Laser Isotope Separation of Yb-176 for the Production of Lu-177

Hyunmin Park, Duck-Hee Kwon, Yongho Cha, Sungmo Nam, Sunkook Kim, Jaemin Han, Yongjoo Rhee, Do-Young Jeong, and Cheol-Jung Kim
Laboratory for Quantum Optics, Korea Atomic Energy Research Institute, P.O. Box 105, Yuseong, Daejeon, Korea
hmpark@kaeri.re.kr

1. Introduction

In these days, the radioisotope, Lu-177, is emerging as an important candidate for the curative treatment of the cancer such as breast, prostate, colon, and brain. The isotope with a half-life of 6.71 days, emits a low energy β^- with the maximum and average energies of 421 keV and 133 keV for the effective treatment of the small tumors. Also it emits a low energy gamma radiation suitable for the simultaneous imaging.

Lu-177 is produced in a reactor by direct (n, γ) neutron radiation of the stable isotope Lu-176. However, in the process, only about 20% of Lu-176 atoms are converted to the wanted Lu-177 and it is very difficult to separate the radioisotopes from the non radioisotopes since both compounds are chemically equivalent. Another method for the production of Lu-177 is through indirect process using the stable isotope Yb-176. Neutron radiation of Yb-176 results in the production of Yb-177, which is converted to Lu-177 through the β–decay with a half-life 1.9 h. In this indirect process, it is easy to separate Lu-177 from Yb-176 due to the chemical difference between Yb and Lu. Therefore, it is possible to create a therapeutic radioisotope Lu-177, which is carrier-free, meaning that it does not contain any non-radioactive isotope. With this reason, it is preferred that we choose indirect process using Yb-176 to produce Lu-177.

Table 1 lists the isotopic abundances of natural Yb and thermal neutron absorption cross-section (σ(b))

Isotope	^{168}Yb	^{170}Yb	^{171}Yb	^{172}Yb	^{173}Yb	^{174}Yb	^{176}Yb
Abundance (%)	0.135	3.03	14.31	21.82	16.13	31.38	12.73
σ(b) for (n, γ)	2300	10	53	1	17	69	2.4

Table 1. Isotopic abundance of the natural Yb and thermal neutron absorption cross-section.

If the enriched Yb-176 instead of natural Yb is used as a target material for the production of Lu-177, the specific activity expected to be dramatically increased. Also using the enriched sample, we can remove the unwanted radioisotope such as Yb-169, which is produced by neutron bombardment of Yb-168 with very high σ(b), 2300 barn.

With these backgrounds, we developed the laser isotope separation technology to enrich Yb-176 to more than 95%.

2. Compact Yb-176 Enrichment System

To obtain the enriched Yb-176 isotope, we established a compact laser isotope separation system as shown in Fig. 2.

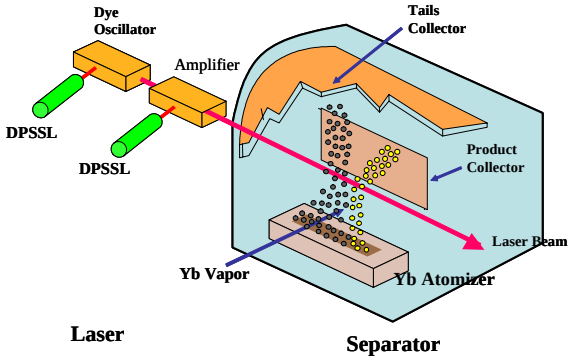

Fig. 2. Compact Yb-176 enrichment system.

The developed system consists of laser system, Yb vapor generating system, and photo-ion extraction system. In order to ionize the Yb-176 atom from the ground state, we used three dye lasers pumped by a 10 kHz DPSSL (Diode-Pumped-Solid-State-Laser). The oscillators of the dye lasers are Hansch type and include an etalon to reduce the linewidth of the lasers. The wavelengths of the dye lasers are stabilized to within 100 MHz by a feedback system which consists of an etalon and picomotors attached to the laser optics. Since the wavelength difference between the second excitation laser and the final ionization laser is small, the two lasers are amplified simultaneously by using the same amplifying dye cell which was pumped by the DPSSL. After the three dye lasers are combined spatially and temporally by using beam-combining optics, they are directed into vacuum chamber to ionize Yb atom.

In vacuum chamber, Yb vapors are generated by heating natural Yb solid samples resistively. The generated vapors are well collimated by using several slits to reduce the Doppler broadening effect. The vaporization rate are measured and controlled optimally by using a direct deposition sensor with a quartz oscillator. Finally, after the Yb-176 atoms are ionized with the absorption of the three-color lasers, the generated photo-ions are extracted with a well designed collection system. When we designed the collection system, we considered the minimization of the deposition of the neutral Yb atoms and the collection efficiency.

3. Results

While we performed the main extraction experiment, we monitored the Yb mass spectrum using TOF(Time of Flight) equipment simultaneously in order to set the laser wavelengths exactly on resonance of Yb-176 and increase the selectivity of ionization. Fig. 3. shows the time-of-flight mass spectrum of Yb isotopes for two cases of natural abundance (a) and selective ionization (b). From the Figure, we can see that only Yb-176 atom (more than 99%) is ionized by the selective photoionization process.

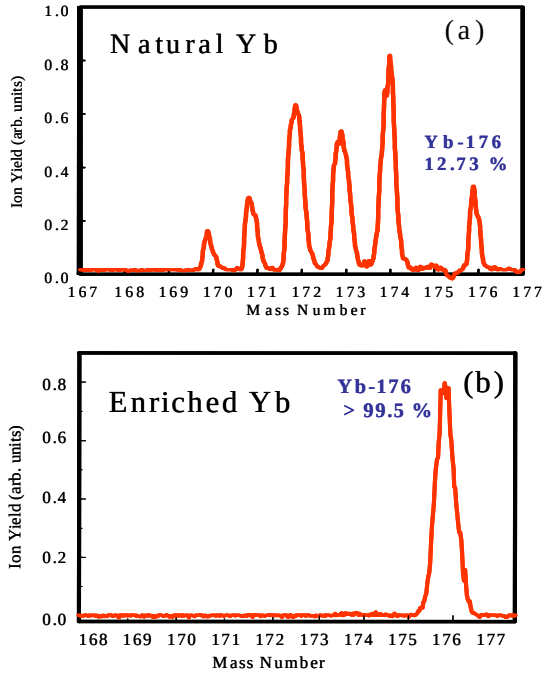

Fig. 3. Time of flight mass spectrum (a) natural Yb (b) after the selective photoionization.

While the wavelengths of the lasers are adjusted to maximize the selectivity of Yb-176, we inserted 3-color lasers into the separation chamber and measured the photo-ion signal to estimate the total quantity of Yb-ions which are generated by the photoionization process in the main separation chamber. Figure. 4 shows the typical photo-ion signal. The averaged photo-ion current is estimated to be about 1mA. Considering the mass of the Yb-176 atom, we can know that the productivity for the enrichment of the Yb-176 is about 6 mg/h.

After we dissolved the collection plates into the10 % nitric acid and analyzed the isotopic abundance of the product. The analysis result is shown in Fig. 5. We can see that the Yb-176 isotope is enriched to more than 95% from the natural abundance of the 12.7 %. If we introduce the separation factor (S) which quantifies the capability of the separation system defined by

$$S \equiv \frac{X_{176}^{f}}{1-X_{176}^{f}} \Big/ \frac{X_{176}^{i}}{1-X_{176}^{i}},$$

where X_{176}^{f} is the abundance of Yb-176 after the enrichment and X_{176}^{i} is the natural abundance, 0.127. S of our system is estimated to be more than 135. This result shows that our Yb-176 enrichment system has the enough capability to achieve the enriched Yb-176 for the medical application through a single stage separation.

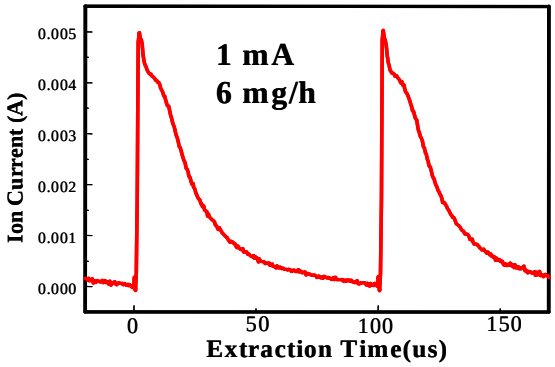

Fig. 4. The measured photo-ion signal.

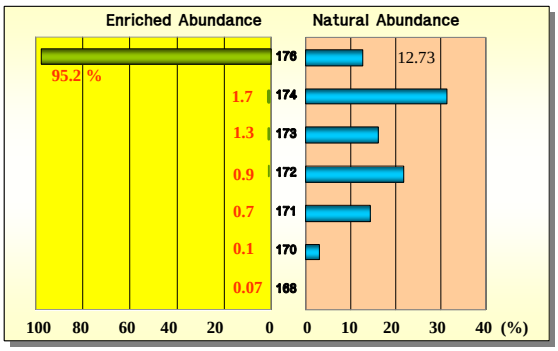

Fig. 5. The isotopic analysis results of the final product

4. Conclusions

We developed the laser separation technology to enrich the Yb-176 stable isotope, which can be transformed to the radioisotope Lu-177. The separation system consisted of the lasers, vaporizer and ion-extraction system. Especially, we made the facility to be very compact using the diode-pumped solid state laser as the pumping sources of dye lasers. As a result, we succeeded to produce the enriched Yb-176 with the abundance more than 95% and the productivity of 6mg/h.

REFERENCES

[1] N. A. Lebedev, A.F. Novgorodov, R. Misiak, J. Brockmann, and F. Rosch , Radiochemical separation of no-carrier-added ^{177}Lu as produced via ^{176}Yb(n,γ) ^{177}Yb-> ^{177}Lu process, Applied Radiation and Isotopes, Vol.53, p. 421, 2000.