Development of a Gas Stopper for Fusion-Evaporation Products

J. A. Sefcik*, M. C. Alfonso, C. M. Folden III
***Department of Physics, Angelo State University, San Angelo, TX**

Introduction

Fusion-evaporation reactions create products with 40-60 MeV of kinetic energy (Figure 1). For it to be possible to study the chemistry of these products, the products must be thermalized. Currently, transactinides (elements with Z ≥ 104) can only be produced with fusion-evaporation reactions. The chemistry of transactinides is of particular interest due to the relativistic effects, which may affect the periodicity of the elements.

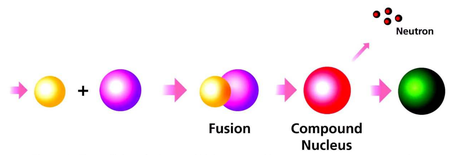

Figure 1: The collision of a beam of high energy with a target creates a compound nucleus when fusion occurs. To lose excess energy, it must split into two separate nuclei in the process of fission, or release energy in the form of something smaller, like neutrons or gamma rays.

Hafnium is a homolog of rutherfordium, the first transactinide element. The reaction considered to produce Hf is a beam of ^{50}Ti at 223 MeV and a target of ^{112}Sn, creating a compound nucleus of ^{162}Hf [1]. This reaction is of interest since Rf can be produced also by a ^{50}Ti beam and a target of ^{208}Pb. The evaporation residue ^{158}Hf was chosen because it is an alpha decaying isotope.

After the initial collision of the beam with the target, the resulting ions then travel through the Momentum Achromat Recoil Separator (MARS). MARS is then used to physically pre-separate ^{158}Hf from unwanted product and beam based on magnetic rigidity and velocity. At the end of MARS is a system containing a variable angle degrader, a reaction transfer chamber (RTC) window, and a gas stopper to thermalize the ions for a chemistry experiment.

Designing a Gas Stopper

Our design is based on the gas stopper at Michigan State University (Figure 2) [2]. This device is used to thermalize ions through gas collisions for further investigation. The thermalization of the ions is due to the random gas collisions by the helium atoms with the hafnium ions. Also, the electrodes in the gas stopper are used to focus the ions into a tight beam at the end of the stopper.

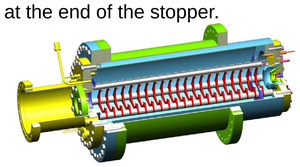

Figure 2:The MSU design is longer, giving the ions a greater length in which to collide with the helium atoms.

The original design for our gas cell (Figure 3) includes six ring electrodes and four “flower petals” to funnel the ions into an extraction nozzle. Our ions are significantly heavier and slower in comparison to the ions thermalized in the gas stopper used at MSU. Due to this, less space is needed in the gas stopper to thermalize the ions.

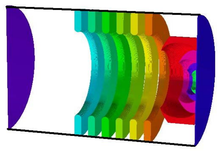

Figure 3: Our design consists of an RTC window, followed by six rings and four petals. The different colors correspond to voltage steps, as the ions travel from left to right.

LISE

LISE is a program that simulates the products of a nuclear reaction being filtered through MARS. In LISE, a beam and a target are input with certain specifications to create the desired isotope. MARS is used to filter the evaporated residues from the unwanted product and beam. Then they pass through a variable angle mylar degrader, which decreases the energy of the ions. After the degrader, the ions then travel through the RTC window and into the gas cell. The RTC window also serves as a way for the ions to lose more of their energy (Figure 4).

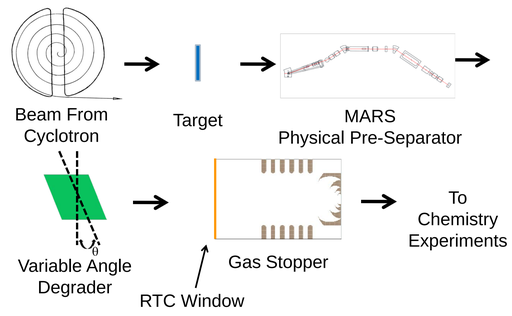

Figure 4: Block diagram of experimental set-up.

The settings of the degrader, RTC window, and pressure of gas stopper are optimized in order for the ions to be thermalized ~25 mm in the gas stopper. When the ions leave the RTC window, they have a spatial distribution determined from LISE (Figure 5 and Figure 6). LISE also gives the total kinetic energy that the ions have (Figure 7). All of these distributions will be used to define the ions in SIMION.

Vertical Distribution | Horizontal Distribution | Energy Distribution

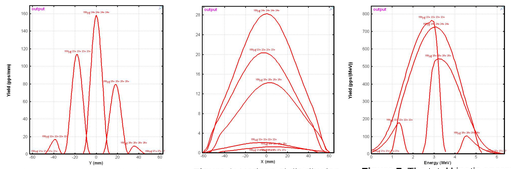

Figure 5: Vertical distribution of ^{158}Hf after RTC window.
Mean: 0 mm, σ : 17 mm

Figure 6: Horizontal distribution of ^{158}Hf after RTC window.
Mean: 0 mm, σ: 21 mm

Figure 7: The total kinetic energy distribution of ^{158}Hf after RTC window.
Mean: 3.0 MeV, σ: 0.9 MeV

SIMION

SIMION is an ion simulation program that calculates trajectories of ions under the influence of electric fields. This program simulates the ions entering the gas stopper. The ions enter the stopper with an energy of ~3 MeV and, when they reach the end of the stopper, their energy has decreased to ~0.1 eV. The optimum helium pressure was determined to be 0.3 atm, which is lower than the pressure used in the MSU gas stopper. This is because our ions are significantly heavier and slower. In each of these collisions, the hafnium ions lose some of their energy. The configuration of the electrodes is optimized along with the voltages applied to these electrodes.

Simulation

Hafnium ions were simulated using three different sets of potential differences for the electrodes (Figure 8). The first simulation began with a voltage at the RTC window of 350 V, then decreased throughout the rest of the gas cell. The next two simulations followed the same pattern, except with 700 V and 1400 V, respectively. Our main goal was to have high survival percentage combined with a low kinetic energy once the ions reached the end of the gas cell.

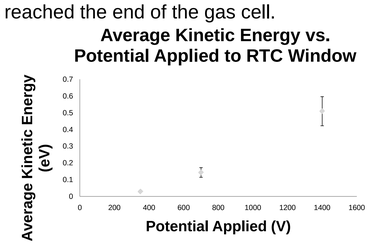

Figure 8: These potentials are for those applied to the RTC window, then decrease at a certain pace down the length of the gas stopper. The standard deviation for 350 V is too small to be seen on the graph.

The simulation of 1400 V resulted in ions with too high of a kinetic energy at the end of the gas stopper. The 350 V simulation resulted in ions with a longer time of flight, so the risk of decay was increased. Due to these two facts, the simulation of 700 V was determined to be optimum. One main variable was the voltage difference between RTC window and the first electrode, so results of potential differences are compared in Figure 9. The optimum voltage difference was determined to be 10 V.

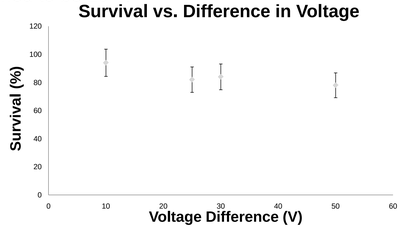

Figure 9: This test was needed in order to determine the best potential difference between the RTC window and the first electrode. This difference had to be enough to give the ions a “forward push”, but not so much that the kinetic energy was significantly increased. When no voltage difference was applied, the time of flight was too long to even be considered.

After several simulations, a problem was noticed: due to the large spatial distribution in both the horizontal and vertical directions, too many ions were being stopped by the first electrode. In order to solve this, we expanded the dimensions of the gas stopper (Figure 10).

After simulating with the wider gas stopper, more problems occurred. A region of space unaffected by any electrodes now existed around the petals, causing a lack of focusing in the petal region. A 5th petal was added to prevent ions from going around the flower (Figure 11).

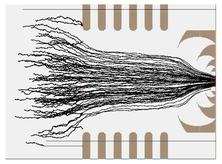

Figure 10: Hindered by the size of the cell, many ions are stopped by either the first electrode or are not created.
Dimension: 13.5 cm x 10 cm x 10 cm

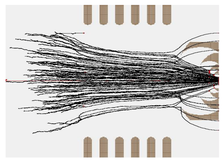

Figure 11: Due to the new width of the gas stopper, the ions experience a lack of focusing in the region of the petals.
Dimension: 13.5 cm x 13 cm x 13 cm

Simulation continued

The final ring was removed to make room for an extra petal. The possibility of eliminating more electrodes in order to decrease cell size and time of flight of the ions was also considered (Figure 12).

The results of the survival of ions from the 3 ring simulation were similar to the simulation with 5 rings. Since the size of the cell decreased, the time of flight decreased by 15%, thus giving the ions less of a chance of decay (Figure 13).

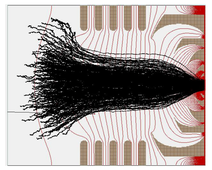

Figure 12: The addition of the 5th petal results in improved focusing.
Dimension: 13.5 cm x 11 cm x 11 cm

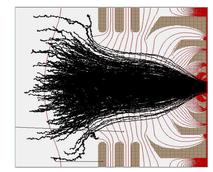

Figure 13: Decreasing to three rings decreased both length and time of flight.
Dimension: 11.5 cm x 11 cm x 11 cm

Simulations were ran again to reaffirm the difference in voltage between the RTC window and the 1st ring (Figure 14).

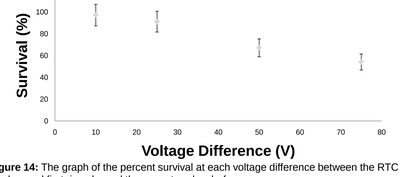

Figure 14: The graph of the percent survival at each voltage difference between the RTC window and first ring showed the same trend as before.

Conclusion/Future Work

We have determined that a 115.5 mm gas stopper is adequate for thermalizing the ions, including 3 rings and 5 petals. The smaller design decreases the time of flight of the ions while still keeping the survival percentage close to 100%.

The gas cell needs to be tested for other elements, such as zirconium, that are homologs of Rf and could therefore provide information on the expected properties of Rf. The most important issue still remaining is to fabricate and test the gas cell. This will require all of the other components to be in place as well, like the variable angle degrader and the RTC window. We also have to optimize the gas flow in the cell and deal with the issues of the ions changing charge state.

References

[1] Ch. E. Düllmann, et al. *Nucl. Instr. and Meth. A.* **551** (2005) 528-539.
[2] L.Weissman, et al. *Nucl. Instr. and Meth. A.* **540** (2005) 245-258.

Acknowledgements

This work was supported by the National Science Foundation.

Contact information

Charles M. Folden III
folden@comp.tamu.edu
http://cyclotron.tamu.edu/folden