PRELIMINARY STUDY OF THE DEMO PLASMA SEPARATOR

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This paper outlines the preliminary study of a plasma components electromagnetic separator. This device is intended for separating the heavy components of spent nuclear fuel (SNF) from the light ones. The power consumed in this process is expected to comprise about $1\cdot10^3$ eV per particle. We performed our experiments with the SNF simulating gas mixture. The results obtained permit to draw a conclusion that the effect of separation may be achieved.
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1. INTRODUCTION

No country throughout the world possesses a closed fuel cycle, and all SNF is sent for the eternal storage. Ukraine produces about 350 tons of SNF annually. One ton radiochemicaly reprocessed SNF brings 7.5 tons of solid and 2200 tons of liquid radioactive waste (RW). Thus radiochemical reprocessing of SNF is the technology for furnishing RW. The electromagnetic separation means are safer but energy consuming and cannot be applied for the required scale of SNF reprocessing. The present paper aims at the development of physical foundations for plasma technology SNF reprocessing spending about $1\cdot10^3$ eV per particle. This facilitates not only restoring SNF, but also obtaining the narrow mass spectra. Subsequent processing of spectra obtained will enhance the efficiency of electromagnetic separation and isotope production.

2. EXPERIMENT SCENARIO

The separation of heavy and light elements occurs with plasma rotating in crossed electric and magnetic fields. On achieving the cyclotron resonance condition $\omega_E \approx \omega_{CI}/2$, the resonant ions are accelerated and can be spatially separated [1-6]. Here $\omega_{Ci} = 9{,}58\cdot10^3\cdot z\cdot\mu^{-1}\cdot B$ is a ion cyclotron frequency for a mass μ and a charge z, and $\omega_E = E/B\cdot r$ is a plasma rotation frequency at a distance r from the axis of rotation.

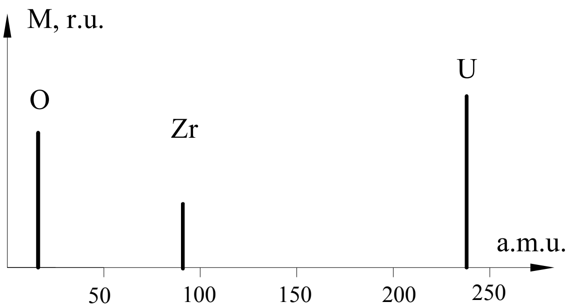

Fig.1. Fuel element composition

Fig. 1 schematically shows the elemental composition of nuclear fuel, in particular UO_2 and Zr. As a result of nuclear disintegration the lighter and transuranic elements are produced (Fig. 2).

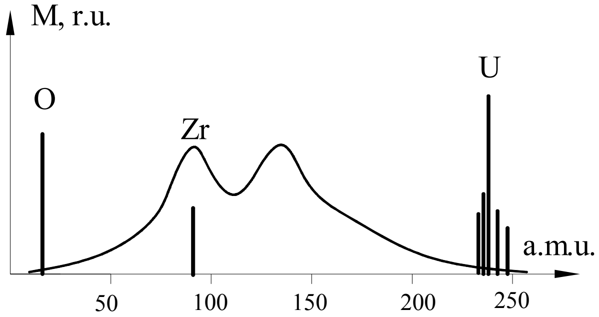

Fig.2. Spent fuel element composition

While processing SNF the light fission products are separated from the heavy ones. At the initial stage of studies it is reasonable to select a simulation object which is more suitable and safer in usage in comparison with SNF [7]. The mixture consisting of 47% Xe, 47% Kr and 6% CO_2 serves as such an object (Fig. 3). Xe simulates uranium. Under resonance condition for Xe, it is transferred to the chamber wall, and the plasma density experiences a 1/3 decrease. This ensures the ion transport in the plasma.

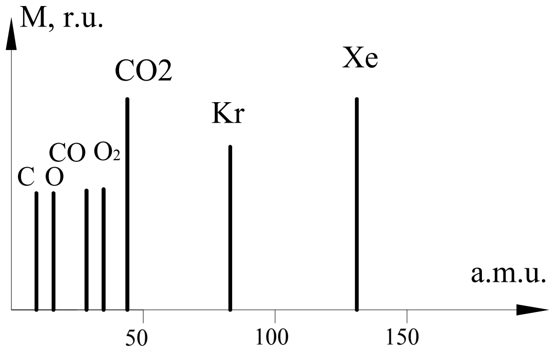

Fig.3. Gas mixture simulating fuel element composition

The gas plasma source based on electron drift and described earlier [7, 8] generates the plasma. Leaving the source it moves along the force lines of a decreasing axially-symmetric magnetic field (Fig.4). In the absence of the radially distributed electric field E_r the plasma extends to the end of a discharge chamber. Switching on the E_r induces the plasma to rotate with the frequency $\omega_E = E_r/B\cdot r$.

Under condition of $\omega_E \approx \omega_{CI}/2$ the resonance acceleration of ions takes place and their spatial release in a radial direction is possible. As the electric field buildsup the acceleration can occur at multiple frequencies of $\omega_{CI}/2, \omega_{CI}/4$, etc.

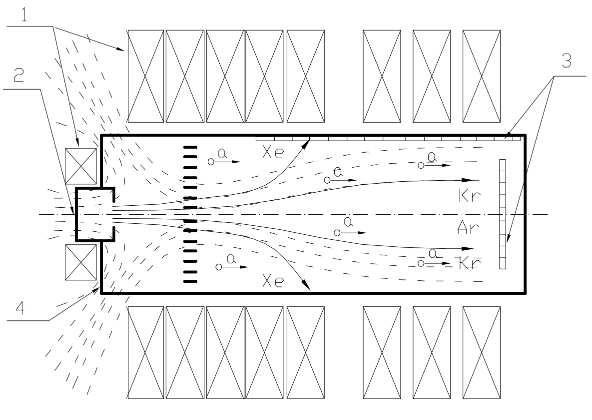

Fig.4. Experiment arraignment: 1 – electromagnetic coils, 2 – plasma source, 3 – longitudinal and butt collectors, 4 – discharge vacuum chamber

The yield of resonantly accelerated Xe ions on the multielectrode collector is expected in a ring domain of the of the chamber wall's middle part. At the following plasma parameters $n_i \approx 10^{10}\text{-}10^{11}$ cm^{-3}, $T_i \approx 10$ eV, $T_{i\,рез} \approx 100$ eV, $T_e \approx 10$ eV, $H \approx 2$ kOe the values of Larmor radii for the light ions, Xe ions and electrons will be $r1 \approx 1$ cm, $r_{ci} \approx 5\text{-}6$ cm, $r_c \approx 10^{-3}$ cm, accordingly. Taking into account the plasma R and r_{ci} radii ratio of Xe ions, $R/r_{ci} \approx 3$ and the phase difference of rotating ions in a field tube the longitudinal size of the Xe - ions yield domain will be $3r_{ci}$. Presently the data about increments of amplitude rise of ion-cyclotron instability are not available, therefore these are preliminary assessments. The butt collector (Fig. 4) consists of four coaxial electrodes that span the plasma cross section. However, the fact that the ions are mainly yielded in the butt collector domain is not a well-defined proof of the separation process. The separation process can be affirmed by elemental analysis of the targets that are located in the ion yield domains. The ion implantation coefficient is 0.1-0.2 as the Xe ions energy reaches 100 eV at saturation concentration of ~ 1-5.10^{14} cm^{-3}. However the recharging processes can significantly complicate the result.

Fig.5 gives E and H values, at which the resonance condition is achieved for four gases with different atomic mass.

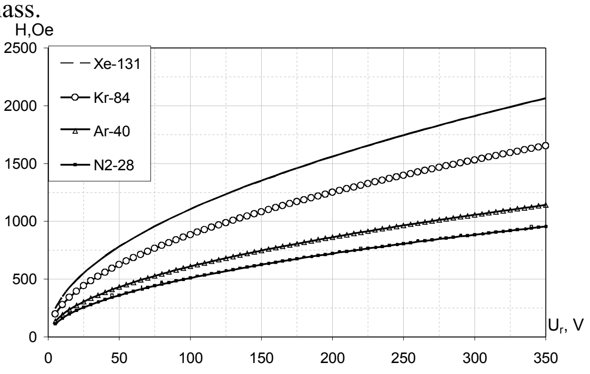

Fig.5. Resonance achieving condition

3. EXPERIMENTAL RESULTS

The experiments were carried out using Xe-Kr-CO_2 mixture and individual Ar and CO_2 gases. Due to the implantation of plasma ions into the walls and ion-initiated desorption the further discharges in individual gases were the discharges in mixtures and time was required to clean the walls. Fig.6-8 gives distribution of current for 4 electrodes of a butt collector.

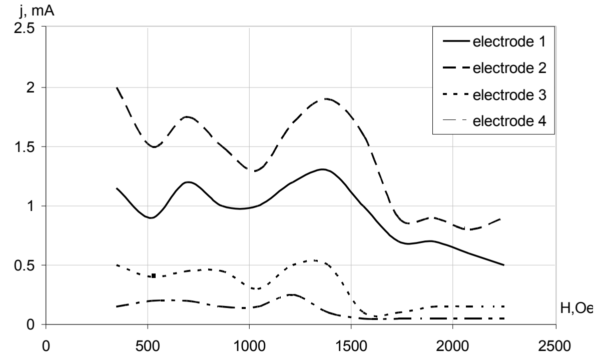

Fig.6. Butt collector current at 150 V (gas mixture)

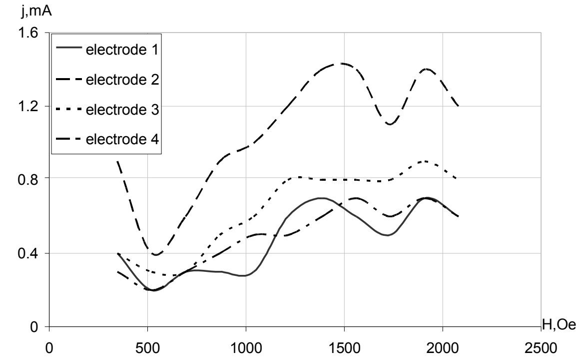

Fig.7. Butt collector current at 100 V (Ar)

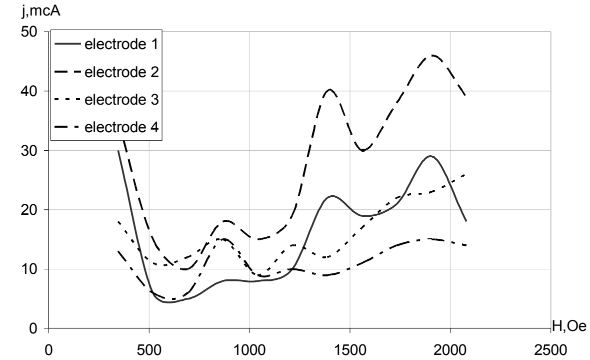

Fig.8. Butt collector current at 100 V (CO_2)

The typical minima that are present in obtained plots can be interpreted using data given in Fig.5. One can see that the minima match with expected arrangement of ions of a given mass in all the Figures. Certain offsetting in position of these minima at the curves for the butt collector electrodes that are located along different radii can be explained by a radial magnetic field inhomogeneity.

4. CONCLUSION

As it follows from the figures the presence of minima can be associated with meeting the resonance condition for certain masses and their escape in the transverse direction. In order to justify the preceding conclusion we need: to conduct the mass analysis of the escaping ions; to study the surfaces in the areas where the certain kinds of accelerated ions are expected to come. We also need to record the electromagnetic radiation intensity in the vicinity of frequencies $\omega_E \approx \omega_{CI}/2$ for ions of different masses and plasma rotation frequency registration.

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ПРЕДВАРИТЕЛЬНОЕ ИССЛЕДОВАНИЕ ДЕМОНСТРАЦИОННОГО ПЛАЗМЕННОГО СЕПАРАТОРА

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Описаны предварительные исследования возможности разделения тяжелой и легкой компонент отработанного ядерного топлива (ОЯТ) при энергозатратах на уровне около $1\cdot 10^3$ эВ/атом на электромагнитном плазменном сепараторе элементов. Эксперименты проводились на смеси газов, имитирующих ОЯТ. Полученные результаты позволяют сделать вывод о достижении эффекта разделения.

ПОПЕРЕДНЄ ДОСЛІДЖЕННЯ ДЕМОНСТРАЦІЙНОГО ПЛАЗМОВОГО СЕПАРАТОРА

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Описано попередні дослідження можливості розділення важкої та легкої компонент відпрацьованого ядерного палива (ВЯП) при енерговитратах на рівні біля $1\cdot10^3$ еВ/атом на електромагнітному плазмовому сепараторі елементів. Експерименти проводились на суміші газів, що імітує ВЯП. Отримані результати дозволяють зробити висновок про досягнення ефекту розділення.