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New recoil transfer chamber for thermalization of heavy ions produced in fusion–evaporation reactions

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ABSTRACT

A new Recoil Transfer Chamber (RTC) has been designed, fabricated, and characterized at the Cyclotron Institute at Texas A&M University. The design is based on a gas stopper that was previously in routine use at the National Superconducting Cyclotron Laboratory. This new RTC uses He gas to stop ions, and a combination of a static electric field and gas flow to maximize the extraction efficiency. In offline experiments, a ^{228}Th source was used to produce ^{216}Po which was successfully extracted even though it has a short half-life. In online experiments using the products of the ^{118}Sn(^{40}Ar, 6n)^{152}Er reaction, an efficiency of several tens of percent was measured.

1. Introduction

The development of efficient gas stoppers, also known as gas catchers, gas cells, or recoil transfer chambers (RTCs), has allowed a variety of sophisticated experiments utilizing thermalized beams to be conducted. These systems can be installed at particle accelerator facilities, where they give access to exotic nuclei far from the line of beta stability. Recent experiments have included first chemistry studies of superheavy elements [1–4], precision mass measurements using Penning traps [5–7], and delivery of radioactive beams to reacceleration facilities [8,9]. These systems typically employ one of two designs. The first design consists of a relatively simple single gas-filled chamber that uses the flow of the gas to extract ions [10–12]. The extraction efficiency of these systems is high, but the resulting beam of thermalized products has a very large and poorly characterized emittance. This makes them unsuitable for next-generation experiments, such as the transmission of superheavy ions to a mass spectrometer (e.g., the FIONA project under development at Lawrence Berkeley National Laboratory). The second design consists of many variations that all use radiofrequency (RF) oscillating electric fields to guide the ions [5,9,13–18]. This reduces the extraction time and increases the efficiency, but these RF systems are extremely complex (for example, [13,14,17–19]), and sometimes require cryogenic cooling [15].

A new RTC has been developed that gives the efficient transport of ions using electric fields without the complexity of an RF system. The new Texas A&M RTC design is primarily based on the gas stopper previously used at the National Superconducting Cyclotron Laboratory (NSCL) [20–23] (see Fig. 1 in [20] for a schematic). The RTC has been simulated, fabricated, and characterized in both offline and online experiments. In the future, the RTC will be used to perform "online" chemistry experiments at Texas A&M University, where activity is produced in an accelerator-based experiment and utilized within a few seconds.

2. Design

In the NSCL gas stopper, the ions were slowed by a rotating variable angle degrader (VAD) and a window, and stopped in a chamber filled with 750 Torr (100 kPa) of He. A decreasing potential

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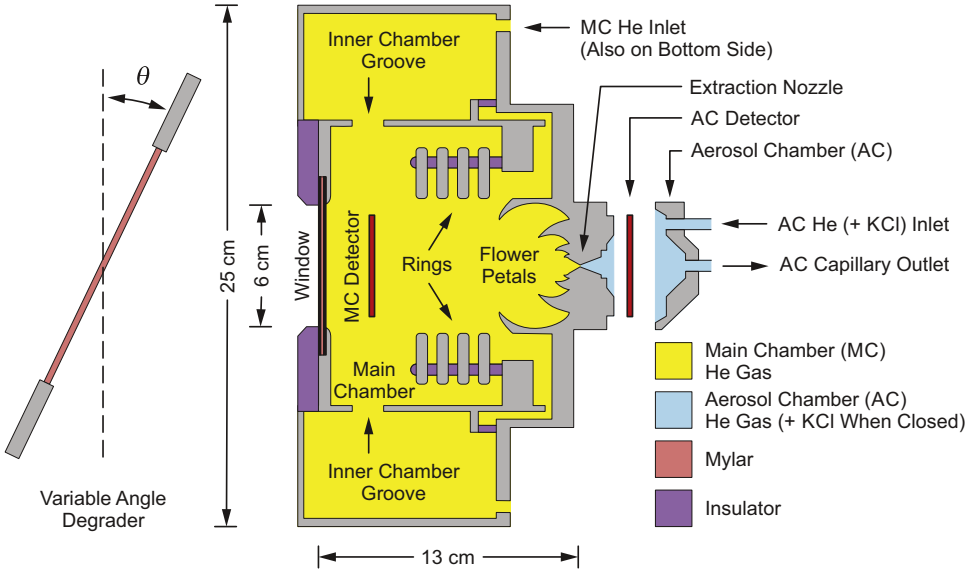

Fig. 1. Schematic of the RTC. Ions enter from the left and pass through the variable angle degrader before entering the window. Yellow color indicates pure He in the main chamber (MC), while blue indicates He gas possibly laden with KCl aerosols in the aerosol chamber (AC) when it is closed. Both detectors are shown inserted, which requires that the AC be retracted. Black lines on the window indicate the Al layer. Some non-essential pieces have been removed for clarity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Properties of reactions used to simulate the RTC. Targets were assumed to have a thickness of 500 μg/cm^2. EVR energies are given after a ~50 μg/cm^2 ^{nat}C stripper foil located immediately downstream of the target. Column 4 gives the required EVR energy to stop the ions 2.5 cm deep in the He gas when the pressure is 228 Torr (30.4 kPa). Spatial distributions are incident on the RTC window. Reduced mobilities were estimated using Ref. [39].

Reaction	EVR	EVR energy after stripper (MeV)	EVR energy after window (MeV)	Horizontal FWHM (mm)	Vertical FWHM (mm)	Estimated reduced mobility (cm^2 V^{-1} s^{-1})
^{70}Ge(^{18}O, 3n)	^{85}Zr	12.5 ± 1.9	1.4 ± 0.3	–[a]	17.2	15.9
^{124}Sn(^{50}Ti, 5n)	^{169}Hf	53.6 ± 3.1	2.6 ± 1.1	–[a]	13.1	15.7
^{208}Pb(^{50}Ti, n)	^{257}Rf	39.5 ± 1.2	3.5 ± 1.0	29.8	7.7	15.6

[a] The distribution was only slightly peaked in the horizontal direction.

gradient created by a series of "ring" electrodes drew the ions toward a set of four hemispherical, concentric "flower petal" electrodes (see Fig. 4.3 in [24] for a picture), and these also had a potential gradient. This second gradient focused the ions toward an extraction nozzle with a diameter of 0.6 mm, where the flow of the gas carried the ions through the nozzle [13,25]. The NSCL gas stopper was in routine use but has now been decommissioned. The new RTC incorporates the NSCL gas stopper's actual flower petal assembly and includes design elements from the previous system.

A schematic of the new RTC design is shown in Fig. 1. In addition to the NSCL components, the RTC incorporates a VAD, an entrance window, a He-filled stopping region, ring electrodes, the flower petal electrodes, and a nozzle. The VAD is made of a single layer of Mylar® (polyethylene terephthalate), and the entrance window that separates the RTC gas from the beamline vacuum is made of aluminized Mylar so that it can be biased (see the discussion in Section 3). The window is supported by a metal grid with a "honeycomb" pattern, and the grid is covered by a "protector screen" that is intended to prevent pieces of the window from being drawn into the beamline if it fails. After passing through the window, the ions enter the "main chamber" (MC) where they are stopped in He with pressure P. The He gas enters the MC from an expansion chamber surrounding the MC by passing through the cylindrical "inner chamber groove." Four ring electrodes transport the ions from the stopping region to the flower petal focusing region. The ions are swept through the nozzle into an "aerosol chamber" (AC). In future experiments, the ions will be attached to aerosol particles and be transported through a capillary to a chemistry laboratory. The volume of the AC was kept small (~15 cm^3), since this reduces the flushing time [12]. Due to the small diameter of the nozzle (0.6 mm), a slight difference in pressure (DP) can be maintained between the MC and the AC in order to ensure that the gas flows the proper direction through the nozzle, while carrying the ions swiftly and efficiently (DP=P_{MC}–P_{AC}). The downstream side of the AC is mounted on a bellows system that allows it to be retracted; i.e., the three metal elements that form the downstream wall of the AC in Fig. 1 can be withdrawn and the system operated without aerosols. All of the experiments in the current work were performed with the downstream wall retracted. Two retractable Si detectors, the "MC detector" inserted through the inner chamber groove and the "AC detector" inserted downstream of the nozzle, were used to measure the extraction efficiency.

3. Simulations

The design of the system was optimized through a series of simulations. The new RTC is designed to stop product beams that have first been purified using physical pre-separation [26]. Specifically, the Momentum Achromat Recoil Spectrometer (MARS) [27,28] was assumed to be the physical pre-separator. MARS has been previously developed for the purification of a beam of heavy element evaporation residues (EVRs) with energies of 150–250 keV/u [29]. The nuclides