New gas stopper for heavy element chemistry research

M. C. Alfonso and C. M. Folden III

The periodicity of the heaviest element is of particular interest because relativistic effects increase as Z^2 (proton number). Relativistic effects change the energies of the valence electrons of the atom, which could lead to a significant change in the element's chemical properties. Transactinides, elements where this effect is expected to be the largest, do not exist naturally and are produced via a fusion-evaporation reaction. Before the chemistry of transactinides can be studied, their energy must be degraded to thermal energies (less than 1 eV), since evaporation residues (EVRs) are created with 30-50 MeV of kinetic energy.

Previous experiments have used a combination of Mylar degraders and a gas cell, also known as a recoil transfer chamber (RTC) and gas stopper, filled with helium gas to thermalize EVRs. These gas cells suffer from low efficiency and poor reproducibility due to turbulent gas flow conditions. We have designed a new RTC that has more laminar flow and uses a series of electrodes that create a potential gradient to more efficiently thermalize and transfer these heavy ions to the appropriate chemistry setup. This device will have a series of rings with decreasing potential to pull the stopped particles through; then at the end four concentric spherical electrodes will be used to focus the ions into an extraction nozzle. The electrode design is based on one used at MSU for stopping lighter and more energetic ions [1].

Through a series of simulations, the optimum design for our gas stopper was determined. SRIM [2] and LISE++ [3] were used to predict the expected spatial and energy distributions of the "model" transactinide ion, ^{257}Rf, out of the Momentum Achromat Recoil Separator (MARS). At the peak of the ^{208}Pb(^{50}Ti, *n*)^{257}Rf excitation function, the products exit the target with 39.6 ± 1.2 MeV of energy. The predicted vertical and horizontal standard deviation was 8 mm and 12.7 mm, respectively, at the entrance of the gas stopper. These particles have an expected range in Ti of about 4.5 μm. The SRIM predicted energy of the particles after passing through a variable angle degrader and RTC window was about 3.5 MeV. The variable angle degrader will be used to correct for uncertainty in degrader thickness by changing its effective thickness which is dependent on its angle and can be used to change the location of the stopped distribution centroid. The optimum gas cell pressure was determined to be 0.3 atm, it needed to be as large as possible to minimize straggling.

SRIM estimated the stopped distribution of the ^{257}Rf ions in the longitudinal direction was only ~5 cm (± 3σ). This is considerably narrower than the distribution of the particles stopped by the MSU gas stopper (>50 cm), evidence that a shorter gas cell with fewer rings could be used to stop EVRs.

SIMION was used to simulate the trajectory of the thermalized ions due to the ring and spherical electrodes. Included in the simulations was the mobility of the ions in He and collisions between the ions and atoms of the gas. SRIM was used to simulate the stopping width of the ions in the longitudinal direction and angular straggling. The voltage distribution was chosen to emulate MSU's. The equipotential lines of the MSU gas stopper (Fig. 1) suggest that the ions stopped in the first fifth of the gas cell will be defocused due to the grounded beryllium window, so biasing the window was simulated.

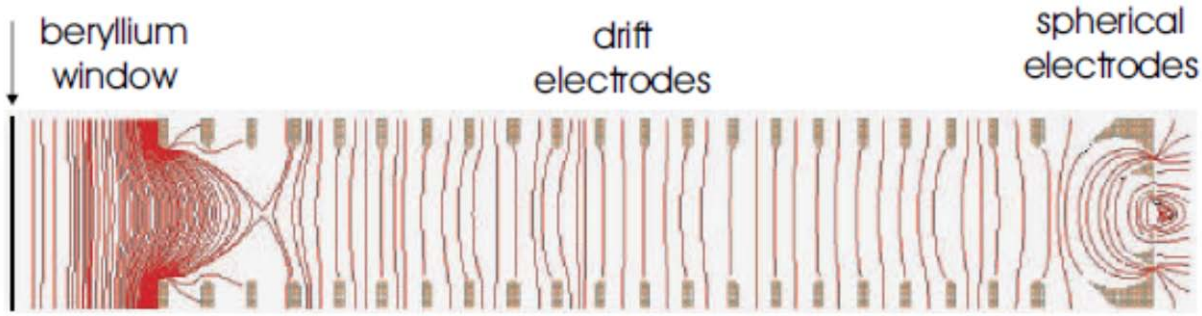

FIG. 1. Equipotential lines of the MSU gas stopper determined by SIMION. Ions travel perpendicular to the lines. [4].

It was discovered that a bias difference between the RTC window and 1st ring created an extra focusing region (Fig. 2). Also it was observed that equipotential lines bowed more at the center axis (more focusing) if the bias difference between the RTC window and the 1st ring was reduced. There is a limit, though, on this difference: If it is too small, the ions will not be guided toward the ring electrodes. Also, for this to work the walls of the chamber have to be the same bias as the window. The outer chamber of this device must be grounded for safety reasons so a two-chamber system is needed. The optimum number of ring electrodes was determined through simulation of gas cells with varying numbers of rings. It was observed that extraction efficiency was independent of ring number. Therefore the minimum number of rings possible was determined. A shorter gas cell has the benefits of decreased extraction time and decreased chance of the ions being neutralized since they go through less gas. It was observed that four rings are optimal; three rings showed signs of reduced focusing (Table I).

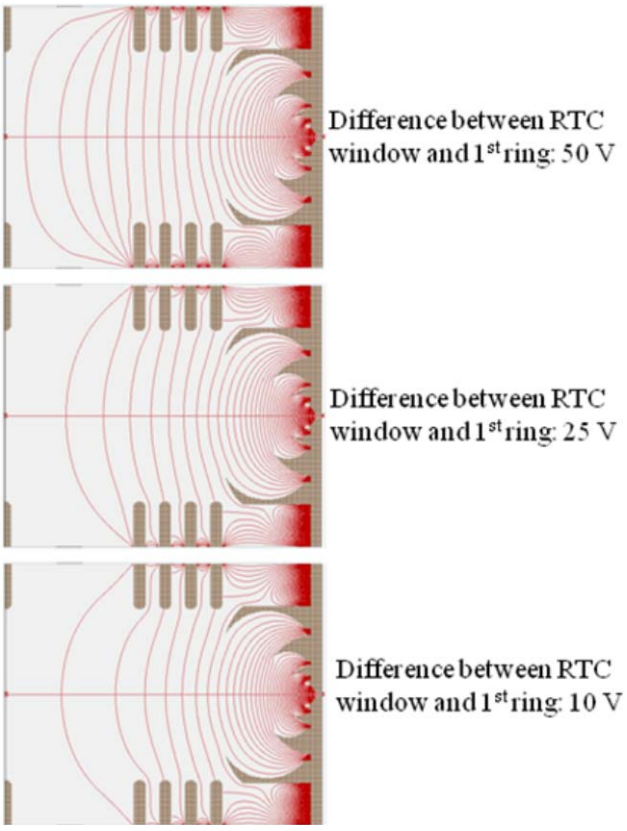

FIG. 2. Equipotential lines for gas stoppers with different voltage distribution from the RTC window to the 1st ring.

Table 1. Simulation results of gas stopper with varying number of rings. As expected, the time-of-flight decreases with the number of rings. Vertical and Horizontal position **σ** describes the ion distribution at the end of the gas stopper.

	3 rings	4 rings	6 rings
Time-of-Flight	9.6 ms	10.9 ms	13. 3 ms
Vertical position σ	1.30 mm	1.28 mm	1.26 mm
Horizontal position σ	1.51 mm	1.42 mm	1.42 mm

The gas flow is also very important to the efficient transportation of the ions to the chemistry experiment. The two-chamber system was advantageous to the gas flow (Fig. 3) because the inner chamber could then have a groove-like inlet for the helium gas. Simulations from a computational fluid dynamics program, STAR-CCM+ [5], (Fig. 3) depict this system having a laminar flow that helps focus the ions in the nozzle region. The results from STAR-CCM+ were coupled to the SIMION simulation, resulting in a 65% extraction efficiency. About 34% of the ions were lost in the last 3 mm of the cell; this area will be examined in detail when maximizing the transmission of the actual gas cell.

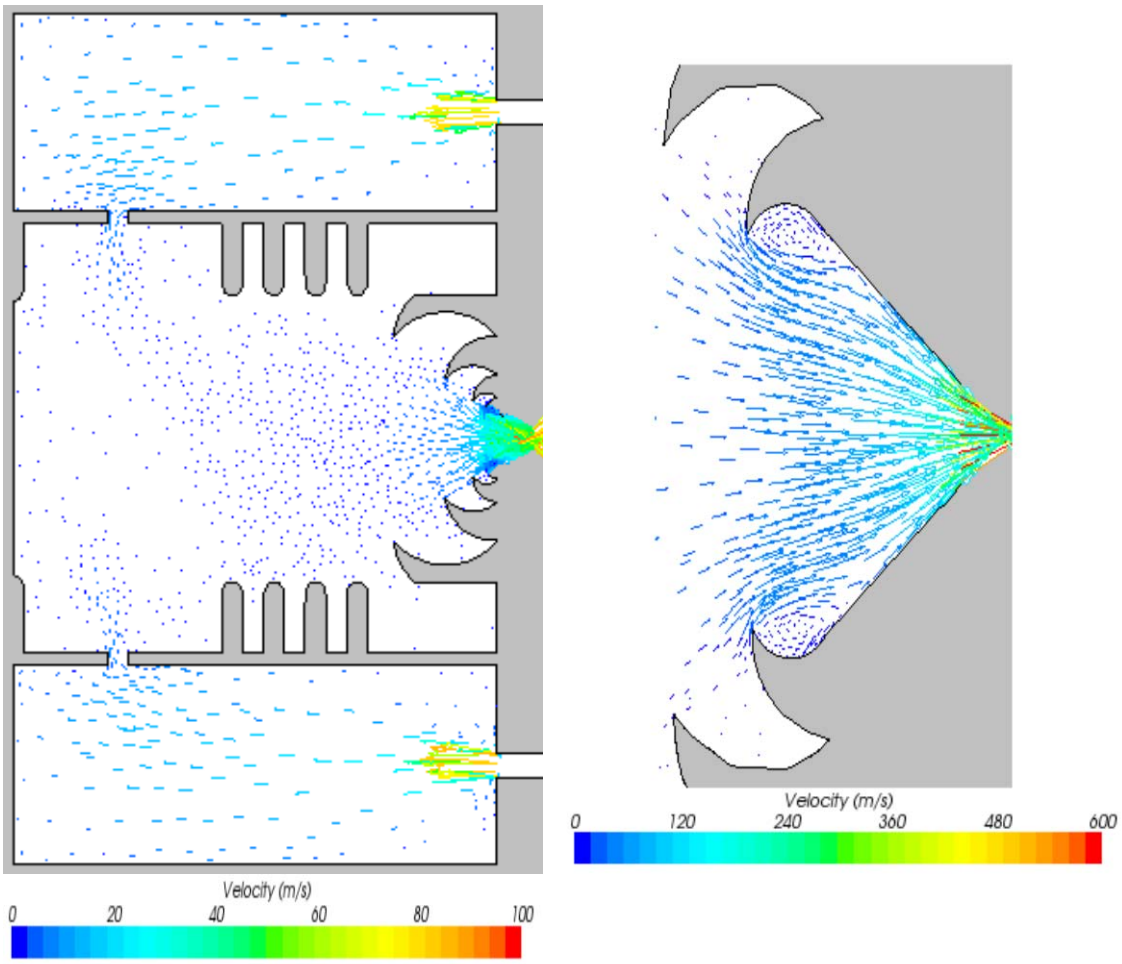

FIG. 3. STAR-CCM+ flow simulation with 0.3 atm He is the chamber and vacuum beyond the nozzle.

The design for the RTC for stopping heavy ions is almost finalized (Fig. 4). The flange containing four concentric spherical electrodes will be reused from the decommissioned MSU gas cell. The window material will be ~2 μm Ti foil supported by a wire grid and its vacuum seal will be made using gold o-rings to reduce contaminants produced by rubber o-rings. Once the entire gas cell has been fabricated, the RTC will first be tested with heavy recoils from an alpha-source. The performance will be optimized by varying the bias applied to the RTC window and the voltage drop across the gas stopper. Next, the gas stopper's efficiency will be determined with fusion reactions with high production rates, such as ^{165}Ho(^{40}Ar, 6n)^{199}At and ^{118}Sn(^{40}Ar, 6n)^{152}Er, since MARS has already been optimized in previous experiments for these reactions. Both offline and online tests should be completed by early 2012.

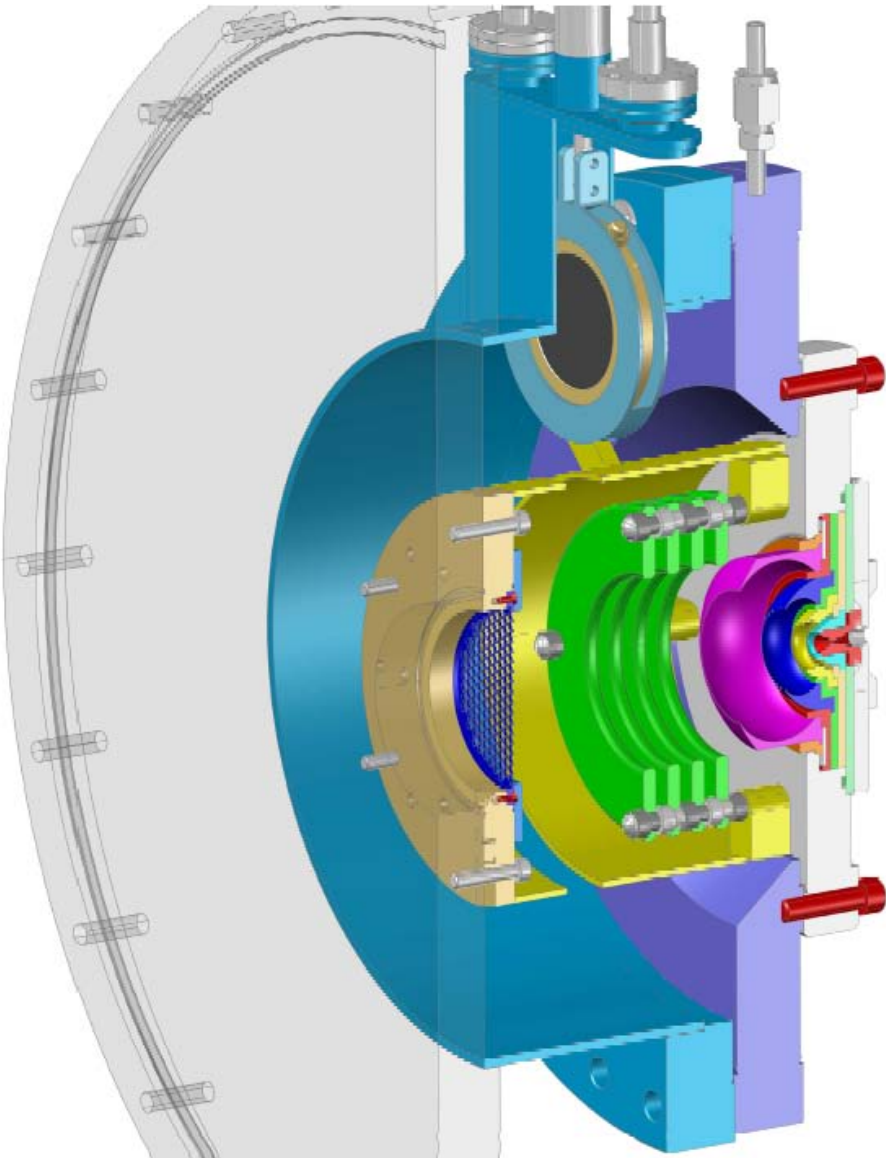

FIG. 4. Preliminary design of actual gas stopper (see main text for more detail). The simulated optimum location for the centroid of the stopped distribution is half-way between RTC window and 1st; a detector in this location will be used to determine the optimum angle of the variable angle degrader. (Courtesy of Stephen Molitor.)

[1] L. Weissman, *et al*., Nucl. Instrum. Methods Phys. Res. **A540**, 245 (2005).
[2] J.F. Ziegler, Computer Code SRIM-2008, www.srim.org.
[3] O.B. Tarasov and D. Bazin, Nucl. Instrum. Methods Phys. Res. **B266**,4657 (2008).
[4] P.A. Lofy, Ph.D. Thesis, Michigan State University (2003).
[5] STAR-CCM+ 5.02.010, CD-adapco, www.cd-adapco.com.