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Archimedes Plasma Mass Filter

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Abstract

Some 60,000 and 46,000 MT of sodium rich nuclear waste are now in storage in the US at Hanford and SRS facilities, respectively. We have developed a technology that uses the high sodium content to advantage: aqueous slurry wastes are first calcined into sodium hydroxide (NaOH) melt slurries, then vaporized and injected into a plasma. The Archimedes Filter separates plasma ions into light and heavy mass groups. For the first time, it is feasible to economically separate large amounts of material in a single-pass plasma device. Such a separation would substantially decontaminate High Level Waste since most radionuclides partition to the heavy fraction. The plasma process is based on setting up fast ExB rotation of a cylindrical plasma. At a certain critical rotational velocity $\omega_E > \omega_B/2$ ions are not confined by axial magnetic field and are lost radially. Because the critical rotational velocity depends on magnetic field the plasma and machine parameters can be set up to separate heavy radionuclides from majority of the light elements in the plasma and, thus, accomplish waste clean up. The paper discusses the Filter process, describes a demonstration device that has been constructed in San Diego, USA, and presents the first experimental results.

Introduction

Radioactive waste sludges have been a particularly difficult issue for pretreatment and immobilization. The present approach at Hanford, the larges nuclear waste storage facility in the U.S., is to vitrify all of the waste, including 37,000 MT of high level waste (HLW). The waste composition is such that over 75% of the sludge (excluding water, carbon, and nitrogen) has mass less than 59 g/mol while 99.9% of radionuclide activity has mass greater than 89 g/mol. Hence, it is clear that a mass separation of this waste would greatly reduce the quantity of radioactive material to be vitrified [1].

Plasma Mass Filter System

The Archimedes Filter [2] utilizes plasma rotation to achieve the mass separation of materials into two fractions: a heavy and a light. The Filter operating regime is collisionless and its mass separation is discontinuous, so it operates in a manner that is distinct from a plasma centrifuge. A Plasma Mass Filter system employs an axial magnetic field and a radial electric field to produce plasma rotation. Simple radial force balance results in all heavy ions above a "cutoff mass" being radially ejected to the wall whereas the lighter ions below the "cutoff mass" are confined and directed along the axial magnetic field to collectors at each end of the device. For a parabolic voltage profile, the plasma rotates as a rigid body and the mass "cutoff" is not dependent on the ion birth position. The magnetic and electric fields determine the location of the "cutoff mass", A_c, according to the relation:

$$A_c = (Mi/Z)/M_H = eB^2R^2/(8VM_H) \tag{1}$$

where Mi/Z is the mass to charge ratio of the cutoff atom, M_H is the mass of hydrogen, B is the magnetic field, R is the plasma radius, V is the voltage at the center, and e is the electronic charge. Plasma geometry and density distribution determine the Filter function slope or width.

Current design of a Commercial Filter unit targets a throughput of around 0.7 MT/day of mixed oxides. For injection, rapid heating to very high temperature is essential to minimize fractionation or distillation of the materials being vaporized.

Demonstration program.

The Archimedes Plasma Mass Filter demonstration device (Demo) has been constructed to demonstrate the basic physics and engineering features using a non-radioactive surrogate waste. The Demo has up to 4 MW of CW RF power to produce a plasma column with 0.4 m radius and 3.9 m length, magnetized up to 1500 G using four large magnet coils. Figure 1 shows a cross-sectional view of the Demo. Helicon waves [3,4] are used to produce and heat the plasma in the Filter. The waves are launched with two phase-controlled four-strap m=0 antennas. To rotate the plasma two sets of concentric electrode arrays are located at each end of the device, with up to 700 V available to bias each electrode from specially designed power supplies.

A number of plasma diagnostics has been designed and implemented on the Demo, including a microwave interferometer, multiple cameras located strategically around the device, including, vertical spectroscopy arrays with high-resolution and survey spectrometers, plunging multiple-tip Langmuir probe system, bolometer arrays, electrode and RF voltage and phase monitors

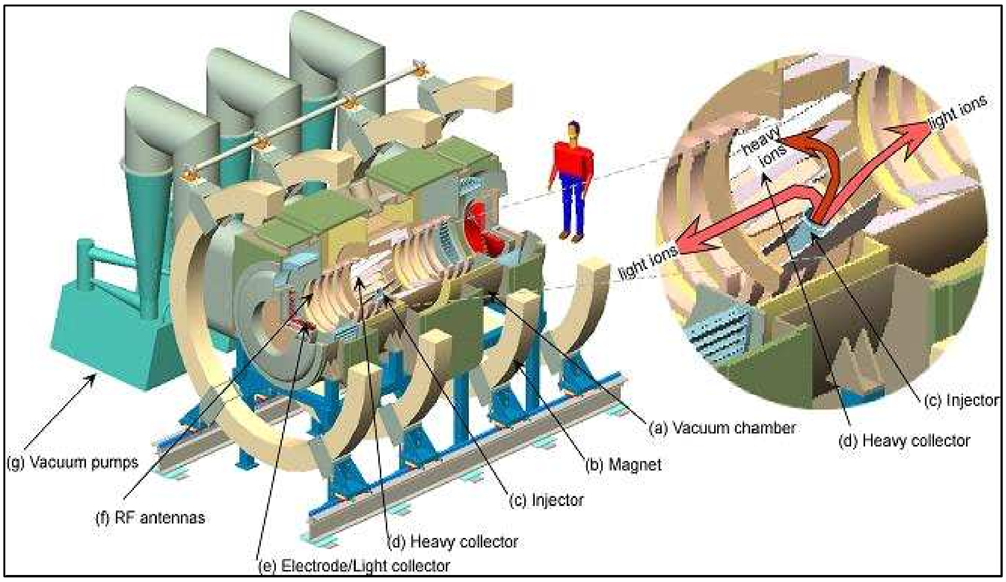

Figure 1. Demo Filter cross-sectional view

Initial Experimental Results

Initial experiments were conducted using noble gas discharges to investigate RF antennas power coupling and basic rotation and separation features of the Filter. Plasma densities in argon gas in the range of 10^{18} m^{-3} were achieved (Fig. 2).

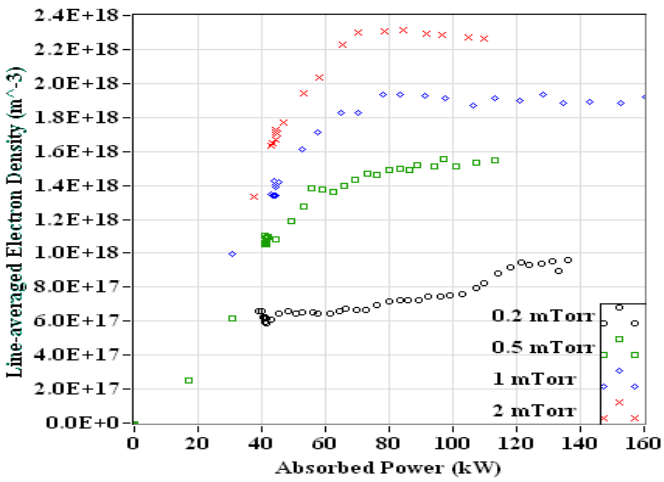

Figure 5. Line-averaged plasma density versus absorbed power for different argon neutral pressures.

During the initial plasma rotation experiments the bias voltages up to 200 V were applied producing rotating plasmas. Langmuir probe measurements indicate that over 80 % of the bias voltage applied on the electrodes appears as a change in radial plasma potential. Plasma rotation velocities were measured spectroscopically by the ion lines

Doppler shift (Fig. 3). Measurements of changes in the ion light intensity ratio of argon relative to xenon ion produce applied bias voltage and magnetic field scalings that are consistent with the Filter separation model. More experiments are planned in the nearest future, including metal traces separation efficiency measurements, high power and high throughput operations, and complex surrogate mixtures separation.

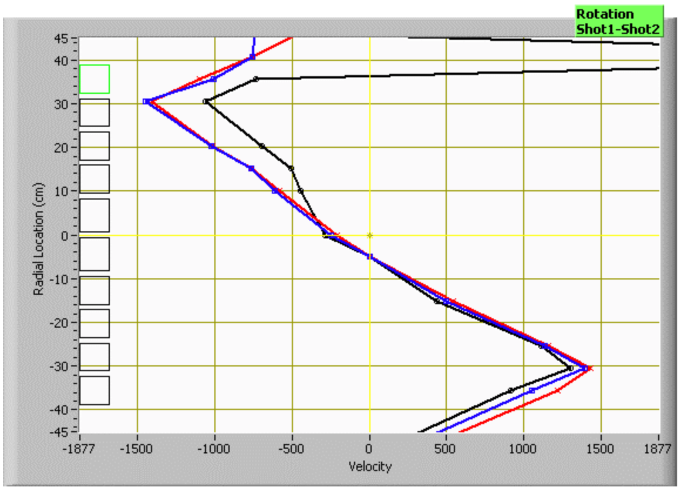

Figure 3. Typical rotation velocity profile measured by Doppler spectroscopy

Summary

Archimedes Plasma Mass Filter brings new technology to nuclear waste problem, allowing separation of radio-nuclides from non-radioactive solids and liquids. Initial experiments have started at the full scale Demo facility in San Diego, USA. Target densities in excess of 10^{18} m^{-3} in noble gas have been achieved. Plasma rotation experiments are in progress, indicating that the magnitude and direction of rotation depends on electrode voltage, while measured rotation velocities are within a factor of three of that expected. Initial noble gas separation study has begun, and the trace metal separation, high throughput and complex feed experimental demonstrations are scheduled

References

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