp.

The lighter mass heavy ions (i.e., those of lower magnetic rigidity) are sharply bent by the cyclotron field and constraints (1), (2), and the minimum value of (3) become limiting. The heavier mass heavy ions (i.e., those of higher magnetic rigidity) are only slightly bent by the ORIC field and a trade-off between constraint (4) and the maximum value of constraint (3) becomes limiting.

References

1. W. T. Milner, et al., Proceedings of this conference.
2. J. K. Bair, et al., ibid.
3. Gregory S. McNeilly and K. N. Fischer, ibid.
4. M. M. Gordon and T. A. Welton, ORNL-2765, 1959.
5. D. I. Hopp, UCLA Tech. Rep. P-67, 1965.
6. L. Shaw, USNRDL-TR-936, 1965.
7. A. C. Paul, LBL-589, 1971.
8. Gregory S. McNeilly and K. N. Fischer, ORNL report in preparation.
9. Ch. Schmelzer, Unilac-Bericht, Nr. 3-67, 1967.

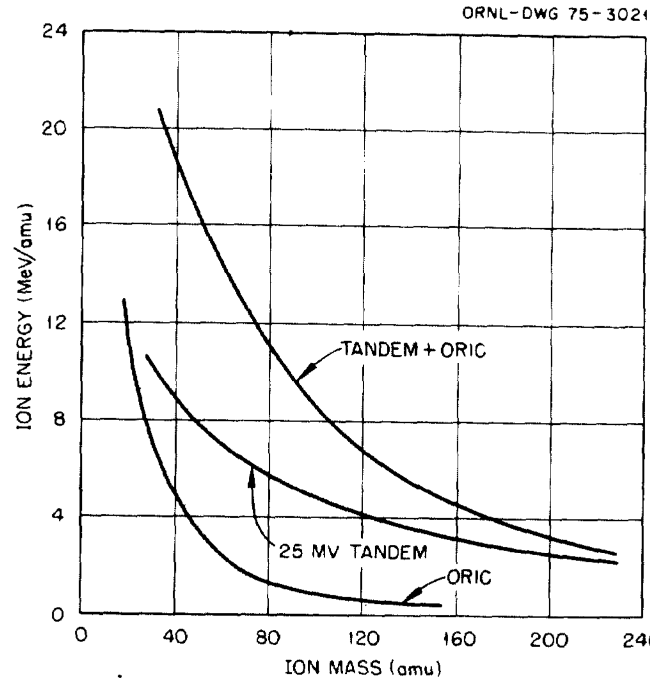


Fig. 1. Maximum energy at full intensity obtainable from ORIC with an internal ion source, the 25 MV tandem, and from the combination of the two accelerators. In the two curves involving the tandem, gas stripping in the terminal is assumed, plus foil stripping in either the high-energy tube (tandem alone), or in ORIC (tandem + ORIC) so that the intensities for these two curves will be comparable.

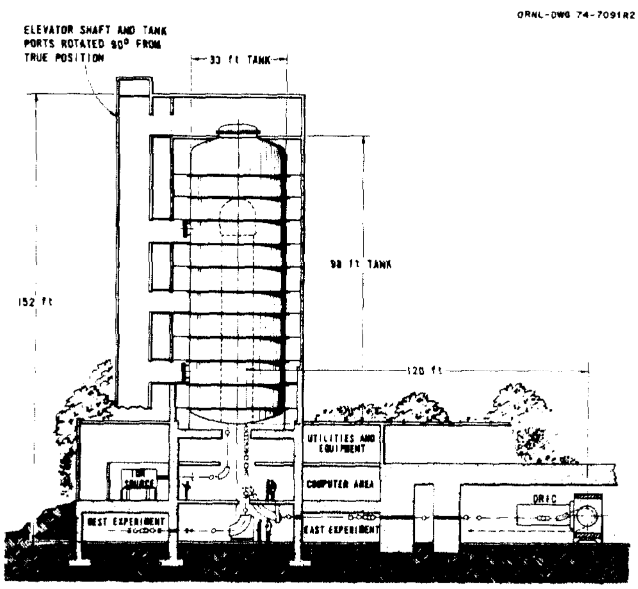


Fig. 2. Cross section of 25 MV tandem-cyclotron system showing injection beam transport line to ORIC.

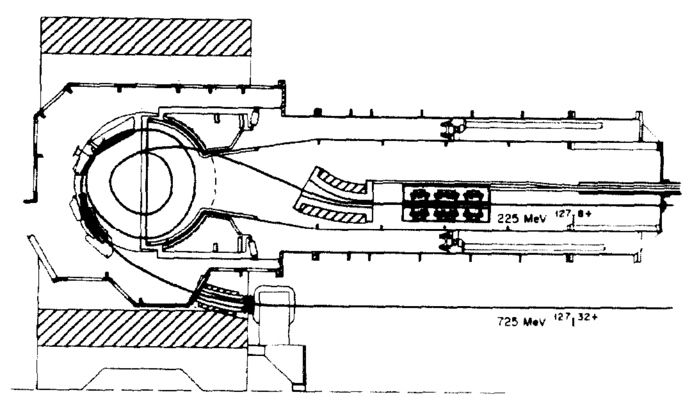
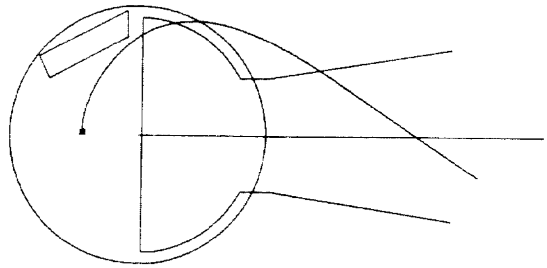


Fig. 3. Cross section of ORIC with a 225 MeV $^{127}I^{8+}$ beam from the tandem stripping to 32^+ and accelerating to 725 MeV. The inflection magnet and the quadrupole are movable to accommodate the full range of beams.

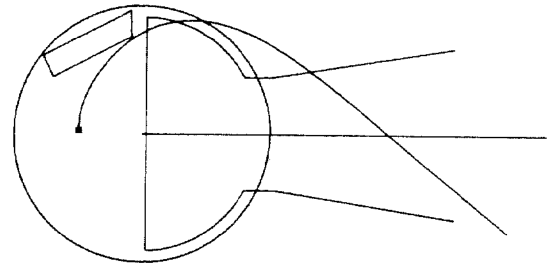
$^{12}C\ 3^+ \rightarrow\ ^{12}C\ 6^+$

INJECTION ENERGY = 80.00 MEV
TANDEM VOLTAGE = 20.00 MV
FOIL ANGLE = 177°



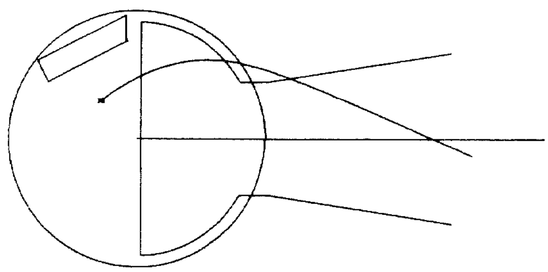
$^{35}CL\ 9^+ \rightarrow\ ^{35}CL\ 16^+$

INJECTION ENERGY =250.00 MEV
TANDEM VOLTAGE = 25.00 MV
FOIL ANGLE = 177°



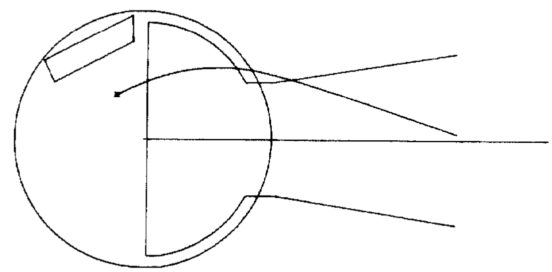
$^{79}BR\ 8^+ \rightarrow\ ^{79}BR^{27+}$

INJECTION ENERGY =225.00 MEV
TANDEM VOLTAGE = 25.00 MV
FOIL ANGLE = 133°



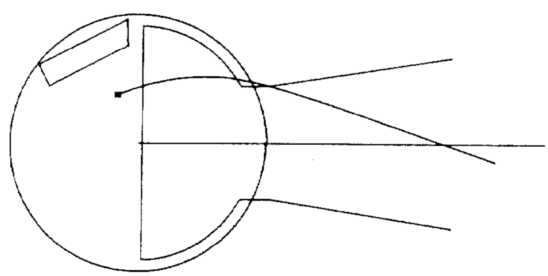
$^{127}I\ 8^+ \rightarrow\ ^{127}I\ 34^+$

INJECTION ENERGY =225.00 MEV
TANDEM VOLTAGE = 25.00 MV
FOIL ANGLE = 121°



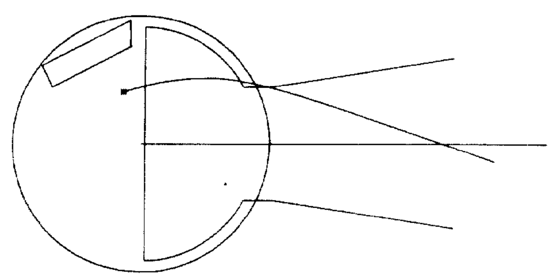
$^{158}GD\ 8^+ \rightarrow\ ^{158}GD^{37+}$

INJECTION ENERGY =225.00 MEV
TANDEM VOLTAGE = 25.00 MV
FOIL ANGLE = 113°



$^{181}TA\ 8^+ \rightarrow\ ^{181}TA^{38+}$

INJECTION ENERGY =225.00 MEV
TANDEM VOLTAGE = 25.00 MV
FOIL ANGLE = 109°



$^{208}PB\ 7^+ \rightarrow\ ^{208}PB^{38+}$

INJECTION ENERGY =200.00 MEV
TANDEM VOLTAGE = 25.00 MV
FOIL ANGLE = 105°

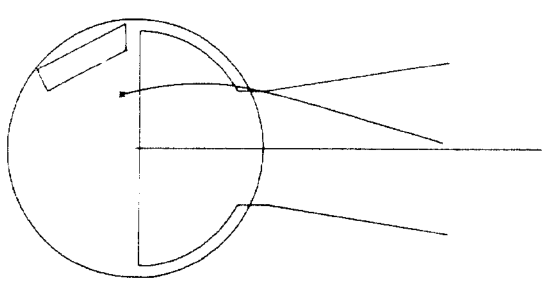


Fig. 4. Calculated trajectories for injection to equilibrium orbits, for various heavy-ions with the indicated charge states, energies and stripper foil angles.