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COMPUTER SIMULATION OF LASER RADIOISOTOPE SEPARTION SYSTEM

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Abstract

The work with the method of atomic vapor laser isotope separation needs to know the accurate energy levels of the element to be separated and its isotopic shifts also need to make calculations depend on physical constants of the isotopes to know the possibility of separation of its isotopes by using laser pulses with specific shape and wavelength. This present study is based on the theoretical equations to legalize the process of isotope separation of Uranium-235 from Uranium metal by using the method of atomic vapor laser isotope separation. A well designed software programs are used to get mathematical results of U-235 enrichment between 3 - 5 % from the Uranium metal and it is the suitable fuel used in nuclear power plants for generating electricity - noting that the isotope U-235 represents 0.711% of the natural Uranium.

Keywords: *software programs, U-235 enrichment*

INTRODUCTION

The process of Uranium enrichment is an important process in the nuclear fuel cycle in order to get the fuel suitable for use in nuclear power plants to generate electricity. There are several methods to enrich Uranium like gaseous diffusion, gas centrifuge and other more complicated methods such as the use of lasers.

Chemical elements found in nature in the form of isotopes which are equal in the number of protons and differ in the number of neutrons, many of these different isotopes had several applications in the field of scientific research, industry, agriculture and medicine induced necessary to make attempts to separate certain elements.

Atomic vapor laser isotope separation (AVLIS) is a general and powerful technique applicable procedure for the enrichment of Uranium that is used as a fuel for many nuclear power plants. AVLIS has been studied by many authors for the enrichment of Uranium-235 (Alhassanieh et al., 2002, Benedict et al„ 1981, Bokhan et al., 2006, Makhijani et al., 2005, Ramakoteswara, 2003, Sarkar, 2010, Trkov, 2010, Villani, 1979, Whitaker, 2005).

The present study discusses in detail a theoretical model designed by the authors to be applied for the enrichment of Uranium-235 by AVLIS. A theoretical approach has been designed for the separation of Uranium-235 reactor fuel, the theoretical computations by the designed software program applied for the nominated theoretical models show good results.

THEORETICAL MODEL

Atomic vapor laser isotope separation model as applied to Uranium is indicated in figure 1, figure 2 and figure 3 and it can be summarized in the following:

- The metallic Uranium is first evaporated in a separator unit contained in a vacuum chamber. Electron bombardment with solid Uranium in a crucible results in localized heating up to 4000 ^oC. The vapor is shaped as a stream of width D_U and length L_U. The vapor density is taken to be 10^{13} atoms / cm^3 and average atomic velocity 40000 cm / sec.

- The interaction chamber just above the evaporation unit proposed in this model to have length L = 100 cm, width W = 4 cm and height H = 4 cm.

- The vapor stream is then illuminated with laser light tuned precisely to a color at which Uranium-235 absorbs energy, three wavelengths of red-orange light of dye lasers were used as radiation sources of wavelengths λ_1, λ_2 and λ_3. These wavelengths are chosen to be (λ_1 = 591.6705 nm, λ_2 = 605.2170 nm and λ_3= 603.1727 nm). Then they are pumped by copper vapor lasers that provide the necessary 20 - 30 ns pulse duration at a repetition frequency of around 10^4 Hz. Each color selectively adds enough energy to ionize or remove an electron from Uranium-235 atoms (IP = 6.2 ev), leaving other isotopes unaffected.

- Because the ionized Uranium-235 atoms are now tagged with a positive charge, they are easily collected on negatively charged surfaces inside the separator unit; the product material Uranium-235 is condensed as liquid.

- The unwanted isotope atoms, Uranium-238, which are unaffected by the laser beam, pass through the product collector, condense on the tailings collector and are removed.

The modeling program exhibit many relations between the variation of laser energy in joule / pulse, variable mirror reflections and:

(a) Percentage of enriched Uranium in the product (X_P)

(b) Amount of Uranium-235 concentrated in the product (P) in gm / sec

(c) Percentage of depleted Uranium in the tail (X_T)

(d) Amount of Uranium-235 concentrated in the tail (T) in gm / sec and

(e) Separative Work Unit (SWU)

- The rate equations modeling are designed as follows:

- Let N_i is the number of atoms of energy E_i per unit cubic centimeter.
- Let I_1, I_2 and I_3 the photon flux of lasers at wavelength λ_1, λ_2 and λ_3.
- Let σ_1, σ_2 and σ_3 the absorption cross section.

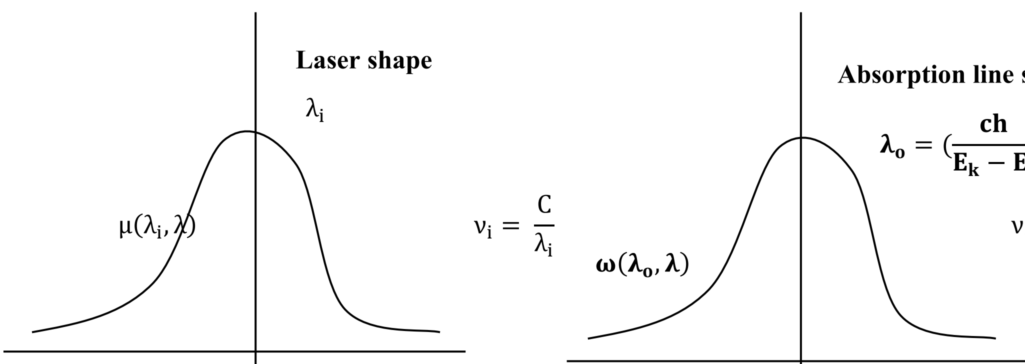
$$\frac{dN_1^{235}}{dt} = \sigma_2 \sum_i I_i \,.\, G^{235}(\lambda_i, E_1, E_2)(N_2^{235} - N_1^{235}) - \sigma_1 \sum_i I_i . G^{235}(\lambda_i, E_1, E_2)(N_1^{235} - N_0^{235}) - \frac{N_1}{\tau_1}$$

$$\frac{dN_2^{235}}{dt} = \sigma_3 \sum_i I_i \,.\, G\,(\lambda_i, E_2, E_3)(N_3^{235} - N_2^{235}) - \sigma_2 \sum_i I_i \,.\, G\,(\lambda_i, E_2, E_3)(N_2^{235} - N_1^{235}) - \frac{N_2}{\tau_2}$$

$$\frac{dN_3^{235}}{dt} = -\,\sigma_3 \sum_i I_i \,.\, G\,(\lambda_i, E_2, E_3)(N_3^{235} - N_2^{235}) - \frac{N_3}{\tau_3}$$

- $N_i^{235} = \sigma_i N_3^{235}$ ..... Ionized Uranium-235
- Where G is a factor depend on the laser shape and absorption line shape.
- The function

$$G\,(\lambda_i, E_j, E_k) = \int_{-\infty}^{\infty} \mu(\lambda_i\,, \lambda).\,\omega(\lambda_o, \lambda)\; d\lambda = \int_{-\infty}^{\infty} e^{-\frac{(\nu_i - \nu)^2}{\Delta\nu_i^2}} \,.\; e^{-\frac{(\nu_o - \nu)^2}{\Delta\nu_o^2}}\, d\nu$$



$$N_p = N_i^{235} + N_i^{238} + N_c^{235} + N_c^{238}$$

Where: N_i are ions collected, N_c are the atoms collected, $\Delta\nu_i$ laser line width and $\Delta\upsilon_o$ is absorption line broadening

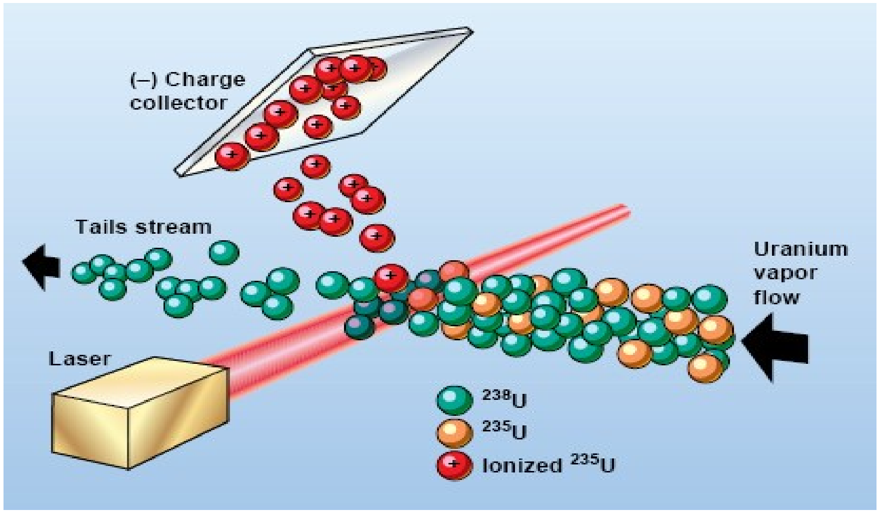


Figure 1: Schematic representation of AVLIS model

Uranium-235 energy levels
50247.3000cm^{-1}
49958.4000 cm^{-1}
URANIUM - 235 IONIZATION HAPPENEDHERE (IP = 6.2 ev)
49934.2200 cm^{-1}
49883.2800 cm^{-1}
33624.7000 cm^{-1}
33584.1800 cm^{-1}
33516.8600 cm^{-1}
33474.9500 cm^{-1}
Second excited energy level for Uranium-235 atom 33421.1200 cm^{-1}
33378.7800 cm^{-1}
33119.0000 cm^{-1}
33083.0200 cm^{-1}
32899.9900 cm^{-1}
First excited energy level for Uranium-235 atom 16900.3866 cm^{-1}
16505.7721 cm^{-1}
620.318200 cm^{-1}
Ground energy level for Uranium-235 atom 000000000 cm^{-1}

Figure 2: Description of Uranium-235 ionization process diagram

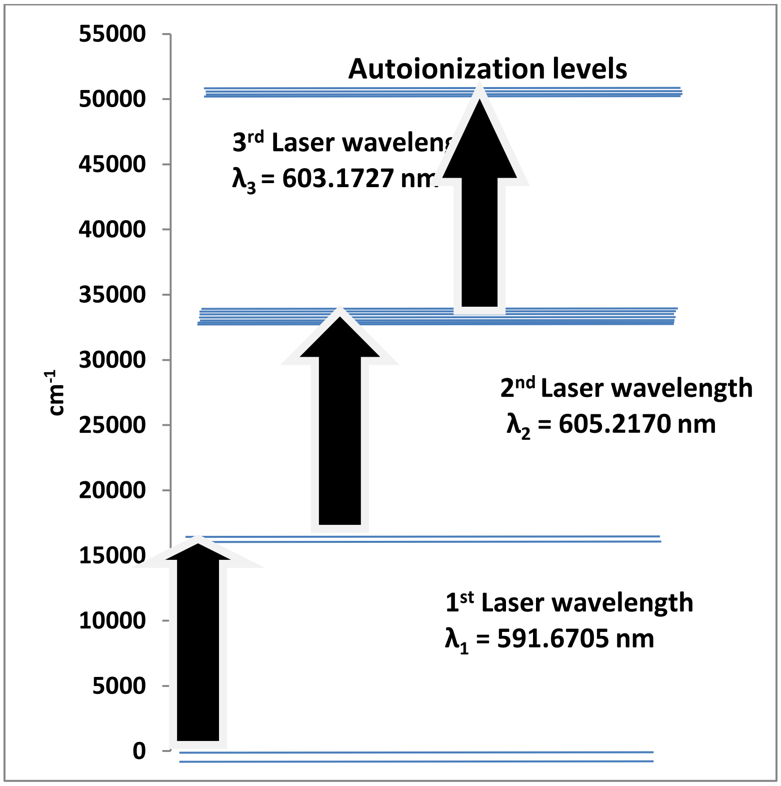


Figure 3: Three wavelengths of dye lasers

NUMERICAL CALCULATIONS

The laser energy can be reflected back to the reaction chamber using mirrors, for the given data the simulation shows that the optimum number of reflections is 15. The mathematically calculated results of the running computer program for different values of laser energy at 15 mirrors reflections are shown in the following table. The delay time between the three laser pulses is very critical. The simulation shows that the delay between the 2^{nd} and 1^{st} laser pulses should be 268 ns and between the 3^{rd} and 2^{nd} laser pulses should be 379 ns.

Laser energy (j / p)	Num. of ref. (n)	X_p %	X_T %	P (g / sec)
0.005	15	0.711444	0.710992	4.25696×10^{-5}
0.05	15	0.723728	0.710782	4.25749×10^{-5}
0.07	15	0.731240	0.710653	4.25782×10^{-5}
0.2	15	0.795065	0.709559	4.26058×10^{-5}
0.5	15	0.993014	0.706156	4.26916×10^{-5}
0.6	15	1.070090	0.704827	4.27250×10^{-5}
0.7	15	1.152070	0.703411	4.27606×10^{-5}
1	15	1.425450	0.698673	4.28797×10^{-5}
2	15	2.589960	0.678185	4.33940×10^{-5}
3	15	4.042600	0.651918	4.40524×10^{-5}

CONCLUSION

The computation results showed an optimum operation condition at laser energy of 3 joule / pulse with 4.0426 % U enrichment with 15 mirrors in a single unit and this is a good percentage of enrichment for Uranium to be used as a fuel in nuclear power plant for generating electricity and the separation plant in this case will be composed of a single stage. The number of units depends on the required rate of production.

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