

A Universal Method For Effusive-Flow Characterization of Target/Vapor Transport Systems For RIB Generation

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Abstract. Decay losses associated with the times required for diffusion-release from ISOL production targets and to effusively-flow to the ion source are principal means whereby short half-life radioactive species are lost between initial formation and utilization. We have developed an experimental method that can be used to determine effusive-flow times of arbitrary geometry target/vapor transport systems. The technique utilizes a fast valve to measure effusive-flow times as short as 0.1 ms for any chemically active or inactive species through any target system, independent of size, geometry and materials of construction. In this report, we describe the effusive-flow experimental arrangement and provide time spectra for noble gases through prototype RIB target/vapor-transport systems.

1 INTRODUCTION

The Isotope Separator On-Line (ISOL) technique is most frequently used to produce short-lived isotopes for research at radioactive ion beam (RIB) facilities such as the Holifield Radioactive Ion Beam Facility (HRIBF) [1]. After being created in the matrix of a solid or liquid target, the short-lived species must diffuse from the target material and then be transported in gaseous or vapor form through the transport system to an ion source where they are ionized and accelerated. Decay losses associated with the times required for the diffusion and effusive-flow processes to take place are principal means whereby short half-life radioactive species are lost between initial formation and utilization [2]. Thus, it is desirable to minimize the times associated with both processes. An experimental method has been developed that can be used to determine effusive-flow times for arbitrary geometry target/vapor transport systems. In this report, we present effusive-flow time spectra experimentally measured for three different target/vapor transport systems *with* and *without* Reticulated Vitreous Carbon Foam (RVCF) in the respective target material reservoirs. (A form of this

material, compressed in the z-direction by a factor of 2 (2 x RVCF), is used as matrices for deposition of target materials for many HRIBF targets [2, 3] and therefore, will be used to simulate the presence of target material in each of the vapor transport systems used in the present studies.) The aim of the present studies is to demonstrate the viability of the technique with the ultimate objective of using it to design optimally coupled vapor transport systems that minimize effusive-flow from the HRIBF targets to existing ion sources, and as a technique that can be universally used to characterize present and future target/vapor transport systems at ISOL facilities.

2 EFFUSIVE-FLOW FORMULA

For an ideal gas in a tube of radius, a , and length, l , at low pressure, the steady-state flow rate, dN/dt , for particles of average velocity, v , flowing through a tube under a density gradient along the tube, dn/dz , is given by [4]:

$$dN/dt = -\{2\pi a^3/3\}v dn/dz = -\{2\pi a^3/3k_B T\}v dp/dz \quad (1)$$

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where n is the particle density, v is the Maxwellian velocity and k_B is Boltzmann's constant.

The average transport time for chemically active radioactive particles with lifetime, $\tau_{1/2}$, to flow through a tubular system can be deduced by solving the time dependent form of Eq.1. The resulting equation is:

$$N = N_0 \exp[-\lambda t] \exp[-t/\tau_c] \quad (2)$$

where N_0 is the number of particles in the volume at time $t = 0$; $\lambda = 0.693/\tau_{1/2}$; the characteristic effusive-flow time, τ_c , is given by

$$\tau_c \cong 3/4 [N_b \tau_0 \exp(-H_a/k_B T) + L/v] \quad (3)$$

where $v = (8k_B T/\pi M)^{1/2}$; H_{ad} is the enthalpy of adsorption; and $\tau_0 \cong 3.4 \cdot 10^{-15}$ s. For noble gas elements which have negligibly small H_{ad} values, $\tau_c \cong 3L/4v$.

3 EXPERIMENTAL ARRANGEMENT

A fast valve system has been designed for specific use in characterizing the effusive-flow properties of targets and vapor-transport systems [5]. The valve system (Figure 1), initially designed to close in 10 ms [6], has been modified to achieve a closing time of 0.1 ms and thus, the device can be used to measure characteristic times of particles with values, $\tau_c \geq 100$ μ s. The valve is close-coupled to the target material reservoir in order to negate any delay times associated with the connecting line between the valve and the reservoir. The characteristic effusive-flow times of the feed gas of interest is determined by rapidly interrupting flow into the target/ion source system

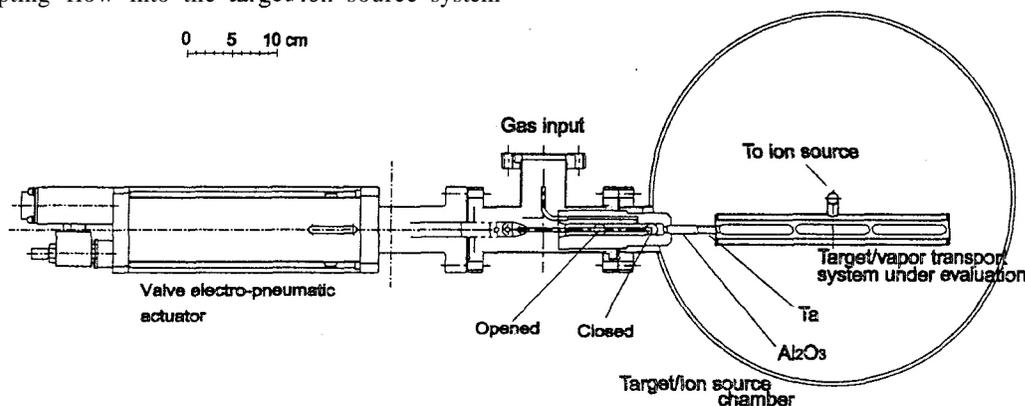


FIGURE 1. Schematic drawing of the fast closing valve, gas input system on the target/ion source chamber.

while monitoring the time dependence of the mass selected ion current.

Three vapor transport systems were evaluated: two versions of low vacuum conductivity system (Figure 2) with serial and a parallel-flow target material reservoirs (Figure 3) and a high vacuum conductivity system (Figure 4). The characteristic flow spectra for noble gases were measured through each of the three all Ta vapor transport systems *with* and *without* 2 x RVCF in the target material reservoir. The 2 x RVCF disks were 2 mm thick and 14.9 mm O.D. and closely stacked in each reservoir to form 192 mm length targets. For the parallel flow system, the disks were placed in a 15.9 mm O.D., slotted tubular holder (58% transparent) that was coaxially mounted in a solid, 24.4 mm I.D. tubular chamber so that the annular distance between the target holder and walls of the chamber was 4.3 mm. The serial and parallel flow conventionally connected systems were connected to the ion source by means of a 9 mm I.D. tube that is bent at 90°, 25 mm above the reservoir. In contrast, the target material reservoir for the high vacuum conductivity system (Figure 4) is connected to the ion source through a 8.5 mm high x 25 mm long x 193 mm wide aperture bent at a 90° angle at the 25 mm position above the reservoir and then tapered at a 45° angle until it connects with the 8.5 mm I.D. transport tube to the ion source.

4 EFFUSIVE DELAY-TIME MEASUREMENTS

Time spectra were measured for noble gases (He, Ne, Ar, Kr and Xe) flowing through the respective systems *with* and *without* Reticulated Vitreous-Carbon Foam (RVCF) in the target material reservoir for different target holder temperatures.

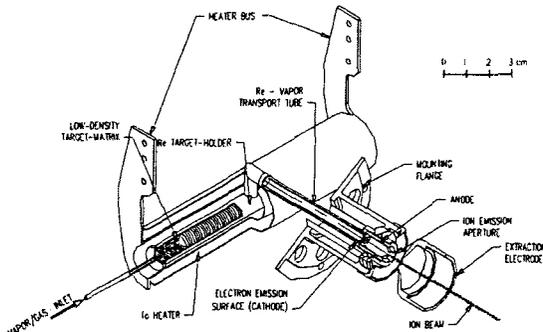


FIGURE 2. Conventional serial-flow vapor transport/ion source system.

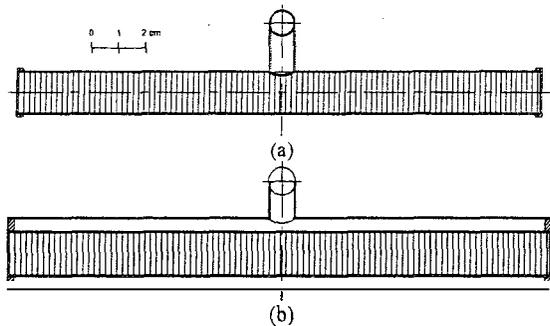


FIGURE 3. (a) The serial-flow and (b) parallel-flow reservoirs to be characterized.

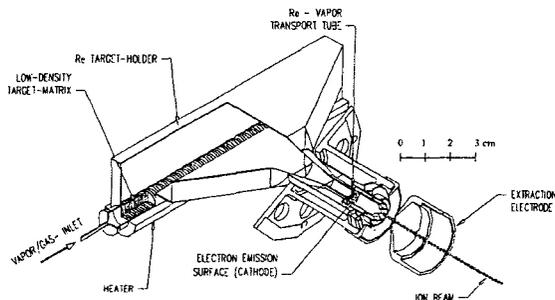


FIGURE 4. High vacuum conductivity target/vapor transport/ion source system for fast effusive-flow.

Conventional serial-flow system

Characteristic time versus temperature data for noble gas elements (He, Ne, Ar, Kr and Xe) flowing through the conventional serial-flow vapor transport system *with* and *without* RVCF material in the target material are shown in Figure 5.

As expected from theory (e.g., Eq. 3), the characteristic times increase with $M^{1/2}$ at the same transport system temperature and decrease with increasing temperature for a given species according to $T^{-1/2}$. As noted, the RVCF does not significantly increase the effusive-flow times of the noble gases,

thus, validating the importance of high permeability targets for RIB applications.

Using the linearity of τ_c with \sqrt{M} (Eq. 3), the average distance traveled per particle, \bar{L} , through the system is found to be 91 m *without* RVCF and 114 m *with* RVCF in the target material reservoir for this system.

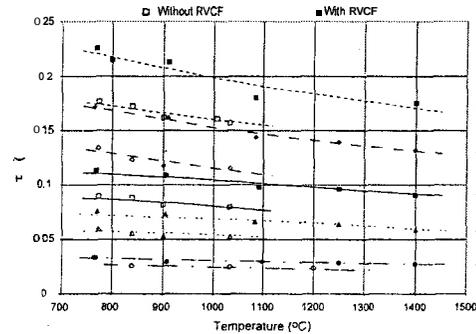
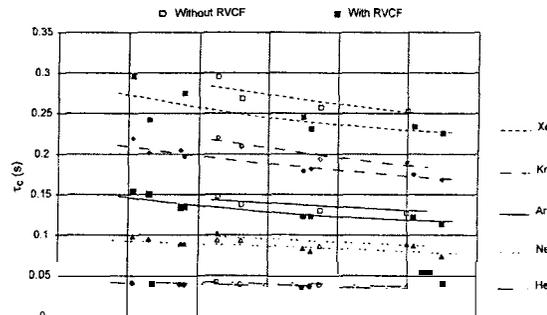


Figure 5: Characteristic times, τ_c , for noble gases versus transport system temperature for the conventional serial-flow coupled vapor transport system displayed in Figure 3a *with* (solid symbols) and *without* RVCF (open symbols) in the target material.

Conventional parallel-flow system

The time distributions of noble gas elements (He, Ne, Ar, Kr and Xe) flowing through the conventional parallel-flow vapor transport system *with* and *without* RVCF material for different temperatures are shown in Figure 6.

The average distances traveled per particle are, respectively, **148 m *with*** and **161 m *without*** target material in the target material reservoir. As noted the

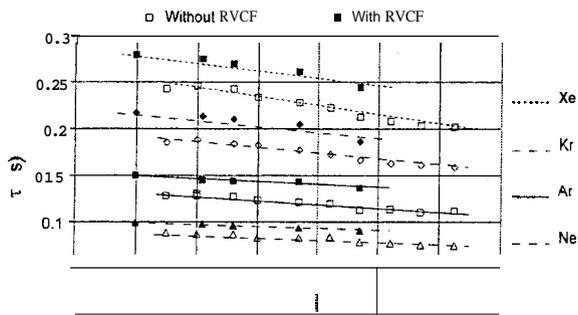


distances traveled are greater without the target material in the reservoir, in contrast to the finding for the conventional serial-flow system.

High-vacuum conductivity serial-flow system

The characteristic effusive flow time versus vapor transport system temperature for noble gases (He, Ne, Ar, Kr and Xe) flowing through the high vacuum conductivity system, are displayed in Figure 7.

Analogous to the results obtained for the conventional serial-flow system, the average distance, \bar{L} , traveled, per particle is less when the target holder is empty. \bar{L} is found to be: 156 m *with* and 140 m *without* 2 x RVCF in the target material reservoir.



5 DISCUSSION AND CONCLUSIONS

At a given temperature, a gas effuses faster through the conventional serial-flow system than through the conventional parallel-flow vapor transport system as illustrated in Figure 8 for Xe. The average distance traveled per particle is greater than the corresponding value for the serially connected system since vacuum conductivities in parallel add linearly. Also the volume and surface area are greater for the parallel-flow system and thus the average time spent in this part of the system increases the transit time. All studies show that the 2 x RVCF does not significantly affect effusive-flow times through these systems. The

characteristic times for the noble gases are decreased whenever RVCF is added to the parallel-flow configuration due to the presence of the parallel open channel surrounding the 2 x RVCF.

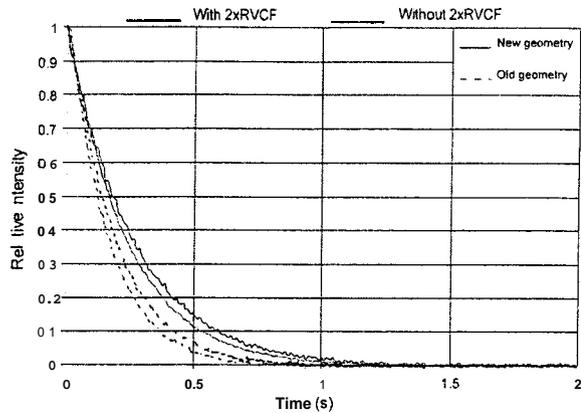


Figure 8: Time spectra for Xe in low and high-conductance geometries, *with* and *without* 2 x RVCF. Vapor transport system temperature: ~ 1000 °C.

Because of the open structure and consequently, higher vacuum conductivity for the system, shown in Figure 4, it was initially believed that transit times for noble gases would be shorter than through the conventional serial-flow system shown in Figure 3a. However, as noted, the times required for noble gases to pass through this system, *with* and *without* target material in the reservoir, are somewhat longer than the corresponding values for the conventional serial-flow system at the same temperature, principally due to the larger surface area/volume of the high vacuum conductivity system.

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