# A New Method for Mass Separation of Radioactive Waste using Magnetic Nozzle

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## 1. Introduction

The disposal of nuclear waste must be solved in order to continuously develop the nuclear industry. It is well known that isotopes in nuclear waste can be divided into three groups by mass: the lightest group (1–65 amu), the intermediate group (80–160 amu), and the heavy group (225–250 amu) [1]. Among them, the intermediate group consists of the highly radioactive fission products and the heavy group is a series of actinoids, moderately radioactive and potentially fissionable. The radioactivity and composition of each group are shown in Fig. 1. It is noticed that the fission product produces more than 99% of the radioactivity despite making up a small fraction of the total mass. Moreover, it is recognized that the separation of two groups with different mass could reduce the amount of highly radioactive isotopes to be disposed.

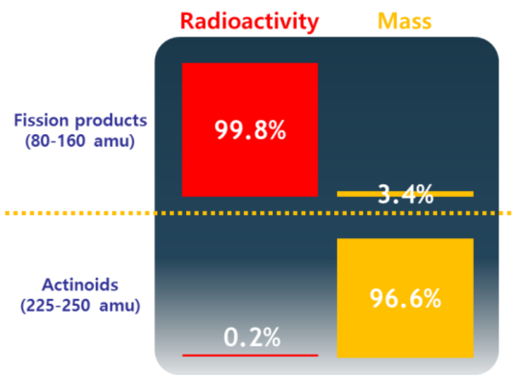


Fig. 1. Spent nuclear fuel produced per year from a 1 GW(electric) light water reactor, divided into three mass categories [1].

Recently, we proposed a new method to separate the two groups with different mass by magnetic nozzle [2]. This method is in principle different from the previously proposed methods [3-5] in terms that a centrifugal force is not utilized in this new technique. Instead, it uses a characteristics of ion motion along a curved magnetic field, which depends on the mass of ions. This paper presents a basic idea of this new technique and simulation results using a PIC (particle-in-cell) code.

## 2. Method for Mass Separation using Magnetic Nozzle

There have been a lot of techniques which were proposed for separating particles based on ion mass. A plasma centrifuge or Calutron might be the oldest ones [3] and a lot of new techniques have been proposed quite recently [4,5]. The recently proposed mass separation method (Ohkawa filter) used a rotating plasma in a magnetic field to create a radial confinement condition that separates heavy ions from light ones [4]. While the Archimedes device was able to demonstrate separation, difficulty in creating the plasma and operating the end electrodes prevented the demonstration of adequate results to continue operation. The other concept dubbed magnetic centrifugal mass filter (MCMF) suggested by PPPL uses different magnetic and centrifugal confinement conditions on either end to produce separation based on mass [5]. Although it is collisional, the method of mass separation is the same as the Ohkawa filter in principle.

A new method for mass separation proposed here is essentially different from the previous ones. Most importantly, it does not use the centrifugal force, so that the rotation of plasma is not needed. The basic idea comes from the phenomenon known as ion detachment from magnetic field in plasma thrusters. Terasaka et al. recently proposed a theoretical background on the ion detachment from magnetic field, says, ions are detached from the curved magnetic field due to the loss of adiabaticity [6]. They suggested a dimensionless non-adiabaticity parameter $\xi$ as following:

$$\xi = \frac{f_{ci} L_B}{v_i} = \frac{qB}{m_i v_i} \left| \frac{\nabla B}{B} \right|^{-1}, \qquad (1)$$

where $f_{ci}$ is the ion cyclotron frequency [Hz], $v_i$ is the ion drift velocity [m/s], $q$ is the elementary charge [C], $m_i$ is the ion mass [kg], and $L_B$ is the scaling length of magnetic field gradient [m]. As can be seen in Eq. (1), $\xi$ is inversely proportional to the ion mass for a given magnetic field configuration. If we assume the ion drift velocity to be determined by the well-known Bohm speed ( $v_B = \sqrt{qT_e/m_i}$ , where $T_e$ is the electron temperature [V]), $\xi$ is inversely proportional to the square root of the ion mass. This relationship between $\xi$ and $m_i$ makes it possible to separate the ions with different mass in curved magnetic field. In other words, the heavier the ion mass, the smaller is the non-adiabaticity parameter, resulting in the separation from the magnetic field earlier than the light ones. Hence, the heavier species propagate more parallel to the applied magnetic field than the lighter ones, and thus are collected in the central region of the magnetic nozzle.

In order to demonstrate the possibility of mass separation in magnetic nozzle, we have carried out some simulations with COMSOL multiphysics simulation package. Simulations are carried out for the ions with different mass of 4 amu and 40 amu for He and Ar (mass ratio: 10), respectively. As shown in Fig. 2, when the ion drift velocity is relatively small (<~10 km/s), the mass separation is ineffective. However, it is observed that the mass separation is greatly enhanced by increasing the ion drift velocity up to 40 km/s.

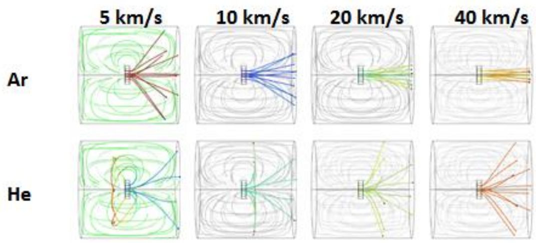


Fig. 2. Trajectories of ion species of different mass (He: 4 amu, Ar: 40 amu) in magnetic nozzle for various ion drift velocities.

## 3. Conclusions and Outlook

In this paper, we proposed a new concept for mass separation without using plasma rotation. In order to demonstrate the possibility of mass separation by this new technique, we are now preparing a series of experiments using a magnetic nozzle experimental device at Seoul National University [7]. Since the device has an ability to produce various magnetic field configurations due to a lot of magnets around the vacuum chamber, it seems to be possible to find out an appropriate operating conditions of mass separation. For increase the efficiency of mass separation in order to be used as a method for mitigation of radioactive waste, a multi-stage treatment system would be possible, as schematically depicted in Fig. 3.

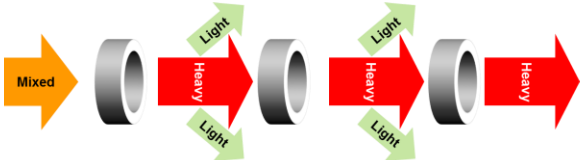


Fig. 3. Mass separation technique using multi-stage magnetic nozzle.

## Acknowledgment

This research was supported by the National Nuclear R&D Program through the National Research Foundation of Korea (NRF) funded by MSIP; Ministry of Science ICT & Future Planning (No. NRF-2016M2B2A9A02945267).

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