The Holifield Heavy Ion Research Facility (HHIRF) accelerator system consists of a 25URC tandem electrostatic Pelletron\(^1\) and the Oak Ridge Isochronous Cyclotron\(^2\) (ORIC). The Pelletron was manufactured by the National Electrostatics Corporation (NEC) and placed into routine operation in 1982. It was the first large accelerator to be constructed in a folded configuration. The design terminal potential is 25 MV. To date, 66 isotopes of 36 elements from H to U, have been provided for the experimental program. Of this number, 27 isotopes were provided using ORIC as an energy booster in coupled operation.

ORIC was completed in the early 1960s as a versatile accelerator with variable energy for both light and heavy ions. ORIC was designed as a \( K = M E/Q\) = 100 cyclotron and can operate at \( K = 105\). In the 1960s, ORIC was used mostly for light ion production. In the 1970s, the experimental program shifted to heavy ions and in the late 1970s, ORIC was modified to be an energy booster for the tandem accelerator using a foil stripping injection system. In 1988, the internal ion source was decommissioned.

Recent developments have concentrated on improving the Pelletron voltage performance and improving ion source capabilities. Presently, the Pelletron can operate for long periods at 24 MV. This improved voltage performance has allowed heavier mass beams to be accelerated for nuclear structure studies in both the tandem-only mode and coupled mode. Table 1 lists some heavy beams recently accelerated in coupled operation. The lead beam was the first coupled operation using foil stripping in the tandem terminal.

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### Table 1. Heavy beams accelerated in coupled operation.

<table>
<thead>
<tr>
<th>Ion</th>
<th>25URC Charge</th>
<th>25URC Voltage</th>
<th>ORIC Charge</th>
<th>MeV/Nucleon</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{148})Nd</td>
<td>8+</td>
<td>23.8</td>
<td>32+</td>
<td>4.73</td>
</tr>
<tr>
<td>(^{150})Sm</td>
<td>8+</td>
<td>23.8</td>
<td>32+</td>
<td>4.67</td>
</tr>
<tr>
<td>(^{156})Gd</td>
<td>9+</td>
<td>22.0</td>
<td>36+</td>
<td>5.61</td>
</tr>
<tr>
<td>(^{200})Po</td>
<td>17+</td>
<td>22.9</td>
<td>44+</td>
<td>4.70</td>
</tr>
</tbody>
</table>

Ion source developments have concentrated on the construction of a multiple-sample cesium-sputter source which can remotely select any one of 60 samples for negative ion production. The samples are contained on the outer surface of three rings of 20 samples each. Construction of this source was motivated by the desire to select and frequently change samples without the presently required 30-minute disruption in accelerator operation. In addition, the source has a three-electrode structure with a high perveance of \( 8 \times 10^{-9} \text{ A/V}^{3/2} \) giving large positive cesium ion currents. The three-electrode system also permits the sample to be independently biased relative to the ionizer, giving improved beam transmission, since the ions will be extracted from a less divergent field.

The second source, shown in Fig. 3, is a radial geometry, magnetic-multi-cusp, plasma-sputter, negative-ion source which can produce high-intensity pulsed and dc beams over a wide spectrum of atomic and molecular species.\(^3\) This source is modeled after those used at LANL and KEK to generate intense pulsed beams of \( H^-\) ions. Recent work at BNL and the University of Tsukuba has shown that these sources can also produce mA pulsed negative heavy ion beams for synchrotron injection.\(^4\) The source also is expected to produce mA dc beams.

### Tandem Terminal ECR Source

Many ECR sources have been built worldwide and are used for cyclotron injection, linac injection, and for

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\(^1\) Research sponsored by the U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.
The number of runs as a function of terminal potential for one-year periods before and after the installation of compressed geometry tubes.

The expected performance improvement from a terminal ECR source, emphasizing a 208Pb beam, is illustrated in Figs. 4 and 5. Figure 4 shows the expected 208Pb current available in the high-voltage terminal of an electrostatic machine as a function of charge state. Results for six cases are shown. The three lower curves are for tandem accelerators at 6, 12, and 24 MV with foil strippers. As the terminal voltage increases from 6 to 24 MV, the peak charge state for an equilibrium distribution from foil strippers increases from 9 to 17 and the corresponding beam energy increases from 0.29 to 2.16 MeV/nucleon. Equally important, the higher beam energy for stripping increases the foil lifetime and, hence, current from 10 pA to 35 pA. For the results of Fig. 4, a foil lifetime of 30 minutes was required, assuming beam current-lifetime products of 1.4, 2.8, and 5.6 pA-min for 6-, 12-, and 24-MeV lead beams, respectively, using 5 μg/cm²-thick, glow-discharge-slickened foils. Clearly, the beam currents available from foil stripping are foil-lifetime limited.

The upper curves in Fig. 4 are for three terminal ECR sources: (1) Measured Bi currents from the all-permanent magnet, lower power, compact, 8-GHz NEOMAFIOS source; (2) Measured Au currents from the ORNL 10.6-GHz source; and (3) Measured Bi currents from the large, high-power, 6.4-GHz LBL source with a 700°C oven vapor feed. For any given charge state, an ECR source can produce at least 20 times more beam current in the terminal than conventional negative ion source operation with conventional foil stripping.

The installation of an ECR source in the tandem terminal has also been studied. Such an ECR source would produce more intense currents of higher charge states for acceleration down the high-energy tube than can be obtained with conventional negative-ion sources and terminal-foil stripping. This improved performance is particularly important for very heavy beams with coupled operation.
A lead beam with an energy between 4.5 and 6.0 MeV/nucleon, and an intensity in the order of one pA, is of strong interest for nuclear structure physics. Such a beam can be produced in coupled operation using ORIC. The product of the transmission, charge-state fraction, and bunching factor through ORIC is about 5%. Consequently, to deliver one pA of beam on target would require about 40 pA of beam in the tandem terminal, assuming a 50% beam loss in the high-energy tube. As shown in Fig. 4, 40 pA of lead cannot be obtained at 24 MV with the present foil lifetime limits. However, the three ECR sources all produce at least 40 pA of beam over a wide range of charge states. The charge states of interest for ORIC injection are between 17+ and 24+.

The determination of the ORIC output energy is somewhat complicated. Injection is achieved by stripping from the tandem charge state to a higher charge state Q through an injection foil. The maximum energy/nucleon from ORIC is then given by E/M = 105 (Q/M)\(z\). Consequently, the maximum energy from ORIC is determined by the charge state Q from the injection foil, which is energy dependent and determined by the tandem energy which, in turn, is determined by the tandem terminal charge state. These relationships are illustrated for \(^{209}\)Pb in Fig. 5, which shows the maximum current one can obtain from ORIC as a function of energy. Three curves are shown: conventional tandem operation with a terminal gas stripping and foil stripping, and tandem operation with an ECR source using the NEOMAFIOS results. The numbers on the curves give the terminal charge state, whereas the bottom scale gives the ORIC charge state Q. The energy range of greatest interest is also shown. Clearly, the installation of a terminal ECR source would allow the HHIRF coupled accelerators to produce lead beams for nuclear structure physics with intensities above one pA.

Figure 6 shows a proposed NEOMAFIOS-like ECR source and beam transport in the tandem terminal mounted in a horizontal plane above the highest casting.