Measurement of the ^{40}Ar + ^{165}Ho excitation function

C. M. Folden III, M. C. Alfonso, A. A. Alharbi, E. Berdugo, P. J. Cammarata, K. R. Lawrence,
D. A. Mayorov, A. C. Raphelt, and B. Roeder

A new program to study the heaviest elements has begun at the Texas A&M University Cyclotron Institute (CI). Experiments to produce these elements require high-intensity beams, efficient separation techniques, and long irradiation times for study. As part of a DOE-sponsored upgrade program, the idle K150 88-Inch Cyclotron is being recommissioned to provide intense, stable beams for experiments in fundamental interactions, rare isotope production, etc. [1]. This upgrade is underway and during the interim the K500 superconducting cyclotron is being used to develop the capabilities at the CI for heavy element experiments.

As a proof-of-principle experiment, the ^{165}Ho(^{40}Ar, xn)$^{205-x}$At excitation function has been measured. This reaction was previously studied by Andreev et al. [2] and was chosen for several reasons. The compound nucleus velocity (0.0204c) is comparable to that in the ^{208}Pb(^{50}Ti, n)^{257}Rf reaction (0.0195c), a future benchmark for our program. The ^{40}Ar + ^{165}Ho reaction has large evaporation residue (EVR) cross sections (up to 12 mb), and our results could be compared to the previously measured excitation function. The target is monoisotopic, making target preparation easier. The half-lives of the most important EVRs are not too long [$t_{1/2}$(^{199}At) = 7 s, $t_{1/2}$(^{200}At) = 43 s], and their alpha branches are large (greater than 50%) [3]. These properties made this reaction suitable for test purposes, and preliminary results are reported here.

A beam of ^{40}Ar^{5+} was delivered by the K500 cyclotron at energies of 200, 205, and 213 MeV with an intensity of typically 50-70 pnA. Stationary targets of 300-µg/cm^2 ^{165}Ho deposited on three thicknesses of ^{nat}Al (0.63, 1.08, and 1.71 µm) were mounted at the target position of the Momentum Achromat Recoil Separator (MARS) [4-5], with the Ho on the downstream side. Using the different target backings as degraders, a total of eight center-of-target energies were studied. A 50-µg/cm^2 ^{nat}C stripper foil was located downstream of the targets to provide charge equilibration. MARS was used to remove unwanted reaction products and unreacted beam. The achromatic section was set for $B\rho \approx 0.64$ T m, corresponding to At^{18+} EVRs. This magnetic rigidity is also less than that of the fully stripped primary beam (^{40}Ar^{18+}, $B\rho \approx 0.71$ T m), reducing the number of scattered beam particles that traversed the separator. The MARS velocity filter was set based on the calibration determined using degraded ^{241}Am alpha particles (described in a separate contribution to this annual report). A 50 mm x 50 mm, 16-strip, position-sensitive detector was used to observe implanting ions and subsequent decays.

The measured excitation function is shown in Fig. 1. The various reaction products were discriminated based on their differing alpha decay energies. The analysis of the overall separator transmission is ongoing, although the separation factor (defined as the number of events with energy greater than 30 MeV divided by the beam dose) was $>8 \times 10^{11}$. If the field strengths in the velocity filter are increased then the separation factor can also be increased, at the expense of transmission, and this will be quantified in a future experiment. These results indicate that it may be feasible to produce heavy elements at the CI.
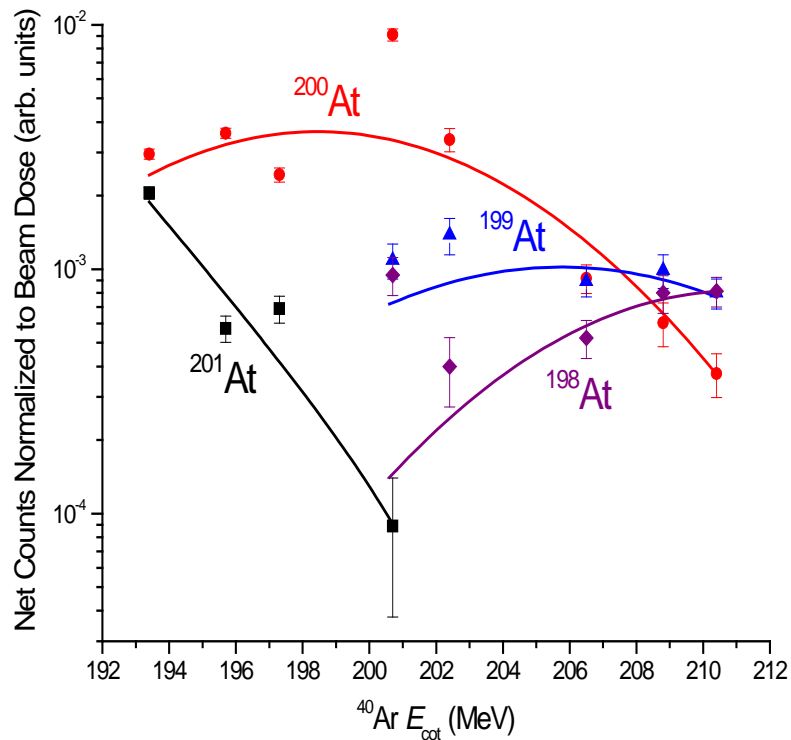
FIG. 1. Preliminary excitation function for the production of At isotopes in the ^{165}Ho(^{40}Ar, xn) reaction. Symbols are: squares, ^{201}At ($4n$); circles, ^{200}At ($5n$); triangles, ^{199}At ($6n$); and diamonds, ^{198}At ($7n$). E_{cot} represents the ^{40}Ar beam energy at the center of the ^{165}Ho targets.

[1] *A Proposed Facility Upgrade for the Texas A&M University Cyclotron Institute* (College Station, TX, 2001); available at http://cyclotron.tamu.edu/facility_upgrade.pdf.

[2] A.N. Andreev *et al.*, Sov. J. Nucl. Phys. **52**, 412 (1990).

[3] *National Nuclear Data Center* (2006); available at http://www.nndc.bnl.gov.

[4] R.E. Tribble, R.H. Burch, and C.A. Gagliardi, Nucl. Instrum. Methods Phys. Res. **A285**, 441 (1989).

[5] R.E. Tribble, C.A. Gagliardi, and W. Liu, Nucl. Instrum. Methods Phys. Res. **B56/57**, 956 (1991).