A Nuclear Solution to a Nuclear Problem

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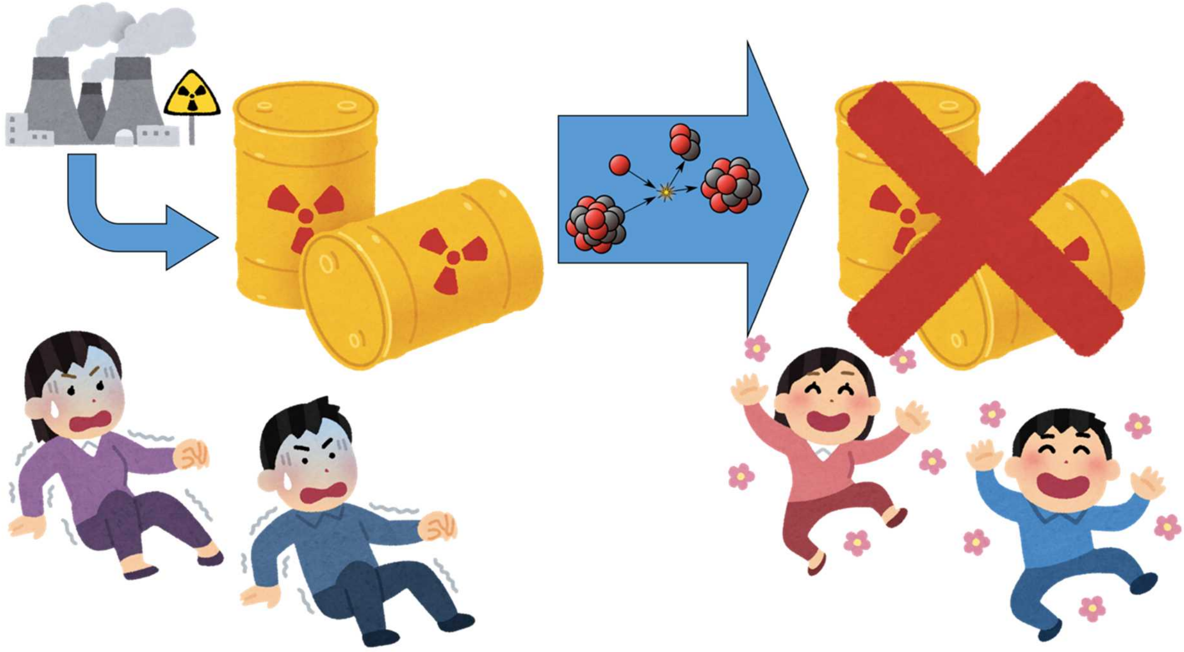

Nuclear power is an important clean energy option. It accounts for about 10% of global electricity supply. However, nuclear waste from nuclear power plants threatens the environment. Recently, a plan to dispose wastewater from the Fukushima Daiichi Nuclear Power Plant has aroused attention in Japan and Asia. In addition, there is another source of nuclear waste which cannot be overlooked.

Physicists in Japan discovered a possible method to tackle nuclear waste created by nuclear plants. They collected the first experimental data for three radioactive isotopes. And they found that nuclear reaction can reduce the radioactive materials effectively.

Every operating plant generates nuclear waste regularly. When the nuclear fuel is used up, the spent fuel is either disposed or reprocessed. After reprocessing, recycled fuel is extracted and the high-level waste (HLW) remains. The HLW is highly radioactive. A typical 1,000-megawatt nuclear reactor creates 3 m^3 HLW [1] per year after waste reprocessing. In 2018, IAEA estimated the global amount of HLW stored to be 22,000 m^3 [2], which is equivalent to about nine Olympic-size swimming pools. The deadly wastes are now stored temporarily in sub-surface facilities. Most countries plan to construct deep geological repositories for permanent disposal of HLW. Unfortunately, most of the attempts to construct a repository in countries, including Japan [3][4], are unsuccessful because of local opposition. Also, it is not a sustainable solution due to the long-term risk of leakage. Due to its unfeasibility and potential danger, an alternative should be proposed.

The alternative is nuclear transmutation, which means the conversion of one isotope into another isotope by nuclear reaction. By bombarding the HLW nuclei with particles, like protons, the radioactive isotopes react and become radiologically harmless isotopes. With this possible solution, it is essential to evaluate its effectiveness.

Wang and his collaborators were interested in three HLW isotopes: caesium-137 (^{137}Cs) [5], strontium-90 (^{90}Sr) [5] and palladium-107 (^{107}Pd) [6]. In contrast to stable isotopes in nature, these three isotopes emit radiation which is hazardous to all forms of life. To evaluate the strategy of waste treatment, we consider two major factors, radiotoxicity and half-life. For radiotoxicity, ^{90}Sr is notorious for its high radioactivity and serious health hazard, while ^{137}Cs is infamous for its mobility in air and water. The half-life of an isotope refers to the time required for half of the radioactive nuclei of a sample to decay. The three isotopes have half-lives longer than 30 years. In particular, ^{107}Pd has a half-life of 6.5 million years. In other words, in every time period from our ancestors began to walk upright to now, the radioactivity of ^{107}Pd is halved. Although these long-lived isotopes do not pose immediate threat to us, their persistent radioactivity may cause an environmental disaster. Once the soil or waterbody is contaminated by the HLW, it becomes radioactive for a long time. The radioactive substances can transfer and accumulate along the food chain. At the end, when human ingests the contaminated food or water, the risk of cancer increases. Hence, it is desirable to shorten the half-lives of HLW isotopes and reduce radioactivity in a short time frame.

Indeed, the researchers found that the half-lives can be drastically reduced by using spallation reaction. You can imagine spallation as firing a bullet into a water balloon. Then, water droplets are scattered from the water sphere. In the spallation reaction of this experiment, the nucleus is first collided by a proton or a deuteron (a nucleus with a proton and a neutron), and then evaporates neutrons and/or protons. The products after reaction are either stable or short-lived. Thus, the HLW becomes less harmful and more manageable after spallation.

The researchers conducted an experiment at RIKEN Nishina Center in Japan. They studied the spallation reactions of ^{137}Cs, ^{90}Sr and ^{107}Pd on proton and deuteron. In this experiment, the team irradiated the beam containing the HLW isotopes on proton or deuteron targets. The accelerators first accelerated uranium-238 (^{238}U) nuclei to an energy of 345 MeV/nucleon, which is equivalent to 70% of light speed. The primary beam then hit a beryllium target, creating various fission products. The interested products, such as ^{137}Cs, were selected by the separator and delivered to the proton or deuteron target. The proton and deuteron targets were made of polyethylene (CH_2) and deuterated polyethylene (CD_2), respectively. After spallation occurred in one of the targets, the scattered product isotopes were identified by the spectrometer.

The team successfully identified over 50 isotopes, which are mostly stable or short-lived, from spallation products for each HLW isotope beam. The spallation cross sections were determined to be about 1 barn (10^{-24} cm^2). It indicates there is a reasonably good chance for the spallation reaction to occur. And the spallation resulted in more than 94% nuclei with half-lives shorter than 30 years. From the results, they claimed that spallation reaction is a promising mechanism to mitigate radioactivity of HLW. Besides, they found deuteron is a better option to transmute HLW [5]. This experiment implicated a possibility to use an accelerator to irradiate the HLW with deuterons.

Though, the accelerator technology today is not good enough to enable efficient treatment of HLW. For example, in Japan, since the Rokkasho Reprocessing Plant produces 417 kg ^{135}Cs per year, it requires a 1-ampere deuteron beam to remove all ^{135}Cs produced [7]. However, the highest beam intensity offered by the most advanced accelerator is about 0.001 ampere. Okuno and his partners [8] proposed a new accelerator that can produce high-intensity deuteron beam at 1 ampere for the purpose of HLW transmutation. This could be a solution to manage the HLW.

Nuclear technology is a double-edged sword. It can bring benefits or disasters to us. Now, scientists are taking steps to alleviate environmental issues brought by nuclear energy. Yet, more time and effort are required before the first HLW transmutation plant. Hopefully, the scientists will achieve responsible and sustainable use of nuclear energy in the future.

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