Conf-741112--5

THE HEAVY-ION ACCELERATOR PROJECT AT OAK RIDGE

A. Zucker and J. B. Ball
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830*

In the past few years we have witnessed many exciting new developments in Heavy Ion science. In nuclear science, acceleration of heavy ions in the medium mass region, has produced interesting new physics regarding the effect of high angular momentum, nuclear macrophysics which describes properties of nuclei in terms such as viscosity and friction, as well as the production of the new isotopes far from the stability line. The discovery of new heavy elements is a consequence of our ability to accelerate particles heavier than helium. The goal in this area of research is to see whether very heavy elements of Z=114 or 130 may be stable sufficiently long to be identified. Heavy ions are currently used in atomic physics as well as in nuclear physics. In this connection, interesting new experiments have been performed on the atomic spectra from highly stripped atoms and a search is under way for the promising phenomena of molecular x-rays, namely the observation of x-rays from compound nuclei that may stay together for only a few revolutions. Finally, heavy ions are being employed in the study of materials both from the fundamental point of view that involves the interaction of atoms with the solid, as well as from the applied point of view where the investigation of radiation damage seems to be facilitated by bombardment with heavy ions.

The Oak Ridge National Laboratory has, therefore, embarked on a program that will considerably enhance its capabilities in this frontier area. In the initial phase, we are purchasing a 25 MV tandem electrostatic accelerator whose beams

*Operated by Union Carbide Corporation for the Atomic Energy Commission.

can be used either by themselves, or can be injected into the Oak Ridge Isochronous Cyclotron (ORIC) for further acceleration. The project includes the necessary modifications to ORIC so that these beams may be injected and further accelerated. The entire project will extend our capability to accelerate ions as high as mass 140 with sufficient energy to penetrate the Coulomb barrier of uranium. We expect completion in about four years. The principal objectives of the Oak Ridge accelerator program are:

1. To develop beams of all ions up to mass 140 with very good energy resolution, time resolution and a high degree of brightness.

2. The intensities of all ions from the tandem Van de Graaff accelerator are specified to be 1 particle μA up to mass 238. It is possible that intensities as high as 4 pμA may be obtained if we are successful in guiding the beam cleanly through the accelerating tubes.

The 25 MV Tandem Accelerator

The new large tandem electrostatic accelerator is designed to operate at terminal potentials from 7 to 25 MV. It departs from the traditional tandem configuration in that it will be of a folded design, with both the low-energy and high-energy acceleration tubes located within the same column structure.

The general concept of a folded tandem is illustrated in Fig. 1 Negative ions from a source located near ground level are inflected into the low-energy tube and accelerated to the positive terminal. After this acceleration the ions pass through a stripping medium, gas or thin foil, which removes a number of electrons; the ions with the desired positive charge state are bent through 180° by a magnet in the terminal, and the positive ions are accelerated in the high-energy column back to ground. The advantages of this folded configuration over a conventional in-line design are: complete removal of undesired ions from the high-energy acceleration stage; reduction of stored energy and consequent lower probability of spark damage; more convenient placement of the ion source with increased flexibility for a possible future addition of a high-energy injector; and a reduction in size of the tank, insulating gas inventory, and building.

The required distance between low- and high-energy accelerating tubes is about 2 meters for a 180° bending magnet with a field of about 15 KΓ. To first order, this distance is invariant with terminal potential since the most probable charge state for a heavy ion scales roughly as the first power of the velocity. Hence, for a heavy-ion machine, the folded design becomes practical when the size of the machine, from electrostatic considerations, has become large enough to accommodate this required 2 m separation distance. For heavy-ion tandem accelerators, the folded concept therefore becomes practical for terminal potentials of 20 MV and greater.

The high-voltage terminal and insulated support column for the ORNL tandem accelerator will be mounted vertically within a steel pressure vessel 10 meters in diameter and 30 meters high. The insulating medium will be pure SF_6 gas at a pressure of seven atmospheres. The location of this new accelerator with respect to the existing ORIC cyclotron is shown in Figs. 2 and 3. These figures show the beam transport line connecting the two machines as well as new experimental areas for use of ion beams directly from the tandem.

The complete tandem accelerator, including the injector, beam handling, gas handling, and control systems will be purchased from a commercial vendor. Specifications for the accelerator call for very careful attention to such properties as beam transport and vacuum systems that are designed to accommodate large currents of heavy ions. To minimize loss of these ions in the beam transport system, the vacuum will be maintained at 1×10^{-7} Torr or better. The ion source injector will be at a potential from 150 to 500 keV, and negative ions from the source will be focussed to a waist at the entrance of the low-energy tube. A quadrupole lens within the low-energy acceleration tube and two lenses in the terminal will provide high quality beam transmission through the accelerator. These focussing elements in conjunction with the complete charge-state selection by the 180° magnet will minimize problems associated with heavy ions striking elements of the acceleration tubes.

The charge will be transmitted to the high voltage terminal by a chain belt charging system with a capability of 600 μA. Power in the terminal will be delivered by 2 or 3 rotating shafts and will amount to 20 to 30 KVA, of which the magnet will probably consume 10 to 15. Ion pumps will provide additional pumping in the dead sections as well as in the terminal. A separate pump is provided for the stripper gas. Because of the importance of keeping the ions from hitting the accelerating structure, the tandem accelerator will be provided with extensive diagnostic equipment. Each dead section will contain a remotely controlled Faraday cup along with a remotely controlled aperture to determine the position of the beam and measure its intensity. There will be two additional Faraday cups in the terminal. Several steering elements are provided to maintain the beam along the axis of the accelerator.

Provision will be made for either gas stripping or foil stripping in the high voltage terminal. In addition, a foil stripper will be installed in a dead section of the column one-third of the way down the high-energy acceleration tube. The maximum energy performance of the machine operated with gas stripping in the terminal and foil stripping in the column is shown as a function of ion mass in Fig. 4. The curve shown assumes selection of the most probable charge state after each stripper.

Also shown on Fig. 4 is the heavy-ion energy performance of the ORIC operating with the internal positive ion Penning source. The dashed line showing the Coulomb barrier for an ion incident on a lead nucleus indicates roughly the ion energy required to study processes involving nuclear reactions.

Whereas the present limit of ORIC is about at chlorine (A=35) the 25 MV tandem with two strippings will extend the capabilities to ions in the region A=90 to 100. Somewhat higher energies may be obtained, of course, at the expense of beam intensity by moving to charges higher than the most probable.

ORIC Injection

As is evident from Fig. 4, the range of ions capable of inducing nuclear reactions is considerably extended by using ORIC as an energy booster for the 25 MV tandem.

A schematic view of the use of ORIC as a booster is shown in Fig. 5 for the case of iodine ions. Capture of the ions into an acceleration orbit is accomplished by placing a stripping foil at a position where the inflection trajectory is tangent to an equilibrium orbit. The radii of curvature of the inflection and equilibrium orbits are chosen to be compatible with the charge change of the ion caused by the stripper foil.

The beams transported from the tandem enter the ORIC through the resonator. Two beam handling elements, a quadrupole lens and an inflection magnet, provide the required injection trajectories. The example shown in Fig. 5 for a beam of iodine ions shows trajectories taken from computer calculations employing measured magnetic fields of the ORIC. Because the injection orbit penetrates the boundary of the present acceleration electrode, the forward region of the dee and the adjacent trimmer capacitors will be modified to accommodate these orbits.

The curve shown in Fig. 4 again assumes two charge changes; a gas stripper in the terminal of the tandem and the foil stripper at the ORIC injection point. To accommodate the range of ion masses and energies implied by this performance curve requires the foil stripper in ORIC to cover an angular range of about 90° with radii from 25 to 50 cm. With the extraction radius of 75 cm, ORIC will thus provide energy gain factors ranging from 2 to 9.

One of the most critical aspects of the combined operation of the two accelerators is the bunching of the tandem beam required to obtain good energy resolution after ORIC acceleration. For $\Delta E/E=10^{-3}$ we must confine the injected beam within 6 degrees of the ORIC rf cycle. Thus the ion optic system of the tandem must be designed not only for high quality transport of d.c. beams but also for minimum time dispersion during pulsed beam operation. The required pulse widths are compared with calculated system performance in Fig. 6. For the lower ORIC frequency limit of 7.5 MHz, the bunching requirements can be easily obtained for ions up to mass 130. For higher masses, acceleration must be shifted to third harmonic operation and the bunching becomes more critical. If the lower frequency limit is shifted to 6.5 MHz when the dee is modified to accommodate injection orbits, then acceleration on the first harmonic can be extended to ions up to about mass 155.

Computer Control System

Another distinguishing feature of the new tandem accelerator is the use of a control system based entirely on digital communication techniques. A small computer, employed as a message switching unit, couples operator consoles to satellite equipment control clusters located near control application points. All control signal paths employ optical or transformer isolation to minimize ground-loop problems. Data transmission to equipment at elevated potentials are by fiber-optic light pipes or focussed-beam light links.

Control consoles make maximum use of modern display techniques that allow the operator to select specific information for continuous display, and to examine seldom-needed information on demand. Control is accomplished through three to five console controls which may be selectively connected to any elements of the accelerator system.

During initial operation, the computer capabilities of the control system will be used principally for information logging, set-point retrieval, and operation surveillance. A similar system is presently coming into operation on the ORIC. As these control systems become operational, parallel software development will be directed toward incorporating control and optimization functions into the system.

Future Plans

In the second phase of this project, it is planned that a larger booster accelerator be added to provide all ions with energies of at least 10 MeV/amu.

The inherent flexibility of the electrostatic accelerator allows a wide range of choices in considering the type of post-accelerator to be employed. Among the possibilities are: a room-temperature linac, a superconducting linac, a separated-sector cyclotron, or a superconducting cyclotron. Present studies for the second phase post accelerator are concentrated on the concept of a superconducting cyclotron. This choice is favored, at the present time, because it appears to offer the most economical means of producing the desired ion energies. Completion of the conceptual design study for the booster accelerator is scheduled for mid-1975.

THE HEAVY-ION ACCELERATOR PROJECT AT OAK RIDGE

A. Zucker and J. B. Ball
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830

Figure Captions

Fig. 1. Schematic view of "folded" tandem electrostatic accelerator.

Fig. 2. Elevation view showing relation of tandem accelerator to existing cyclotron.

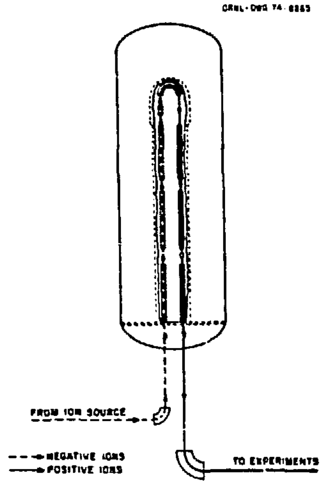
Fig. 3. Plan view of accelerator facility.

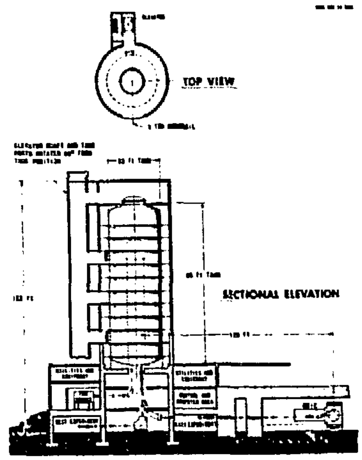
Fig. 4. Energy per nucleon as a function of ion mass.

Fig. 5. Injection and deflection paths of typical heavy-ion beam in ORIC. Only the first and last turns are indicated.

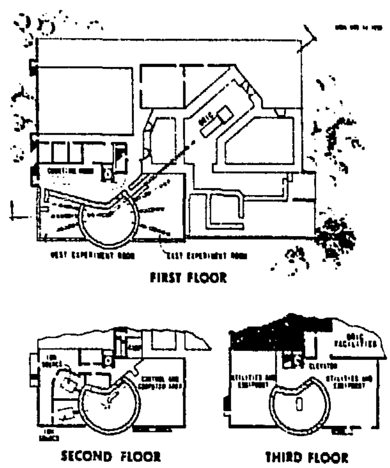
Fig. 6. Calculated pulsed beam performance of the ORNL tandem compared with ORIC injection requirements.

ORNL-DWG 74-[illegible]

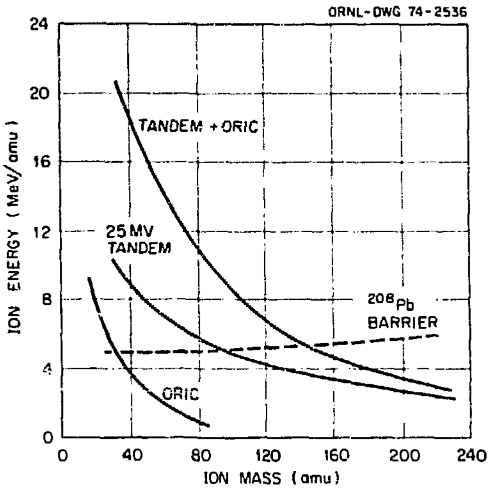

FROM ION SOURCE
TO EXPERIMENTS
NEGATIVE IONS
POSITIVE IONS



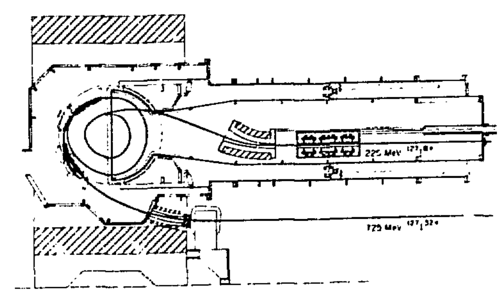
HEAVY-ION FACILITY

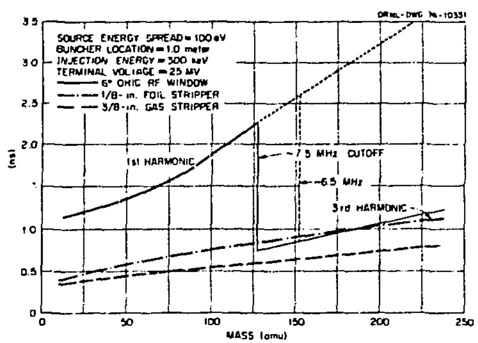


HEAVY-ION FACILITY



ORNL-DWG 74-2536
ION ENERGY (MeV/amu)
ION MASS (amu)
TANDEM + ORIC
25 MV TANDEM
ORIC
208Pb BARRIER
0
4
8
12
16
20
24
0
40
80
120
160
200
240


225 MeV $^{127}I^{8+}$
725 MeV $^{127}I^{32+}$



System Time Dispersion (Buncher, 180° and 90° Magnets).