# THE EFFUSIVE-FLOW PROPERTIES OF TARGET/VAPOR-TRANSPORT SYSTEMS FOR RADIOACTIVE ION BEAM APPLICATIONS*

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*Abstract*

We have developed a fast valve system (closing time ~100 μs) that can be used to accurately measure the effusion times of various species through arbitrary geometry and size vapor transport systems with and without target material in the reservoir. The effusive-flow times are characteristic of the system and thus serve as figures of merit for assessing the quality of a given vapor-transport system as well as for assessing the permeability properties of a given target design. This article presents effusive-flow data measured with the fast valve system for noble gases flowing through a target reservoir and ion source system routinely used to generate radioactive species at the HRIBF. We determine added delay times associated with compressed reticulated-vitreous-carbon-foam (RVCF) disks, which are used for target coating matrices.

## INTRODUCTION

The isotope separator on-line (ISOL) technique is an efficient method for producing 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 a transport system to an ion source where a fraction of the species are ionized and accelerated. The principal means whereby short half-life radioactive species are lost between initial formation and utilization are attributable to delay times required for the diffusion and effusive-flow processes to take place in relation to the lifetime of the isotope of interest. Thus, both processes must be minimized if useful beam intensities of interesting isotopes are to be realized. We have developed a simple and versatile experimental method for measuring effusive-flow times of gaseous or vaporous materials through any vapor-transport system [2,3]. The ultimate objective of these developments will be to use them as tools for optimally designing vapor-transport systems for RIB applications so as to reduce the times required for transport of a given short-lived species to the ion source to values as low as practically achievable and thereby increase the intensities of short-lived RIBs for research at ISOL-based facilities.

In this article, we present experimentally measured effusive-flow time spectra for a serial-flow target reservoir system with reticulated-vitreous-carbon-foam (RVCF) material [4]. RVCF is low-density and highly permeable as required for fast effusive-flow of particles following diffusion-release from thin-layer target material deposits onto the surfaces of the material. The experimental setup can be used to characterize present and future target/vapor transport systems.

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## EXPERIMENTAL

The effusive-flow measurements were conducted on an off-line test facility equipped with a target/vapor-transport system, an ion source, and other essential components such as beam transport lenses, beam steerers, Faraday cups, a magnetic analyzer for mass selection, and data acquisition instrumentation.

The fast-valve was installed as close as possible to the target-material reservoir of the vapor-transport system under evaluation in order to minimize delay times associated with the connecting line between the valve and the reservoir. The fast-valve system consists of an electro-pneumatic actuator that drives a shutter for closing gas flow to the target material reservoir. More detailed description can be found elsewhere [2,3].

The Electron Beam Plasma Ion Source (EBPIS) [5] was used in the present experiments. The efficiency of the EBPIS is constant at pressures < ~2.67x10$^{-2}$ Pa [6] and therefore, does not change during measurements at the flow-rates used to measure the effusive-flow properties of a given target vapor-transport system. The transport tube and target material reservoir are heated by passing a (cathode) current along the transport-tube, the end of which serves as the cathode (cathode temperature: ~2125 $^0$C) for the ion source. The cathode heating current was kept at 360~362 A during all measurements.

The characteristic flow properties of the serial-coupled vapor-transport system (Fig. 1), filled with RVCF, were evaluated with He, Ne, Ar, Kr, and Xe. (The serial-coupled vapor transport system is identical in geometry but longer than those used at the HRIBF.)

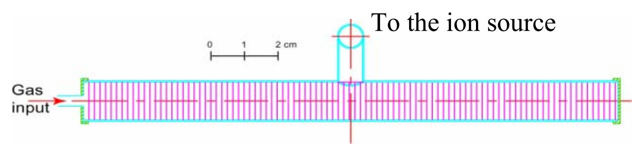


Figure 1: Serial-flow target material reservoir.

The RVCF was used to simulate the presence of target material in the vapor-transport system. RVCF is available in compressed forms by factors 2, 4, 6 and 10 (Fig. 2), referred to as 2x, 4x, 6x, and 10xRVCF, respectively. Higher compression factor RVCF materials have larger surface-to-volume ratios making possible the fabrication of shorter ISOL targets. For RIB applications, it is important to minimize delay times that lead to losses of short-lived radioactive isotopes. Therefore, it is important to quantitatively evaluate the effusive-flow time characteristics of various compression factor forms of RVCF. The target material reservoir was filled with 14.7 mm diameter RVCF disks to form 192 mm long targets.

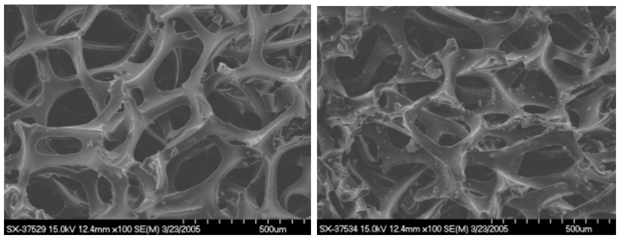


Figure 2: Scanning Electron Micrographs of 4xRVCF (left) and 6xRVCF (right).

Temperatures of the target material reservoir were measured with type K thermocouples and found to range between 515 and 553 ºC. Test gases were fed into one end of the target material reservoir of the vapor transport system through the aperture of the fast valve via a calibrated leak. The most abundant isotope of each test gas was used to derive evacuation time spectra. After establishing a steady-state ion signal of an isotope of the gas under investigation, the fast-valve was abruptly closed at which time the steady-state ion beam signal abruptly decreases to zero. The time dependence of the decay process was recorded and the characteristic effusive-flow time for particles to travel through the vapor-transport system extracted from the decay spectra.

## RESULTS AND DISCUSSION

Figure 3 shows an example of the effusive-flow spectra taken without RVCF in the target material reservoir at $T$ = 826 K. The number of particles, $N(t)$, remaining in the transport tube after evacuation time $t$ for stable isotopes is given by [2,3]:

$$N(t) = N_0 \exp(-t/\tau_c) \qquad (1)$$

where $N_0$ is the number of particles in the volume at time $t$ = 0. The steady-state ion beam signal decreases exponentially, as can been seen in Fig. 1. (For the case shown in Fig. 1, $R^2$ = 0.9993 for exponential fitting.) The time required for the signal to decay to 1/$e$ of its steady state value is defined as the characteristic-time, $\tau_c$, required for a particle of the gas under investigation to travel through the vapor-transport system (the transport time of the beam to the mass analysis Faraday cup is negligibly small ($He \cong 4.2$ µs; $Xe \cong 24.2$ µs)).

The characteristic time $\tau_c$ can be written as [2,3]:

$$\tau_c = ¾[\, N_b\, \tau_{ad} \;+\; L/v] \qquad (2)$$

where $N_b$ is the average number of bounces that a particle makes during passage through the target matrix and vapor transport system; $\tau_{ad}$ is the adsorption time of a particle on the walls of the target/vapor-transport system; $L$ is average the distance traveled per particle; $k_B$ is Bolzmann's constant, $v = \left(8k_B T/\pi M\right)^{1/2}$ is the velocity of the particle of mass $M$. Since the enthalpy of adsorption for noble gases are negligibly small ($\tau_{ad} \approx 0$)

$$\tau_c = CL\{M[\mathrm{amu}]/T[\mathrm{K}]\}^{1/2} \qquad (3)$$

where $C$ is a constant. As noted, in this approximation, characteristic times through the vapor-transport system are expected to vary linearly with $M^{1/2}$ at fixed $T$ since the distance traveled per particle $L$ only depends on the geometry and size of the vapor-transport system and the permeability of the RVCF placed in the target material reservoir.

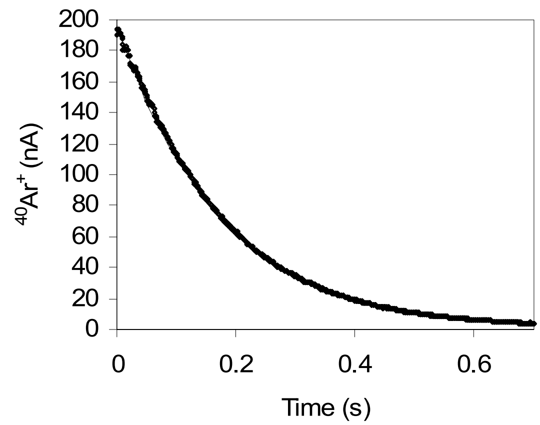


Figure3: Effusive-flow spectrum of $^{40}$Ar in the serial-coupled vapor transport system.

Figure 4 displays $\tau_c$ as a function of $M^{1/2}$ for He, Ne, Ar, Kr, and Xe *without* and *with* RVCF in the reservoir. As noted, $\tau_c$ is linearly correlated with $M^{1/2}$, as expected from Eq. 3. The characteristic effusive-flow times, $\tau_c$ increase with increasing RVCF density.

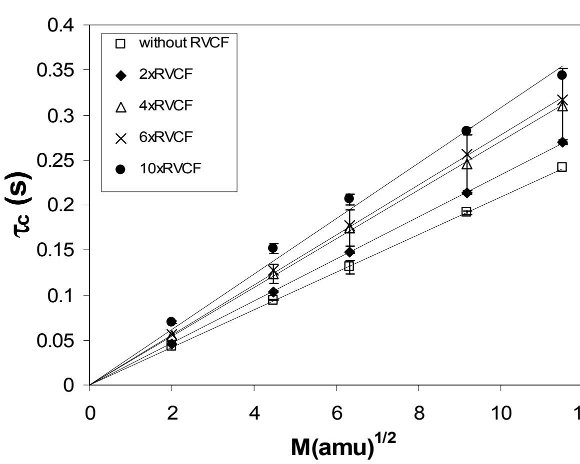


Figure 4: Characteristic effusive-flow time, $\tau_c$, versus $M^{1/2}$.


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Figure 5 shows $\tau_c$ as a function of relative RVCF density, $\rho/\rho_0$. ($\rho/\rho_0$ values are determined by dividing the measured densities, $\rho$ =0.09, 0.17, 0.28, 0.58 g/cm$^3$ for 2x, 4x, 6x, and 10xRVCF, respectively, by the density of glassy carbon (1.49 g/cm$^3$); $\rho/\rho_0 = 0$ without RVCF in the reservoir.) For a given mass and temperature, $T$, $\tau_c$ is proportional to $L$ through the relation

$$L \cong L_0\left(1 + A\frac{\rho}{\rho_0}\right) \quad (4)$$

where $L_0$ is the distance traveled per particle without RVCF in the reservoir and $A$ is a constant. This equation only holds when $\rho$ is small. Solid lines in Fig. 5 are linear fits to the data. The constant $A$, determined by fits to these data, has value $A = 0.79 \pm 0.18$.

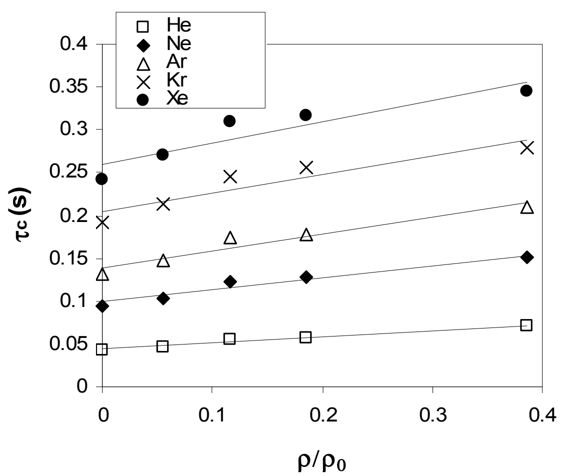


*Figure 5: Effusive-flow characteristic time,* $\tau_c$, as a function of the material density in the target holder.

The characteristic delay times with RVCF in the target material reservoir increase linearly with relative density from the intrinsic values with no RVCF in the target material reservoir. (Under the temperature conditions used in the present experiments, the presence of 10XRVCF in the reservoir increases the transport time for Xe above that with no RVCF in the reservoir by ~ 40% (~0.1 s). As noted, RVCF has good transport properties, even at the highest practically useable compression (10xRVCF).

## CONCLUSIONS

Effusive-flow properties of compressed forms of RVCF, suitable for use as matrices for ISOL target fabrication, were measured for noble gases flowing through a serial coupled vapor-transport system using a fast valve system [2,3]. As expected, the effusion spectra are purely exponential in character. The characteristic effusive-flow times $\tau_c$ were found to increase linearly with the square-root of particle mass ($M^{1/2}$) and relative density $\rho/\rho_0$. Under the temperature conditions used in the present experiments, the presence of 10XRVCF in the reservoir increases the transport time for Xe above that with no RVCF in the reservoir by ~ 40% (~0.1 s). Importantly, RVCF has good transport properties, even at the highest practically useable compression (10xRVCF) and therefore, has the high permeability attributes required of production target matrices for use at ISOL-based RIB research facilities.

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