Development of a gas stopper for heavy element chemistry

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Studying the chemistry of the transactinides is of particular interest due to relativistic effects. As Z (proton number) increases, the speed of the innermost electrons becomes increasingly more relativistic, changing the energies of the electron orbitals in the atom. This could lead to significantly different chemical and physical properties for heavy elements than expected. Transactinides ($Z > 103$) can only be created via fusion-evaporation reactions which produce evaporation residues (EVRs) with 30 – 50 MeV of kinetic energy. However, chemistry systems are studied at sub-eV energy levels. Therefore, these EVRs must be degraded before their chemistry can be studied.

Previous work in the field of heavy elements has used a combination of degraders and a gas cell, also known Recoil Transfer Chamber (RTC), to facilitate the chemical study of EVRs. Transactinides are produced with a very low rate and their half-lives can be very short so it is critical that the RTC be as efficient and fast as possible. An RTC for heavy elements has been designed and fabricated at the Cyclotron Institute (Fig. 1) that is a hybrid of gas cells used in the transactinides field [1] and one used at Michigan State University for stopping projectile fragmentation reaction products [2]. Our gas cell uses more laminar flow and a series of electrodes that create a potential gradient to efficiently transport the EVRs to the appropriate chemistry apparatus. The electrode system contains four rings with a decreasing potential that pulls the ion through; at the end there are four concentric spherical electrodes (so-called flower petals) that are used to focus the ions into the Extraction Nozzle. This electrode system is based on the gas cell from Michigan State University [2].

A two-chamber design was implemented in the RTC. In the Main Chamber, the electrode system and gas flow carry the ions through an Extraction Nozzle to a so-called Aerosol Chamber. In this chamber, ions attach to KCl aerosol clusters which aid in the transmission of the EVRs through the Transportation Capillary to the appropriate chemistry experiment. (Bare ions have a greater chance of getting trapped on the sides of the capillary than ion-aerosol clusters). The design of the gas cell was also driven by results from gas flow simulations by STAR-CCM++ (Fig. 2) [3]. It is critical that the gas flow in the Main Chamber does not hinder the focusing of the electrode system; by adding the Inner Chamber Groove (see Fig. 1) the flow in the region where the ions are thermalized and focused by the electric field is more laminar. A negative pressure differential between the two chambers is needed to limit the aerosol contamination in the Main Chamber, which may hinder the focusing ability of the electrode system. The gas flow in the Extraction Nozzle also had to be optimized since it is the dominate component in this region. Lastly, the gas flow in the Aerosol Chamber had to be optimized to carry the ion-aerosol clusters into the Transportation Capillary. The RTC has been fabricated and preliminary characterization results are presented here.

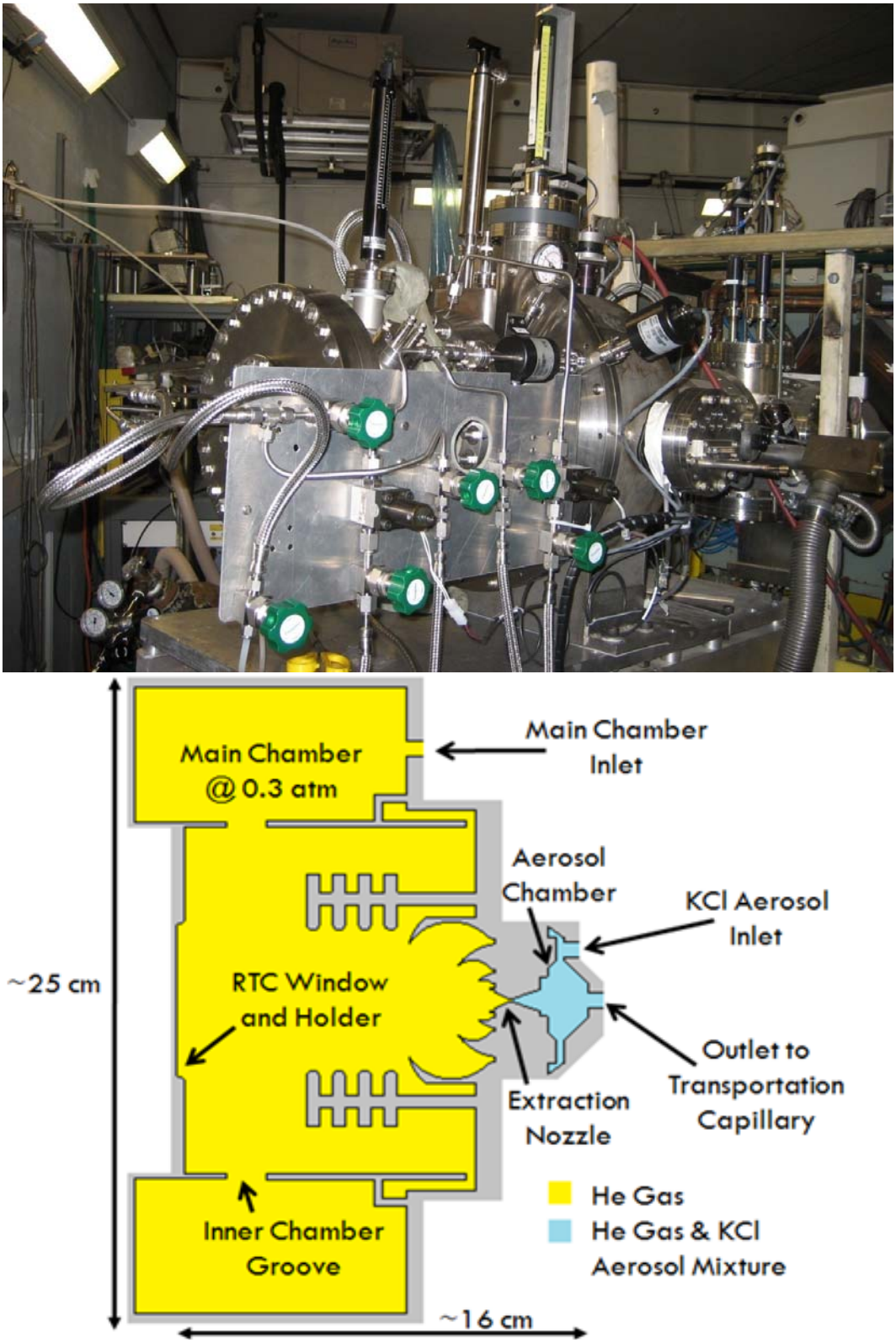

FIG. 1. Top: picture of the actual RTC attached to the detector chamber at end of the MARS beamline. Bottom: schematic picture of the RTC (see main text for more detail).

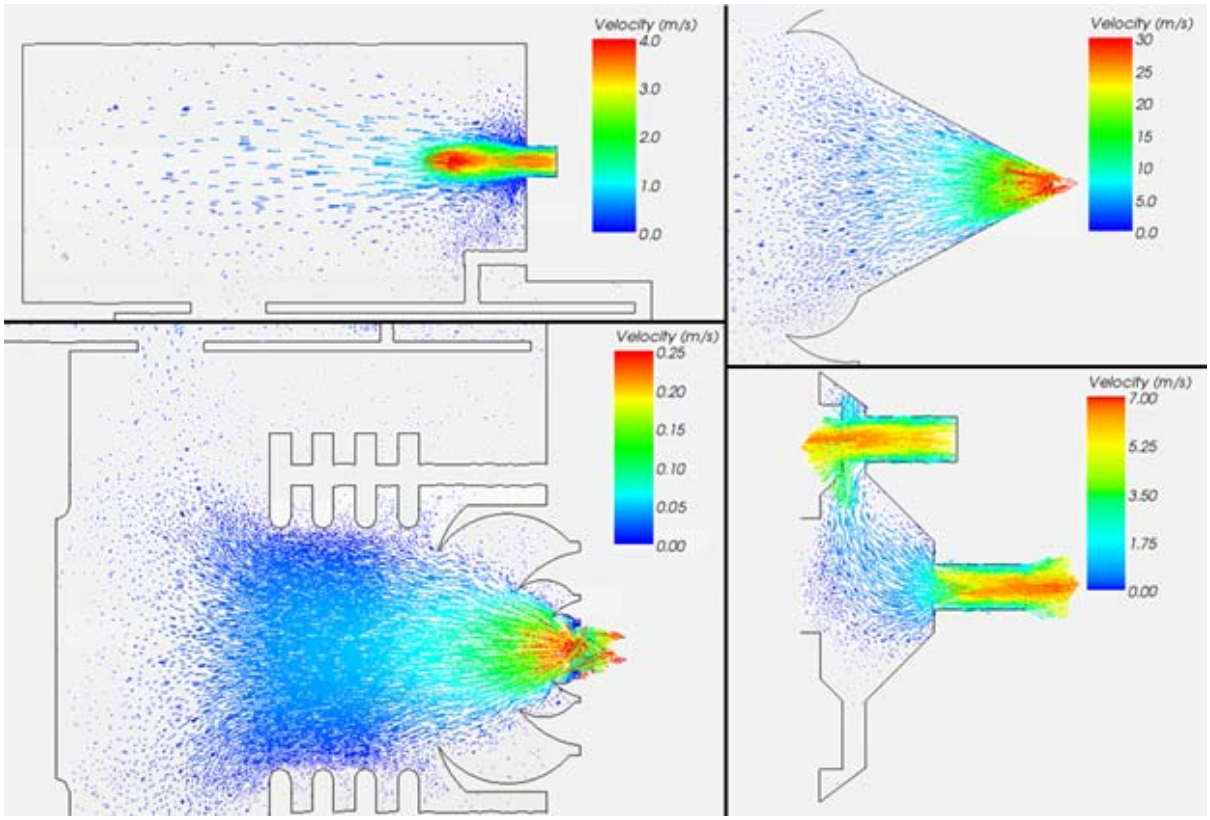

FIG. 2. Gas flow simulations of the finalized gas cell design. Pump speed simulated was 4 L/min with a -15 torr differential between the Main Chamber and Aerosol Chamber. The two quadrants to the left show how the Inner Chamber Groove creates a laminar flow in the critical region of the Main Chamber. The simulated gas flow in the Extraction Nozzle can be seen in the top right quadrant. In this region gas flow becomes the more dominate force and directs the ions through to the Aerosol Chamber. Lastly, the bottom right quadrant shows a favorable flow that carries the ions into the Transportation Capillary.

A two-detector system has been installed in the RTC to monitor the transportation of ions through the system. A large-area detector was placed where the peak of the stopped ion distribution is expected to be. This detector can be plunged in and out of the beam path and will make it possible to select the optimum degraders upstream of the RTC. An identical detector was placed directly downstream of the Extraction Nozzle, so the gas flow and electrode system in the Main Chamber could be optimized. The second detector requires that the Aerosol Chamber be on a retractable system.

The negative pressure differential (PD) between the Main Chamber and Aerosol Chamber also affects the magnitude of the flow in the Main Chamber. As the PD between the two chambers is increased the flow in the Main Chamber becomes increasingly more forceful. This is very important in the Extraction Nozzle where there is minimal focusing due to the electrode system. STAR-CCM+ simulations indicated there was a maximum possible flow out of the Main Chamber of 2.9 L/min. During offline testing it was discovered that the maximum PD possible depended strongly on the conductance of the system. The most important factor influencing the conductance is the inner diameter of the Transportation Capillary. Thus, capillaries with varying inner diameters (1/16”, 3/32”, 1/8”, 5/32”) and a constant length (25 ft) were tested. The maximum PD for the individual capillaries was determined by

closing the Aerosol Chamber inlet and holding the Main Chamber at a constant 228 torr (0.3 atm) with flow only from the Main Chamber inlet. The data (Table I) suggest that a capillary with an inner diameter smaller than 1/8" cannot be used because no PD is possible with these smaller capillaries.

Table I. Maximum achievable PD as a function of the inner diameter of the Transportation Capillary. As the inner diameter of the capillary increases the maximum PD increases. Capillaries with a maximum DP 0 torr cannot be used on the RTC.

Inner Diameter of Capillary	Maximum PD
1/16"	0 torr
3/32"	0 torr
1/8"	24 torr
5/32"	56 torr

The effects of inner diameter of the capillary and PD on transmission through the Main Chamber were tested using positively charged ^{216}Po recoils from a ^{228}Th source to simulate thermalized EVRs. Almost all recoils formed in the ^{228}Th source are neutral. However, a small amount of ^{220}Rn, a gaseous element, constantly emanates out of the source. ^{216}Po daughters from the emanated ^{220}Rn remain in a positive charge state and can be transported through the RTC. A ^{228}Th source with an activity of 2.3×10^3 Bq was attached to the linear actuator in the Main Chamber and the detector downstream of the Extraction Nozzle was used to measure the transmission of ^{216}Po recoils. SIMION [4] was used to determine the optimum electric field settings shown in Fig. 3; this voltage distribution was held constant while both the 1/8" and 5/32" inner diameter capillary were tested with varying PDs. As shown in Fig. 4, the transmission is constant with a PD of ≥15 torr. Also, the difference in transmission between the two different capillaries is not significant. Previous experiments on other RTCs suggest that the flow becomes turbulent in the Transportation Capillary at high flow rates [5]; this may decrease the transmission of the ion-aerosol

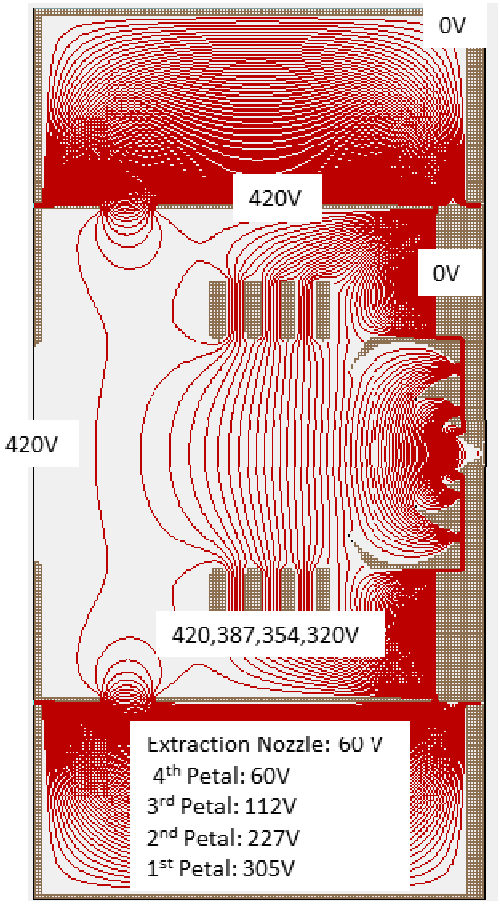

FIG. 3. Equipotential lines diagrams from an optimized SIMION simulation. Ions travel perpendicular to these lines.

clusters through the capillary. Therefore, the 1/8" inner diameter capillary was selected for further studies.

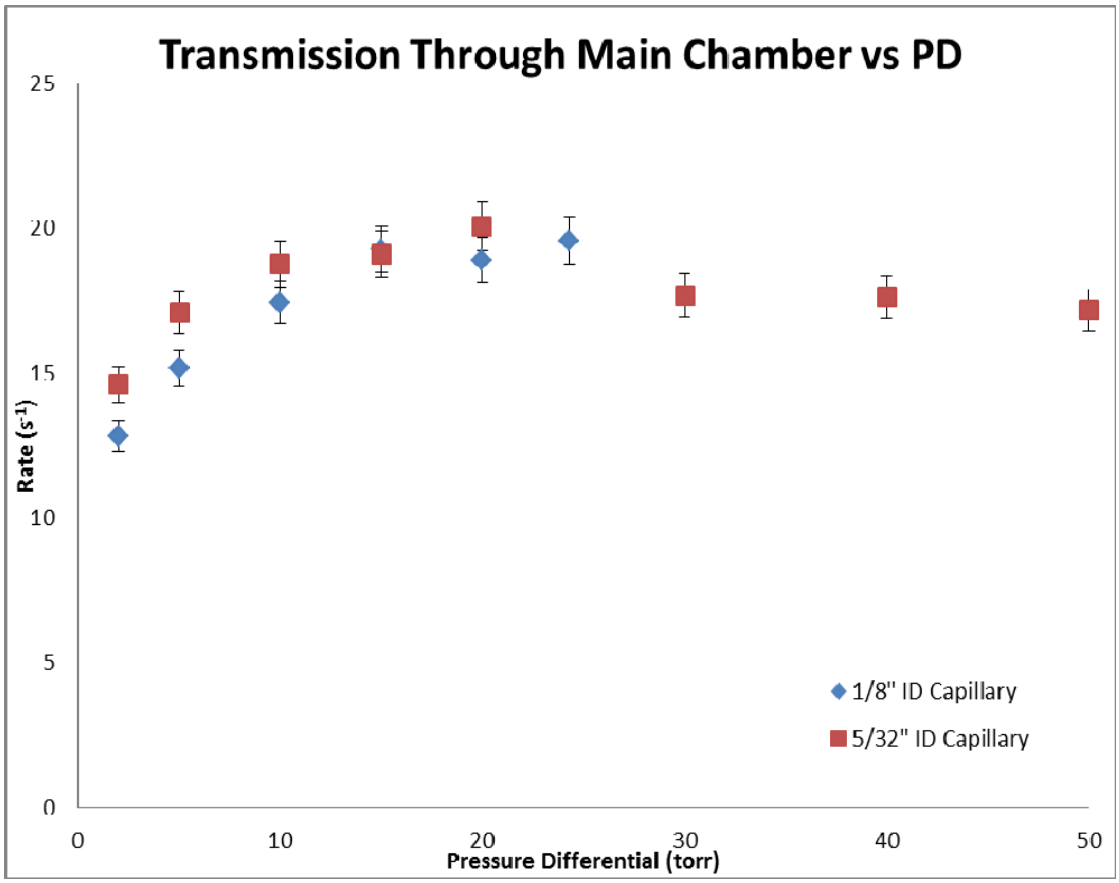

FIG. 4. Transmission through the Main Chamber as a function of PD between the two chambers and inner diameter (ID) of the capillary. A systematic error of 4.2% was calculated and applied to all data points.

Lastly, the effects of the electric field and gas flow on transmission were separately measured. This was first done by measuring the transmission without gas flow but with optimum electric field settings (Fig. 3); a transmission of less than 1% of the maximum transmission was detected. Also, tests were conducted with gas flow (PD set to 15 torr) and the electric field off; a transmission of less than 3% of the maximum transmission was detected. This is evidence that both gas flow and the electric field are needed to efficiently transmit the ions through the Main Chamber.

Assuming that the fraction of ^{220}Rn emitting from the source is 3% [6], the RTC has an efficiency of approximately 70%. Also the half life of ^{216}Po is 150 ms, which is short enough that the transportation time in the RTC is significant. Simulations from SIMION show a time-of-flight of approximately 20 ms for these electric field settings (Fig. 3). Decay loss corrections are included in the efficiency quoted above.

Currently, the RTC has been fabricated and offline tests of the RTC's electric field with ^{228}Th recoils will continue. A beam experiment is planned for the end of May 2012 to test the gas stopper's

efficiency. The reaction ^{118}Sn(^{40}Ar, 6n)^{152}Er will be used since the Momentum Recoil Achromat Spectrometer (MARS) has already been optimized in previous experiments; this reaction also has orders of magnitude higher cross section than transactinide production reactions [7]. Commissioning experiments of the RTC with this high cross section reaction will be completed by Fall 2012. Then the RTC will be used to facilitate the testing of new chemical systems for transactinides.

[1] C.E. Düllmann et al., Nucl. Instrum. Methods Phys. Res. A**551**, 528 (2005).
[2] L. Weissman *et al*., Nucl. Instrum. Methods Phys. Res. A**540**, 245 (2005).
[3] STAR-CCM+ 5.02.010, CD-adapco, www.cd-adapco.com.
[4] SIMION, www.simion.com.
[5] R. Sudowe, private communication.
[6] A. Sakoda *et al.,* Applied Radiation Isotopes **69**, 1422 (2011).
[7] R.L. Hahn *et al.,* Phys. Rev. Lett. **42**, 218 (1979).