Research and Development to Reduce Radioactive Waste by Accelerator

Current Status and Prospects for Partitioning and Transmutation Technology

Japan Atomic Energy Agency

Introduction

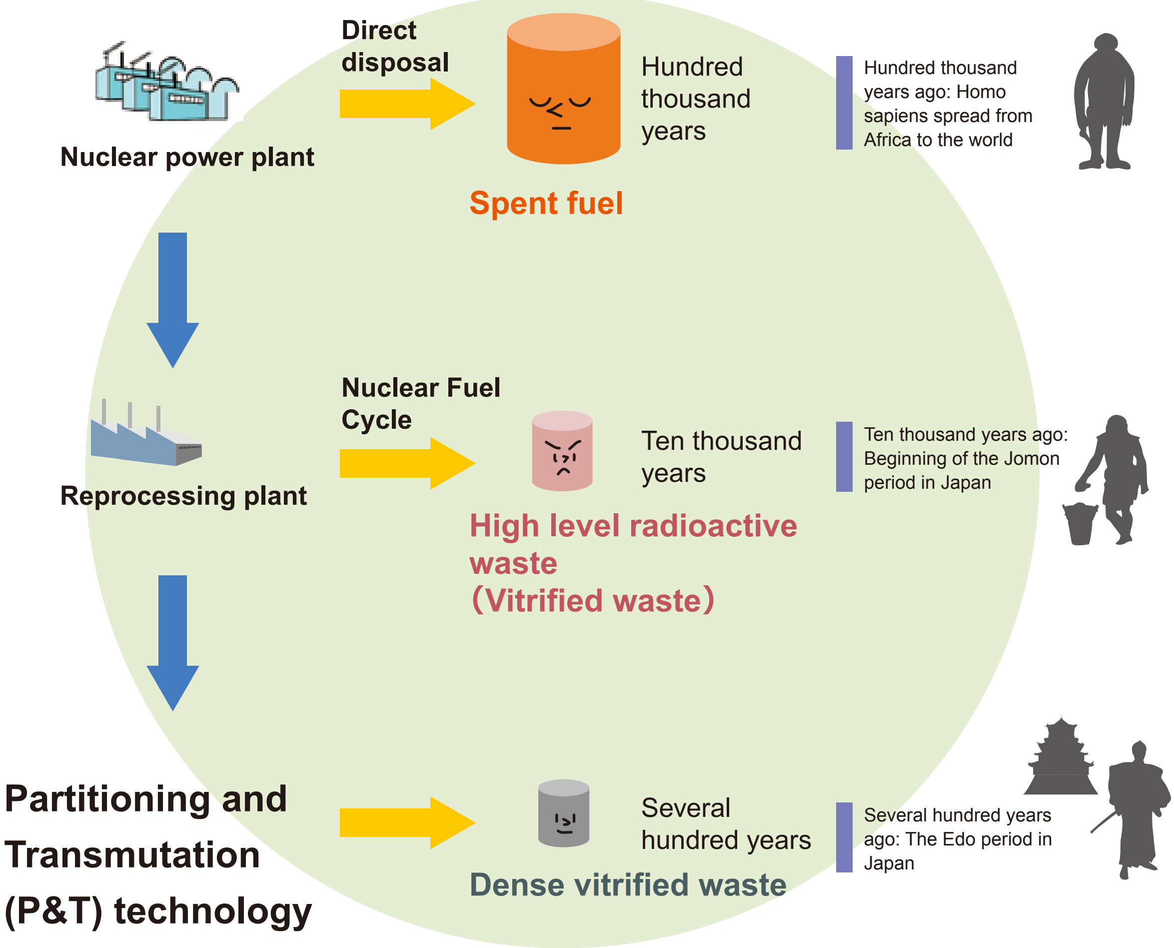
We humans need to secure stable energy resources for prolonged periods to enjoy a heathy and abundant life. Therefore, it is important to utilize several energy resources including fossil energy, renewable energy and nuclear energy.

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.

The period required to reduce the radiotoxicity of each waste to the natural uranium ore's one after the disposal.



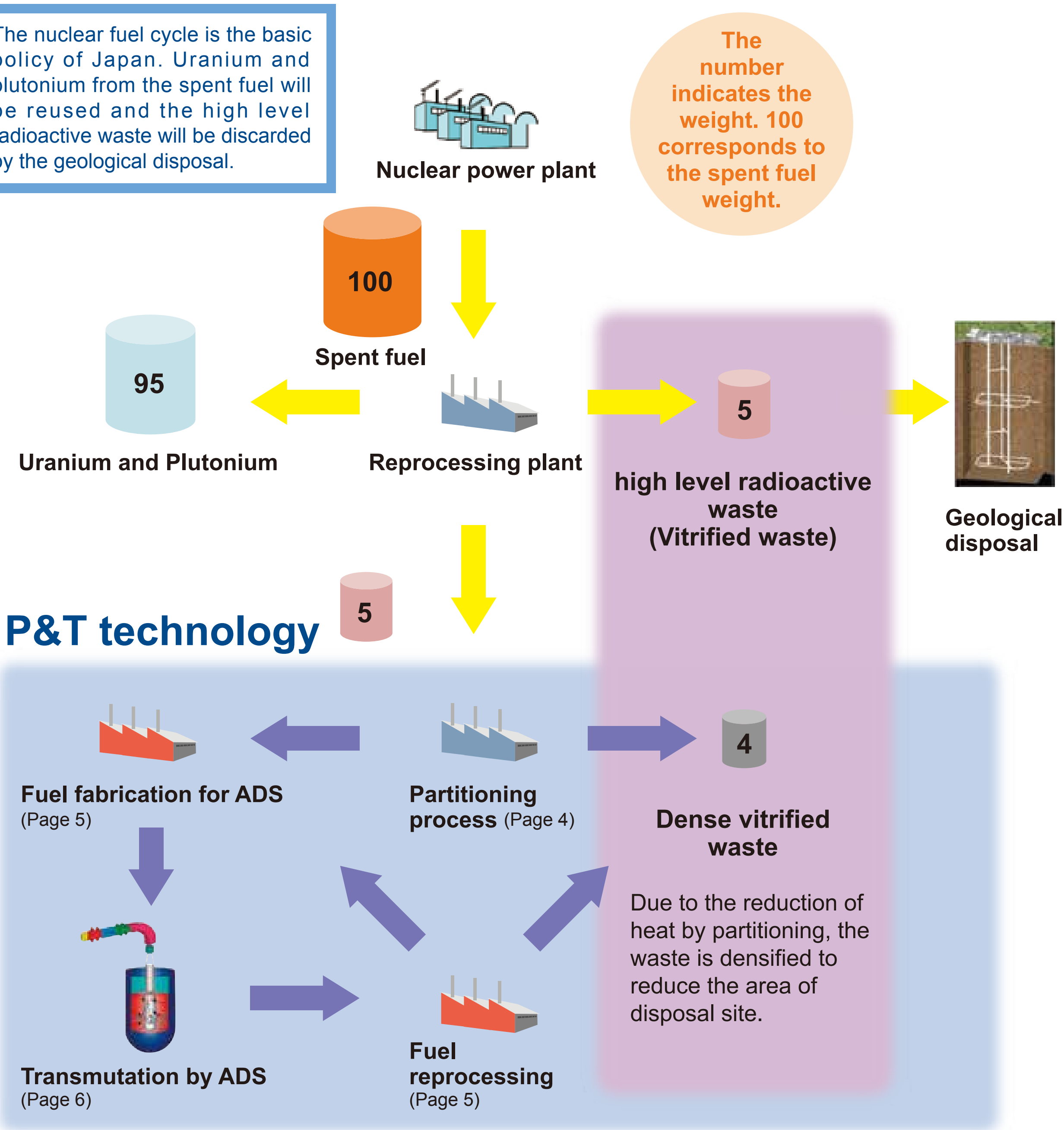
The introduction of P&T technology has a possibility to reduce the time of radiotoxicity reduction from inconceivable long period to several hundred years.

Partitioning and Transmutation Technology

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.

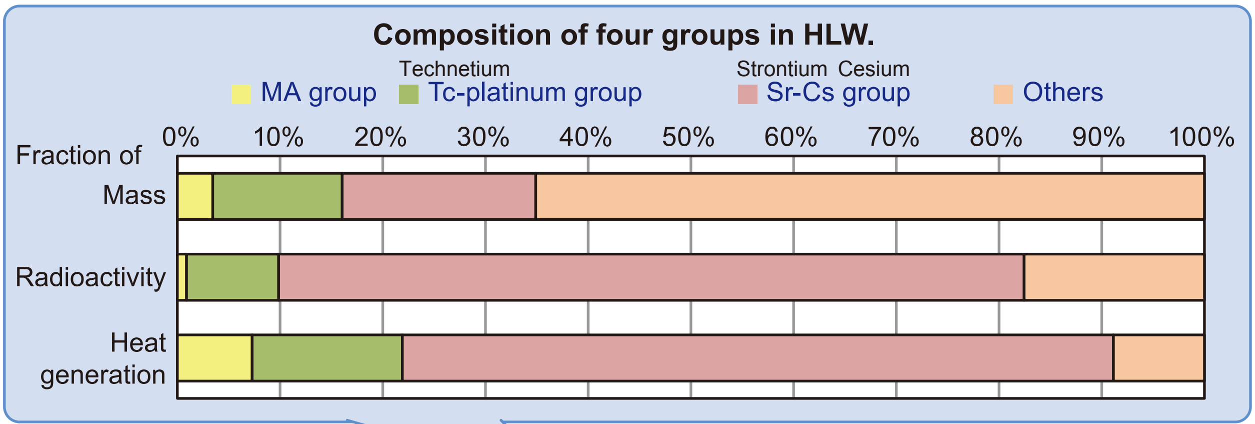
The nuclear fuel cycle is the basic policy of Japan. Uranium and plutonium from the spent fuel will be reused and the high level radioactive waste will be discarded by the geological disposal.

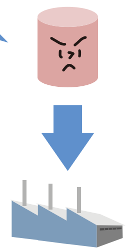


P&T technology aims to reduce the burden of the geological disposal by the partition of wastes and the transmutation of long-lived nuclides.

Partitioning Process

High level radioactive waste (HLW) containing fission products and minor actinide (MA) is generated by the reprocessing of spent fuel. The partitioning process has been developed to separate elements in HLW into four groups depending on their chemical properties and uses.





HLW

Partitioning process

MA group	Tc-platinum group	Sr-Cs group	Others
(Np, Am, Cm) Neptunium Americium Curium ・heat generation in long term ・radiotoxicity : high ・half-life : long	(Tc, Ru, Rh, Pd) Technetium Ruthenium Rhodium Palladium ・rare metals ・adverse effect on vitrification	(Sr, Y, Cs, Ba) Strontium Yttrium Cesium Barium ・heat generation : high ・radioactivity : high	(Zr, Mo, lanthanoid, etc.) Zirconium Molybdenum ・heat generation : low ・radiotoxicity : low ・half-life : short
Transmutation to short-lived or stable isotope	Utilization as catalyst	Utilization as heat or radiation source	Geological disposal as dense vitrified waste

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After the partitioning, long-lived radioactive nuclides are transmuted to low radiotoxic nuclides and other elements are utilized or disposed depending on each property of the elements.

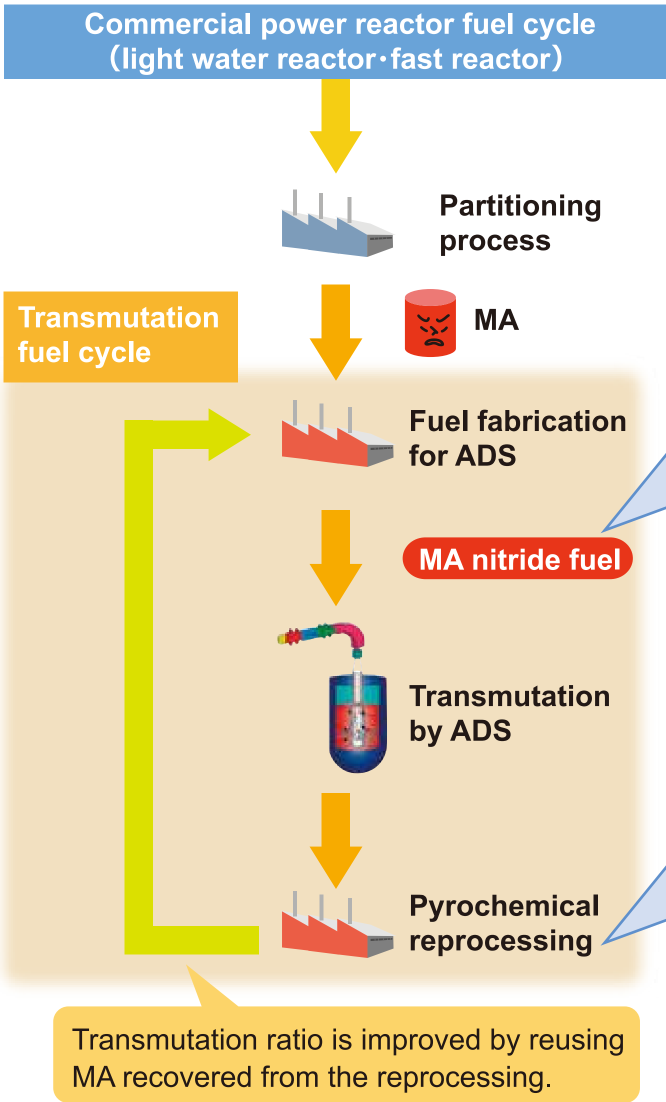
Future research issues (1) Improvement of the economic efficiency and (2)reduction in the amount of secondary waste

・Exclusion of the process which is easy to generate deposition.
➡ Operability, maintenance property and the economic efficiency are improved.
・Use of extractant which consists of carbon, hydrogen, oxygen and nitrogen.
➡ Extractant can be incinerated to reduce the amount of the secondary waste.

Fuel Fabrication and Reprocessing

Fuel fabrication technology for ADS and reprocessing technology of spent fuel generated from ADS have been developed.

Fuel for ADS has high heat generation and high radioactivity because it contains high concentration MA. From these characteristics, nitride fuel and pyrochemical reprocessing have been studied as the first candidate for the transmutation fuel cycle.



Characteristics of nitride fuel

- ○ High heat conductivity and high melting point
  - ➡ Easy to cool and high safety margin
- ○ Actinides form solid solutions in each other.
  - ➡ Flexibility of fuel composition is large
- ● Unstable in the air
  - ➡ Treatment in an inert atmosphere is required

Characteristics of pyrochemical reprocessing

- ○ Using molten salt and liquid metal
  - ➡ High radiation resistance and high heat resistance
- ● Treatment in an inert atmosphere is required

Technology to fabricate high quality fuel has been developed. MA recovered from the pyrochemical reprocessing will be recycled as fuel for ADS.

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

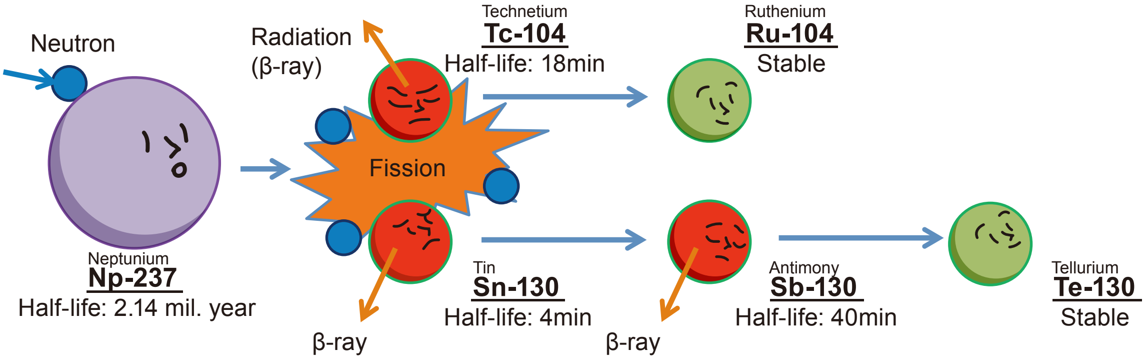
・Pyrochemical reprocessing: Improvement of MA recovery ratio

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)

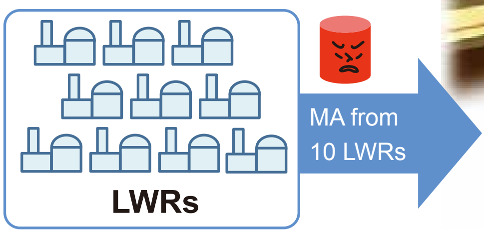
U, Pu and MA are changed to other nuclides (transmutation) by the fission reaction induced by neutrons. Long-lived nuclides will be changed to short-lived or stable nuclides. (The figure below indicates an example. The various nuclides are produced by the fission reaction.)

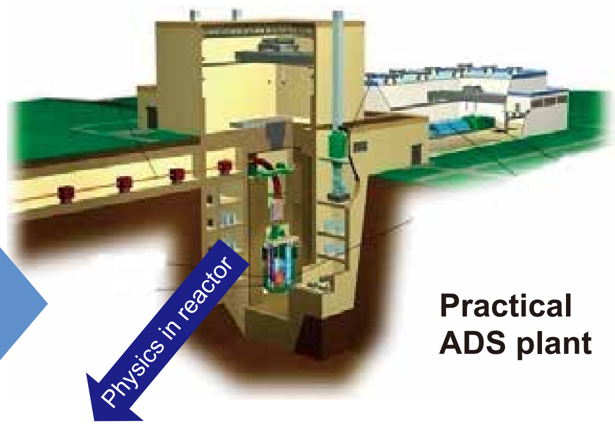


ADS is a hybrid system of proton accelerator and nuclear reactor loading MA fuel. The ADS aims more efficient transmutation than that by fast reactor. The nuclear reactor is designed to keep subcritical state. It means that the reactor is unable to maintain the fission chain reaction without an external 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.

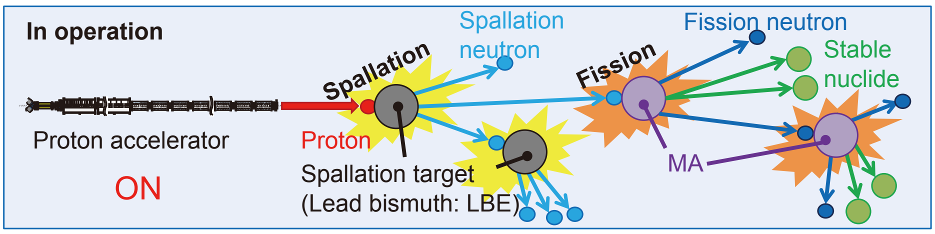
Efficient transmutation

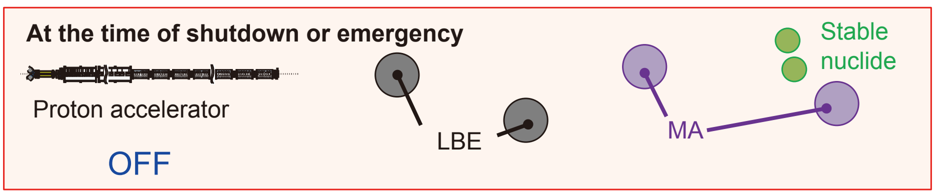
MA from 10 light water reactors (LWRs) can be transmuted by the ADS (800MW) per year.





Practical ADS plant



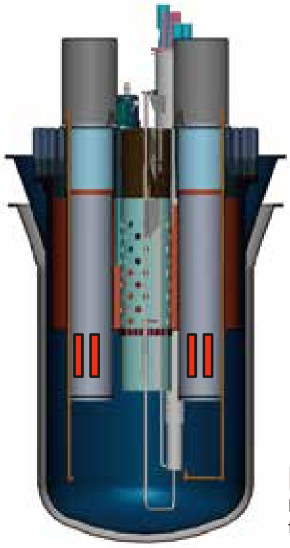


Accelerator: OFF
➡Fission reaction: STOP

Safer system

As the research and development project for ADS in the world, MYRRHA project has been promoted in Europe and Belgium has led the project.
In this project, the construction of 100MW thermal ADS at Belgium has been planned.
JAEA has exchanged some information about the project with the project team.

The main purpose of MYRRHA project is the construction of ADS as the irradiation machine. Therefore, MYRRHA will not transmute MA. However, significant results will be derived from this project such as neutronic characteristics in subcritical reactor, LBE handling technology and building up experience of operation.

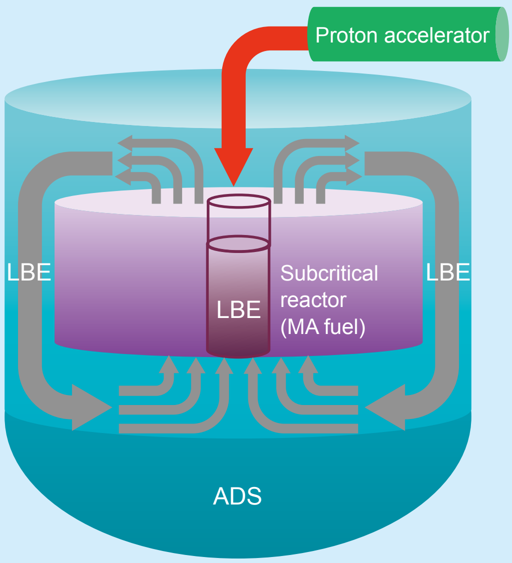


MYRRHA
Multi-purpose hybrid research reactor for high-tech applications

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.

Future research issues

Research and development for each field are required.



Issue 1

Understanding of neutronic characteristics and operation controllability for subcritical reactor
➡ Experiment by using new experimental facility (Page 8, TEF-P)

Issue 2

Technical development of Liquid LBE for the use as the coolant and spallation target
➡ Experiment by using new experimental facility (Page 8, TEF-T)

Issue 3

Realization of high intensity proton accelerator with high efficiency, high reliability and low-cost

Transmutation Experimental Facility (TEF)

The construction of TEF (Transmutation Experimental Facility) has been started at J-PARC (Japan Proton Accelerator Research Complex) in Tokai-mura, Ibaraki-ken to perform R&D for the transmutation by ADS.

Key issues on R&D for ADS

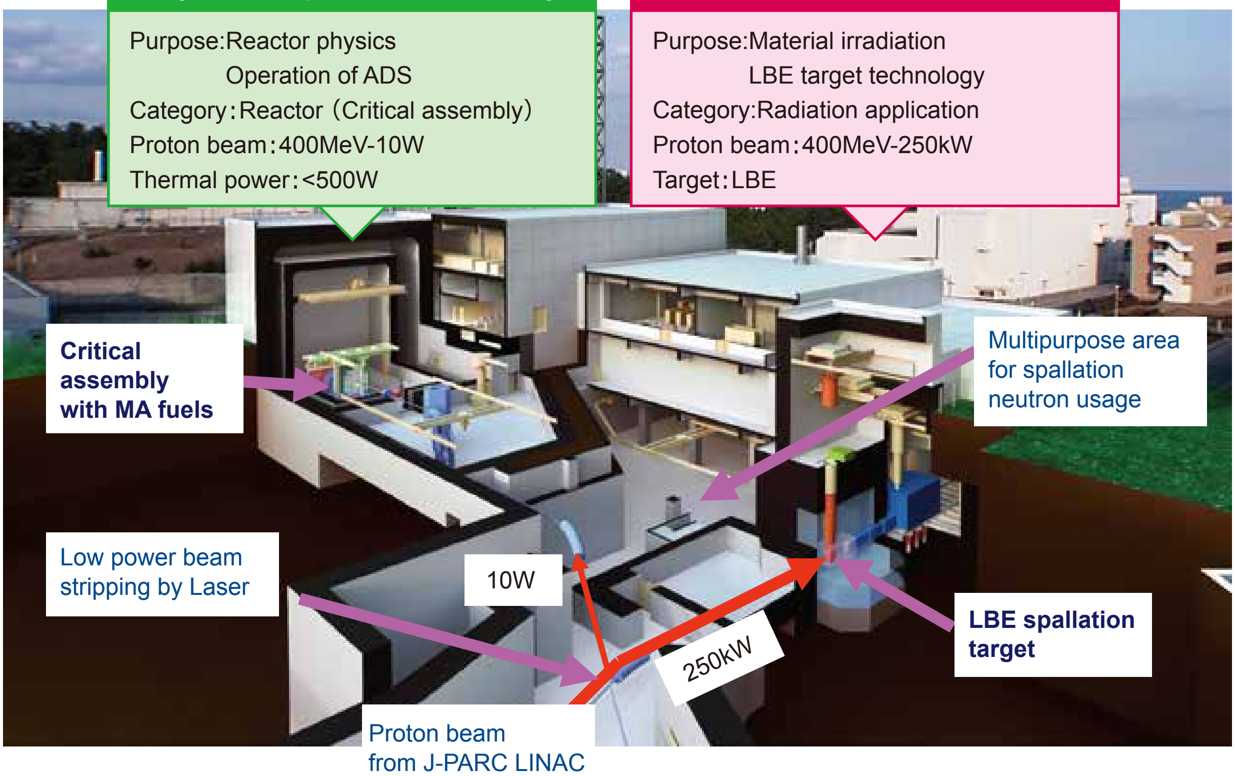
Subcritical reactor	LBE (Lead Bismuth Eutectic) and materials
● Reactor physics experiment with MA fuel ● Operation test on accelerator driven subcritical reactor	● Evaluation of proton irradiation effects on material properties. ● R&D of LBE spallation target technology
Critical assembly which can load MA and utilize proton beam is required.	LBE flowing loop which can utilize proton beam is required.

TEF-P : Transmutation Physics Experimental Facility

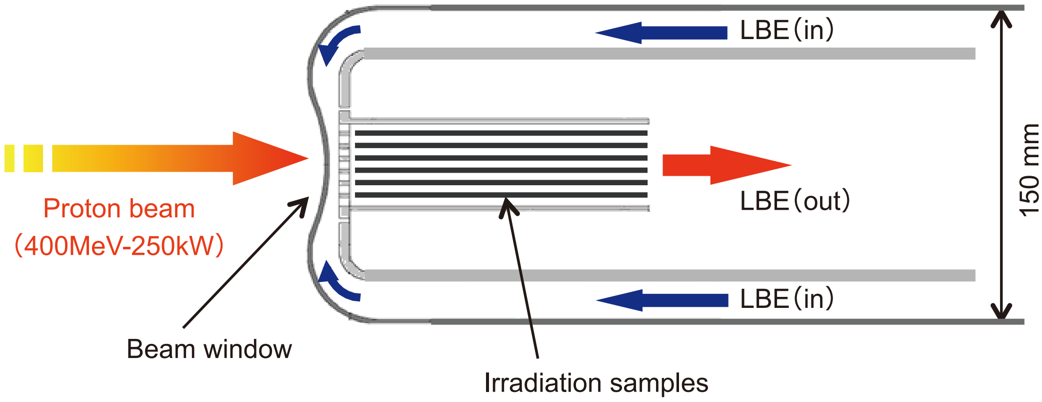
Purpose:Reactor physics
Operation of ADS
Category:Reactor（Critical assembly）
Proton beam:400MeV-10W
Thermal power:<500W

TEF-T : ADS Target Test Facility

Purpose:Material irradiation
LBE target technology
Category:Radiation application
Proton beam:400MeV-250kW
Target:LBE



Cross sectional birds-eye view of Transmutation Physics Experimental Facility (TEF-P, left) and ADS Target Test Facility (TEF-T, right).



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.

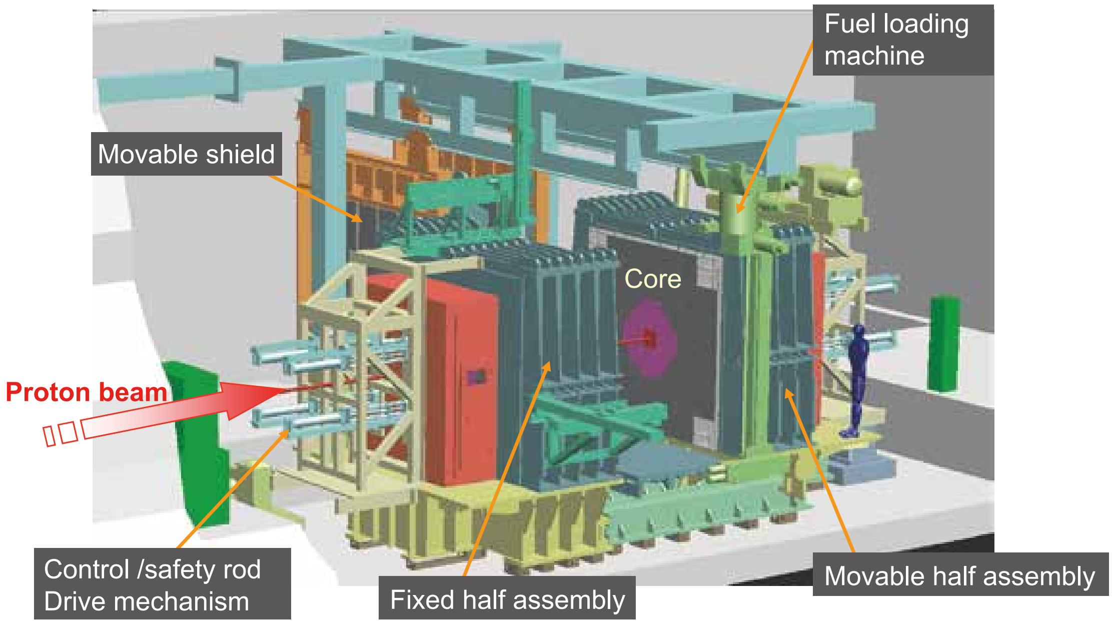


Illustration around critical assembly of TEF-P.

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.

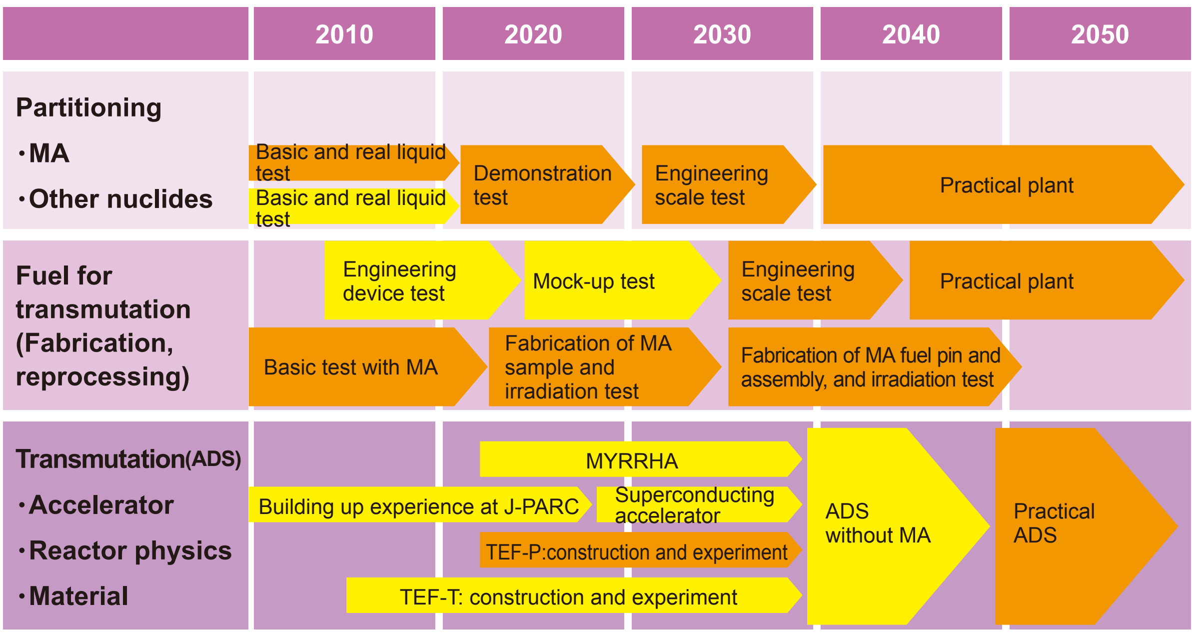
We aim at the construction of practical ADS plant based on the data and knowledge obtained by the R&D performed at these facilities.

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 (TRL9). 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） Fusion reactor（TRL6）
Concept development level（TRL1～3）	Partitioning（TRL3） MA fuel fabrication（TRL2） ADS（TRL3）	

＊Achieved level if these facilities would be constructed



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.

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 nuclide 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 nuclide (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 every radioactive 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 amerisium-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 elements from 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 salt 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.

Nuclide
Nuclide 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 electrorefining or the solvent extraction between molten salt and liquid metal phases.

Radiotoxicity (potential radiotoxicity)
Radiotoxicity is a radiation dose when all radioisotopes 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 tube 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.

Japan Atomic Energy Agency

Partitioning and Transmutation Technology Unit,
Nuclear Science and Engineering Center
http://nsec.jaea.go.jp/top.html

Transmutation Section, J-PARC center
http://j-parc.jp/Transmutation/en/index.html

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