Research and Development to Reduce Radioactive Waste by Accelerator

Current Status and Prospects for Partitioning and Transmutation Technology
We humans need to secure stable energy resources for prolonged periods to enjoy a healthy and abundant life. Therefore, it is important to utilize several energy resources including fossil energy, renewable energy and nuclear energy.

As for the utilization of nuclear energy, it is absolutely necessary to develop the technology for disposal of radioactive wastes such as spent fuel as well as safety improvement. This is a common issue for all countries which have utilized nuclear energy.

Most of the countries utilizing nuclear energy have a policy to dispose of the spent fuel or the radioactive wastes in a geological disposal site. The spent fuel and the radioactive wastes have to be stably stored in the geological disposal site for periods ranging from tens of thousands to several thousand years. This is a big issue and a burden for the utilization of nuclear energy.

Partitioning and Transmutation (P&T) technology is to reduce the burden of geological disposal. This technology has a possibility to shorten the time required to reduce the radiotoxicity of wastes to the natural uranium ore’s one.

Partitioning and Transmutation (P&T) technology is to separate elements in high level radioactive waste discharged from the reprocessing plant depending on intended use to transmute long-lived nuclides to short-lived or stable ones.

For the transmutation, the following two methods which utilize a fast reactor or an Accelerator-Driven System (ADS) are investigated. Here, we focus on P&T technology with ADS.

Introduction

Partitioning and Transmutation Technology

The nuclear fuel cycle is the basic policy of Japan. Uranium and plutonium from the spent fuel will be reused and the high level radioactive waste will be discarded by the geological disposal.

P&T technology aims to reduce the burden of the geological disposal by the partition of wastes and the transmutation of long-lived nuclides.
The development of the industrial equipment considered with the heat generation of MA and the tasks listed below are engaged.

- **Fuel fabrication**: Evaluating an effect of impurities in fuel
- **Improvement of predictability of fuel behavior**

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**Future research issues**

1. Improvement of the economic efficiency and reduction in the amount of secondary waste
2. Exclusion of the process which is easy to generate deposition.
3. Use of extractant which consists of carbon, hydrogen, oxygen and nitrogen.
4. Extractant can be incinerated to reduce the amount of the secondary waste.

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**Future research issues**

The development of the industrial equipment considered with the heat generation of MA and the tasks listed below are engaged.

- Fuel fabrication: Evaluating an effect of impurities in fuel improvement of predictability of fuel behavior
- Pyrochemical reprocessing: Improvement of MA recovery ratio
Future research issues\footnote{Research and development for each field are required.}

Efficient transmutation\footnote{MA from 10 light water reactors (LWRs) can be transmuted by the ADS (800MW) per year.}

Transmutation by ADS

The research and development for Accelerator-Driven System (ADS) have been performed as an efficient transmutation system.

Transmutation of MA (and heavy nuclides)

U, Pu and MA are changed to other nuclides (transmutation) by the fission reaction induced by neutrons. Long-lived nuclides will be changed to short-lived or stable nuclides. (The figure below indicates an example. The various nuclides are produced by the fission reaction.)

ADS is a hybrid system of proton accelerator and nuclear reactor loading MA fuel. The ADS aims more efficient transmutation than that by fast reactor. The nuclear reactor is designed to keep subcritical state. It means that the reactor is unable to maintain the fission chain reaction without an external neutron source. In the ADS, the spallation neutrons produced by the spallation reaction between LBE (lead-bismuth) and the proton beam injected from the accelerator are supplied.

MA will be reduced efficiently and safely by the ADS. For the realization of the ADS, JAEA proceeds the research and development for various fields such as accelerator, nuclear reactor physics, material, plant technology and so on.

International cooperation for the ADS has also promoted actively.
We aim at the construction of practical ADS plant based on the data and knowledge obtained by the R&D performed at these facilities.

At TEF-T, the irradiated beam window of the target and the samples installed in the target will be examined. Then, the life time of beam window materials and performance of new materials will be evaluated.

We have planned ADS simulation experiments by using proton beam from J-PARC LINAC. And we consider critical experimental apparatus into which kg-order MA fuel can be loaded.

Cross sectional view of TEF-T LBE spallation target.

At the beam window of ADS, performance of the beam window material will be deteriorated by proton irradiation and corrosion in high temperature flowing LBE. At TEF-T, the irradiated beam window of the target and the samples installed in the target will be examined. Then, the life time of beam window materials and performance of new materials will be evaluated.
Future Prospects

To comprehend the technology level of P&T technology, TRL (Technology Readiness Level) which has been used by NASA (National Aeronautics and Space Administration) was employed to evaluate P&T technology. Then, most of the technologies were estimated as the end of the concept development level (TRL3). It was shown that there is the big wall to reach the performance demonstration level (TRL5). JAEA aims to raise TRL for each technology by infrastructure constructions such as TEF.

**Level** | **P&T technology** | **Other technology**
---|---|---
Performance demonstration level (TRL7~9) | (MYRRHA, Practical plant)* | Reprocessing of LWR fuels (TRL8)
Principle demonstration level (TRL4~6) | (TEF, Engineering scale test)* | Fast reactor (TRL6)
Concept development level (TRL1~3) | Partitioning (TRL3) MA fuel fabrication (TRL2) ADS (TRL3) | Fusion reactor (TRL6)

*Achieved level if these facilities would be constructed

**Future Prospects**

**Glossary**

**Actinide**
- Actinide is a general term for the 15 chemical elements from actinium (atomic number 89) to lawrencium (103). All of the actinides are radioactive, and it contains uranium and plutonium which can be used as nuclear fuel.
- **Beam window**
  - Beam window is a structural boundary between proton accelerator and spallation target. It will be used under the severe condition due to the heat generation by proton beam and pressure by the spallation target (accelerator side is vacuum).
- **Beta ray (β-ray)**
  - Beta ray is a kind of radiations and is an electron or positron. Beta ray is shut by thin aluminum or plastic plate. Other typical radiations are alpha, gamma and neutron rays.

**Critical assembly**
- Critical assembly is a small and low-power critical experimental apparatus for the research of reactor physics field. The assembly can be changed for the purpose of the experiment, by changing composition and configuration of fuel, moderator and structure.

**Fission product (FP)**
- Fission product is a nucleus left after the fission reaction and radioactive decay. FP is mostly radioactive.

**Fission reaction**
- Fission reaction is a type of nuclear reaction. The reaction is that heavy nuclei (ex. U, Pu) irradiated by a neutron produces two lighter nuclides and a few neutrons and releases a very large amount of energy.

**Half-life**
- Half-life is a time required for a quantity of radioactive isotope becoming half by radioactive decay. The half-life is fixed by every radioactive life isotope and takes the wide time range from more than several billions of years to less than a one-millionth second.

**High level radioactive waste (HLW)**
- HLW is high level radioactive liquid and its vitrified waste after collected uranium and plutonium by reprocessing spent fuel. It includes fission products represented by strontium-90 and cesium-137, and minor actinide represented by americium-241 and neptunium-237.

**J-PARC (Japan Proton Accelerator Research Complex)**
- J-PARC is the proton accelerators and the experimental facilities to conduct cutting-edge research across a wide range of scientific fields. In 2008, Phase 1 facilities were completed at Tokai research center of JAEA. J-PARC is operated in cooperation with High Energy Accelerator Research Organization (KEK) and JAEA.

**Lanthanoid (Ln)**
- Lanthanoid is a general term of lanthanum (atomic number 57) to lutetium (71). These elements resemble each other in physical and chemical properties. The light lanthanoid elements whose atomic number are smaller than gadolinium are included in HLW.

**Lead-bismuth eutectic (LBE)**
- LBE is an eutectic alloy of lead and bismuth. LBE is proposed as a spallation target material and core coolant for ADS because of its low melting temperature and chemical stability.

**Minor actinide (MA)**
- Minor actinide is an actinide element contained in the spent fuel except for uranium and plutonium. (ex. neptunium, americium and curium)

**Molten salt**
- Molten salt is liquid in the liquid phase. It is used as a solvent in the pyrochemical reprocessing of the spent fuel.

**Nuclear fuel cycle**
- Fissionable plutonium is generated in the spent fuel when uranium is used in a nuclear reactor. Fissionable plutonium can be reused in a reactor as nuclear fuel by reprocessing spent fuel. The nuclear fuel cycle means the whole system including the fabrication of nuclear fuel, the reuse of it and the disposal of spent fuel.

**Nucleide**
- Nucleide is an atomic species specified by numbers of protons and neutrons. For example, uranium-238 (mass number 238) has 92 protons and 146 neutrons and uranium-235 (mass number 235) has 92 protons and 143 neutrons.

**Platinum group element**
- Platinum group element is a general term of six elements of ruthenium, rhodium, palladium, osmium, iridium, and platinum. These elements resemble each other in physical and chemical properties. Spent fuel contains ruthenium, rhodium, and palladium.

**Pyrochemical reprocessing**
- Pyrochemical reprocessing is an element separation method using no aqueous solution against aqueous reprocessing such as PUREX process. In the typical method, fuel composition elements dissolved in molten salt are separated from the fission products by the electroreftting or the solvent extraction between molten salt and liquid metal phases.

**Radiotoxicity (potential radioactivity)**
- Radiotoxicity is a radiation dose when all radionuclides included in the spent fuel or other wastes would be ingested by public.

**Spallation reaction**
- Spallation reaction is a type of nuclear reaction that a heavy material (ex. Pb) is fractured by high energy particles such as proton. In that time, a number of nuclides and neutrons are generated as fragment.

**Super conducting accelerator**
- Super conducting accelerator is an accelerator with super conducting cavity to accelerate charged particle (here, proton). Higher electric efficiency and larger diameter of beam line are characteristics of the accelerator in comparison with normal conducting accelerators.

**Technology Readiness Level (TRL)**
- Technology readiness level is a measure to assess the maturity of a new technology systematically.

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<tr>
<th>Partitioning</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
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<td>• MA</td>
<td>Basic- and real liquid test</td>
<td>Demonstration test</td>
<td>Engineering scale test</td>
<td>Practical plant</td>
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<tr>
<td>• Other nuclides</td>
<td>Basic- and real liquid test</td>
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<tr>
<th>Fuel for transmutation (Fabrication, reprocessing)</th>
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<th>2020</th>
<th>2030</th>
<th>2040</th>
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<tbody>
<tr>
<td>Engineering device test</td>
<td>Mock-up test</td>
<td>Engineering scale test</td>
<td>Practical plant</td>
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<td>Basic test with MA</td>
<td>Fabrication of MA sample and irradiation test</td>
<td>Fabrication of MA fast pin and assembly (HLW) and irradiation test</td>
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<tr>
<th>Transmutation(ADS)</th>
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<tr>
<td>• Accelerator</td>
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<td>Building up experience at J-PARC</td>
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This color means the experiment or the facility with the use of MA

JAEA promotes the infrastructure constructions and R&Ds for each technology to introduce P&T technology.