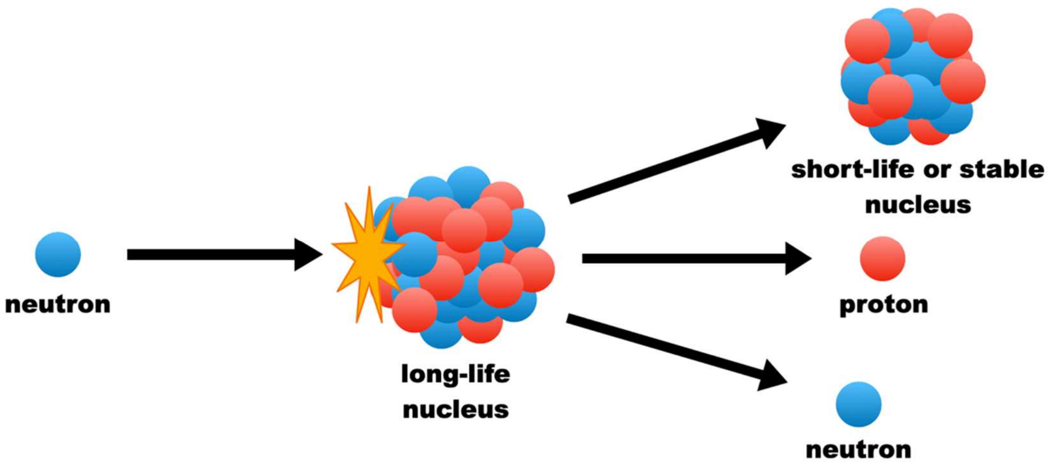

Latest technology for disposal of nuclear waste using nuclear transmutation

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Modern society has the problem of disposing of high-level radioactive waste. Nuclear power generation is always accompanied with spent nuclear fuel. The nuclear waste that remains finally emits so strong radiation that if a person were to get close to it, one's life would be in danger in even 20 seconds. Therefore, it is essential to dispose of this nuclear fuel in a safe way. One of the reasons why it is difficult to dispose of this nuclear waste is that there are Long Lived Fission Products (LLFPs), which have long lifetime against nuclear decay. Typical LLFPs include ^{93}Zr (half-life: 1.53 million years), ^{99}Tc (21.1 million years), ^{107}Pd (6.5 million years), ^{129}I (15.7 million years), and ^{135}Cs (2.3 million years). It will take such amount of time for radiation intensity to be halved.

The current processing method is to bury the radioactive waste deep underground, more than 300 m below the ground. However, it is quite difficult to select a disposal site due to the difficulty of getting the cooperation of local citizens because of concerns about radioactive materials and of ensuring the stability of the underground state. In particular, Japan is a volcanically active region, and it is difficult to prove safety for such a long-time scale.

Therefore, as an alternative processing method, a technology called nuclear transmutation that change long-life nuclei into shorter-life ones has been considered. In this method, fast neutrons or protons are bombarded to a nucleus to convert it into another nucleus. For example, when ^{107}Pd, one of the LLFPs, is collided with deuterons, some are converted into stable nuclei of ^{106}Pd, others into ^{103}Pd with a half-life of less than a year. There are two types of transmutation, one is using a nuclear reactor and the other is using an accelerator. Research on the conversion of long-lived minor actinides, which are elements with atomic numbers between 93 and 103 excluding plutonium, has been progressing in the method using nuclear reactors. However, the neutrons coming from the reactors have so low energy that the probability of reaction with the LLFPs is very low. Therefore, it is believed that accelerator-based conversion is essential for the conversion of LLFPs.

In order to realize this transmutation, both separation and transmutation technologies are indispensable. Radioactive waste contains various types of nuclear materials, such as rare metals which can be reused as resources in the future, and nuclei that has long lifetime. Therefore, it is necessary to develop the technology to extract and condense only those nuclei that need to be transmuted. That makes the efficiency of nuclear reactions increased. If the extracted nuclei can be transmuted into nuclei with short half-life using a high-intensity accelerator, it is expected that disposal of nuclear waste by transmutation can be practical[1].

As a separation technique, the laser even-odd separation method was successfully used to separate palladium isotope that has different neutron number with high purity in 2017[2]. ^{107}Pd is one of the LLFPs. Since palladium with an even mass number is a stable isotope, it is important to separate it from those with an odd mass number. In this method, because odd mass number isotopes have nuclear spin (angular momentum), it can be selectively ionized by controlling the polarization of the laser beam. Although this method has been used before, the ion collection rate was low. In this study, however, a high collection rate was achieved by improving the method of excitation. This method can be applied to other nuclides, and future research is expected to realize it.

Also, a new accelerator concept was invented in 2019 that would provide a high level of conversion ability comparable to the processing ability of nuclear waste currently in use[3]. In order to achieve the same level of processing power as the existing processing plants, the intensity of the beam needed to be 300 times higher than that of the existing accelerators. The existing high-intensity proton accelerators used Radio Frequency Quadrupole (RFQ) accelerators. This accelerator can shape, converge, and accelerate the beam simultaneously by applying and adjusting voltage. However, in order to increase the intensity of the beam of this RFQ accelerator, a strong electric field for converging the beam of large radius must be needed, and eventually this will reach the discharge limit. If the electric field is too strong, discharge occurs between the electrodes and the electric field will lost. It is thought that the RFQ accelerator can only produce beams up to a few centimeters in diameter. To solve this problem, accelerators that use magnetic fields for beam convergence was proposed in this research. By using magnetic fields, beam aperture can be increased without discharge problems. In addition, the proposed new accelerator has a cellular structure, and the beam can be controlled in each cell, so it is shown that the accelerator can shape and accelerate high-intensity deuteron beam with the diameter of 10 cm.

As this essay explained above in terms of laser separation technology and accelerator, the feasibility of disposal of radioactive nuclear waste using nuclear transmutation has been discussed, and the development of equipment and the collection of data on the reactions are already underway. For practical use, I think it is needed to be collect more data on nuclear transmutation related to LLFPs and research for further efficiency improvement. I believe that it is necessary to combine this research in these various fields finally, and the problem can be solved by promoting multifaceted research.

Reference

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