Role of the Fast Reactor and Efforts on Monju

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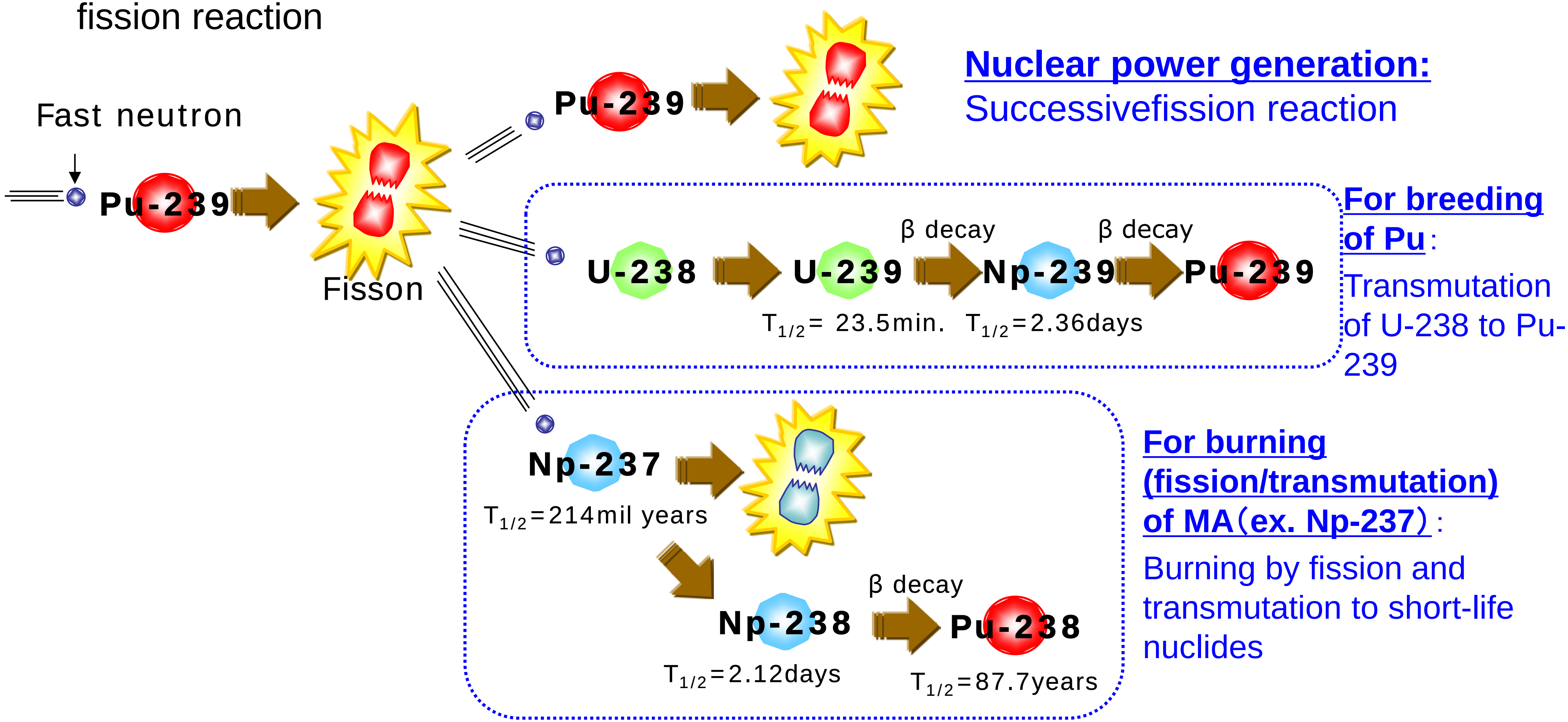
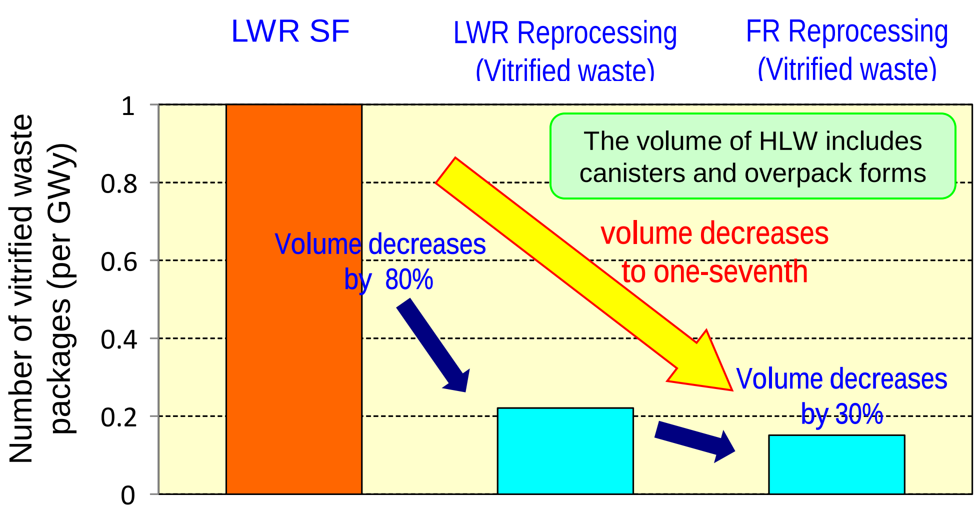
Feature of nuclear reaction in fast neutron reactor

- Higher number of neutron production per fission
- Higher fission reaction probability toward to neutron loss for fuel nuclides (Uranium(U), Plutonium(Pu), Minor Actinides(MA)).
- Pu breeding and MA burning (by fission or transmutation) are possible while continuous fission reaction



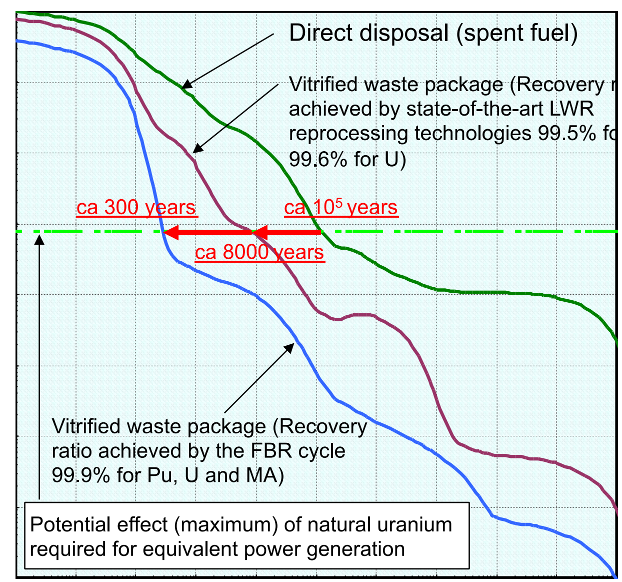
Radioactive Waste discharged from FR Cycle

- FR cycle has a large effect in reducing both waste amount and radiotoxicity, because it contains Pu and MA within the cycle system making long-lived radioisotopes emitted outside the system minimum.
- Vitrified waste package in the FR cycle in comparison with LWR fuel direct disposal
  - Reduction in high-level radioactive waste (HLW) volume
  - Reduction in the area for HLW requiring geological disposal
  - Reduction in potential radiotoxicity of HLW



Reduction in HLW volume

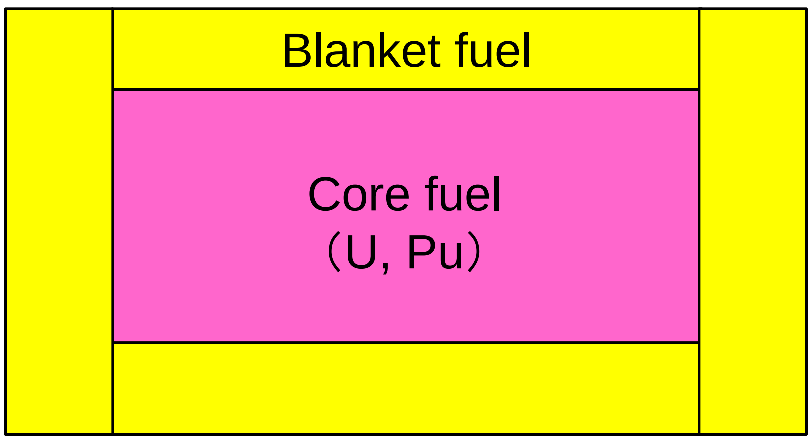
*) A relative value assuming that the potential effect of spent fuel at the first year is 1.



Reduction in duration of potential toxicity

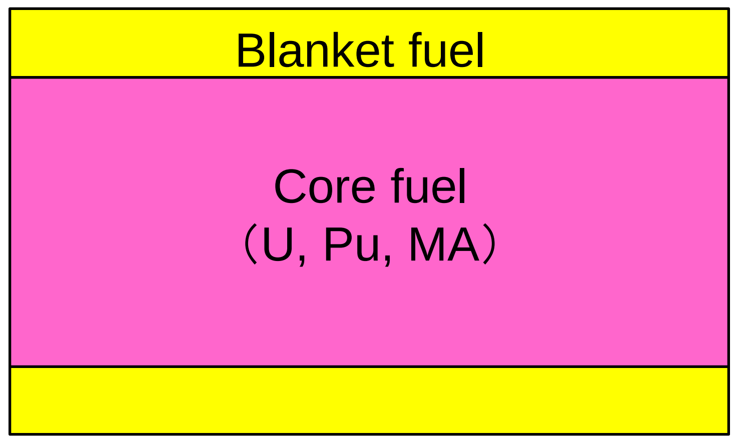
Total amount of TRU in FR cycle system

- By the change of fuel composition for loading fuel, Pu-breeding and MA-burning (by fission or transmutation) are possible. The amount of TRU(Pu, MA) in a fuel cycle system can also be controlled.
  - Set blanket fuels consisted of U to around core fuels →Pu breeding
  - Replacement of blanket fuels to core fuels & Higher Pu enrichment of core fuel→Pu burning
  - Higher MA concentration in core fuels→MA burning



Concept of Fast Breeder Reactor (FBR)

By adding blanket fuels in the radial and axial directions, Pu-breeding becomes possible in short-term.



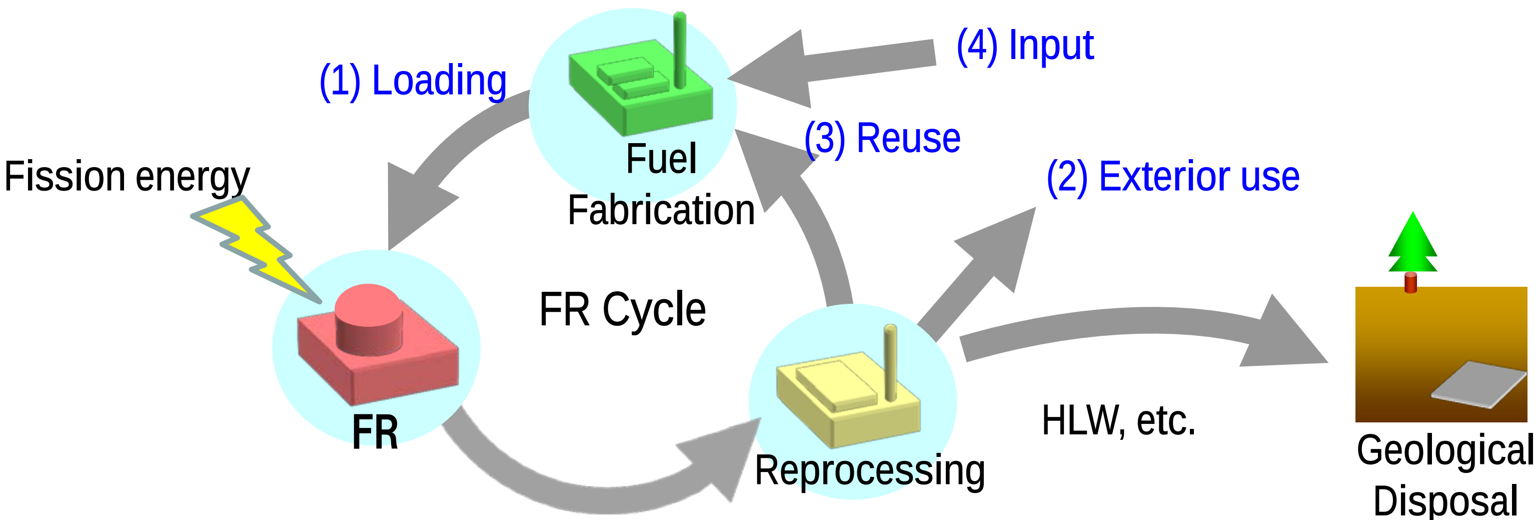
Concept of Fast Reactor (FR)

Depending on our aims, core fuel composition and amount of blanket fuels are optimized.（Blanket fuels are not always set.）

Significance of FR Cycle depending on Social Circumstances and Development Status

Mode*	(1)Loading	(2)Exterior use	(3)Reuse	(4)Input	Significance, Purpose
Pu breeding mode	U, Pu, MA	Pu increment(for extended power generation capacity	U decreased, Pu loaded, MA	U compensating decreased amount	Enlarge FR generation capacity without Pu stockpile, Maximum utilization of U resources
Sustainable mode	U, Pu, MA	None	U decreased Pu & MA unchanged	U compensating decreased amount	Maximum and sustainable utilization of U resources, Minimize influence of waste to environment
TRU manage-ment mode(1)	U, Pu, MA	None	U, Pu, MA decreased	U, Pu and MA Compensating decreased amount	Control TRU amount in LWR cycle, Reduce influence of waste to environment
TRU manage-ment mode(2)	U, Degraded Pu	Pu (in Pu-thermal use)	U, Degraded Pu	U compensating decreased amount Degraded Pu	Control Pu amount by utilizing degraded Pu coming from LWR cycle

* Cycle mode concepts shown in the table are only examples. Combination of different indices could be possible, i.e. with or without recycling of MA, elements of MA to be recycled. Furthermore, transmutation of long-lived fission product (FP) might be considered.



Change in the Significance of FBR Development

Initial Term (1966): Pu breeding mode

•FBR introduced to avoid uranium constraints and enforce energy supply capability

•Conducted as a all-out national project by public and private sectors

•Directed to enhance the breeding capability in short-term to produce Pu required for introduction of FBRs

Nuclear Power Nation Plan (2006): Stationary mode (Pu breeding mode in the transitional phase)

•Electricity share of nuclear power expected to be maintained over 30-40% after 2030

•Commercial introduction of FRs targeted in 2050 (MA recycling in future assumed)

•Formulation of a transition scenario (demo. reactor & related fuel cycle facilities in around 2025; Second reprocessing plant in around 2045)

•Performance targets set out in terms of safety, economics, environmental effect, resource utilization efficiency, proliferation resistance, coexistence of LWRs and FRs

Strategic Energy Plan (2014): Steady mode (Option for future power source); TRU burning mode (Pursuing potential for reduction in volume and toxicity of waste)

•Nuclear power recognized as an important base-load power source

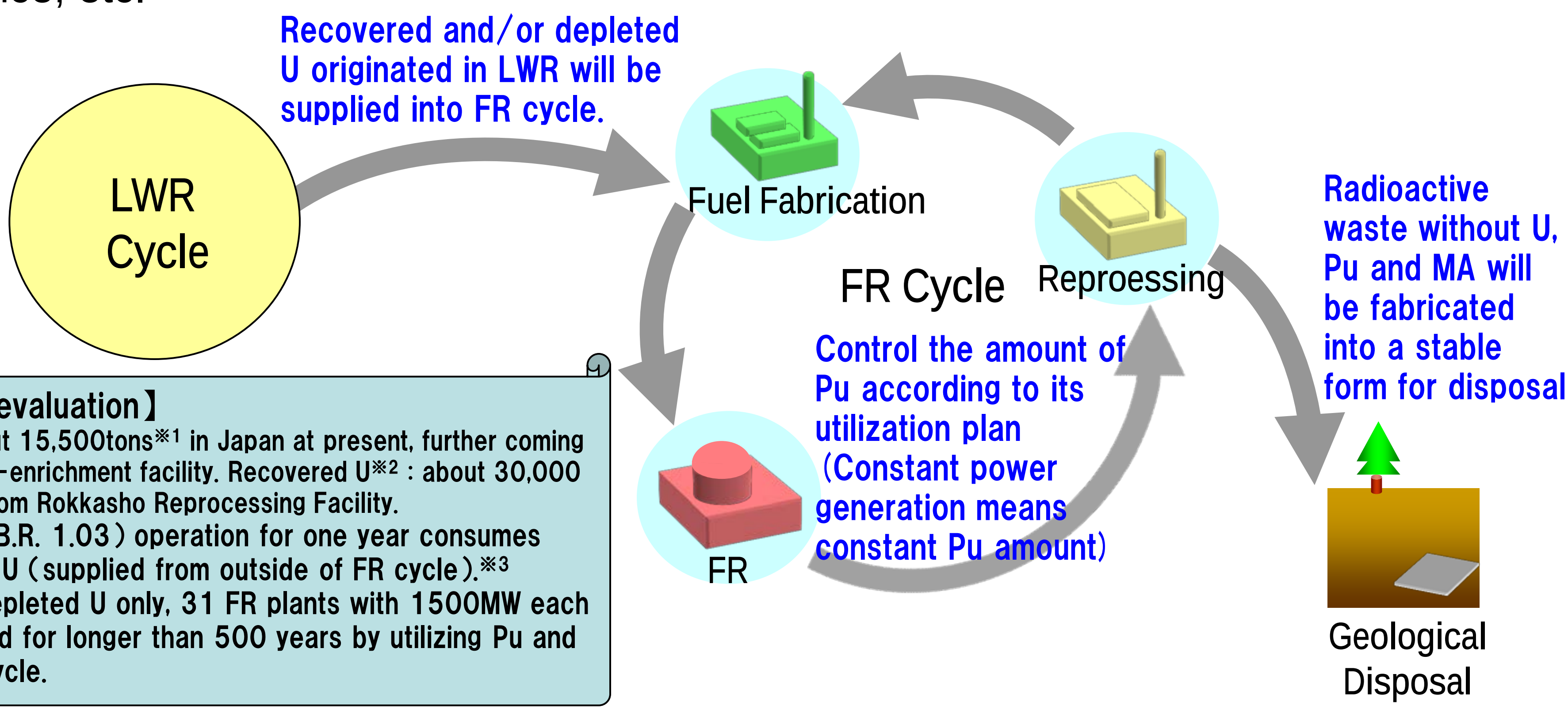
•Fundamentally enhances efforts to solve SF issues and comprehensively promotes development of technologies for reducing volume and toxicity of waste including nuclear transmutation technology

•Promotes a nuclear fuel cycle and aims to compile research results expected in Monju research plan

•Flexibility in the strategy is required for the med- and long-term measures for a nuclear fuel cycle

For future sustainable energy source (Sustainable Mode)

- Generate electricity in FR cycle system sustainably without additional uranium resources
- Minimize the amount of Pu and MA transferred to waste reasonably by their recycling
- Harmonize the need to realize FR system, including safety, economy and proliferation resistance, etc.



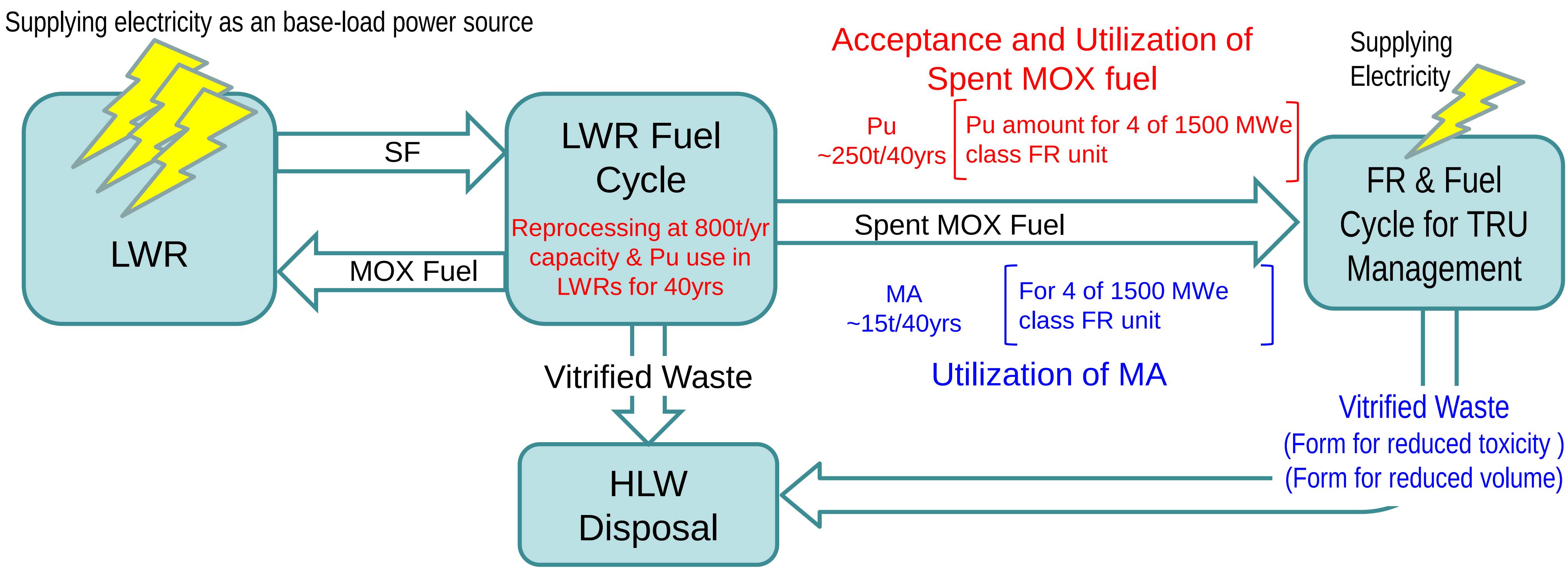
【Example of evaluation】

Depleted U: about 15,500tons※1 in Japan at present, further coming from domestic U-enrichment facility. Recovered U※2 : about 30,000 tons will come from Rokkasho Reprocessing Facility.
1500MW FBR(B.R. 1.03) operation for one year consumes about1.1ton of U (supplied from outside of FR cycle).※3
With present depleted U only, 31 FR plants with 1500MW each can be operated for longer than 500 years by utilizing Pu and MA in the FR cycle.

※1:Amount of depleted U (about 15,514tons) comes from the open source. See (http://www.mext.go.jp/a_menu/kaihatu/gensi/hoshou/1324742.html) .
※2:Amount of recovered U has been estimated by assuming 32,000 tons of SF will be reprocessed in Rokkasho Reprocessing Facility.
※3:Characteristic data for FBR comes from Reference 2-2 in document 1-1 of 28th Commissioners' meeting of Japan Atomic Energy Commission held in July 2009 (p. 39).

For complementing LWR cycle (TRU management mode)

- TRU Management Mode: conduct TRU management in our near-term LWR fuel cycle flexibly in combination with FRs

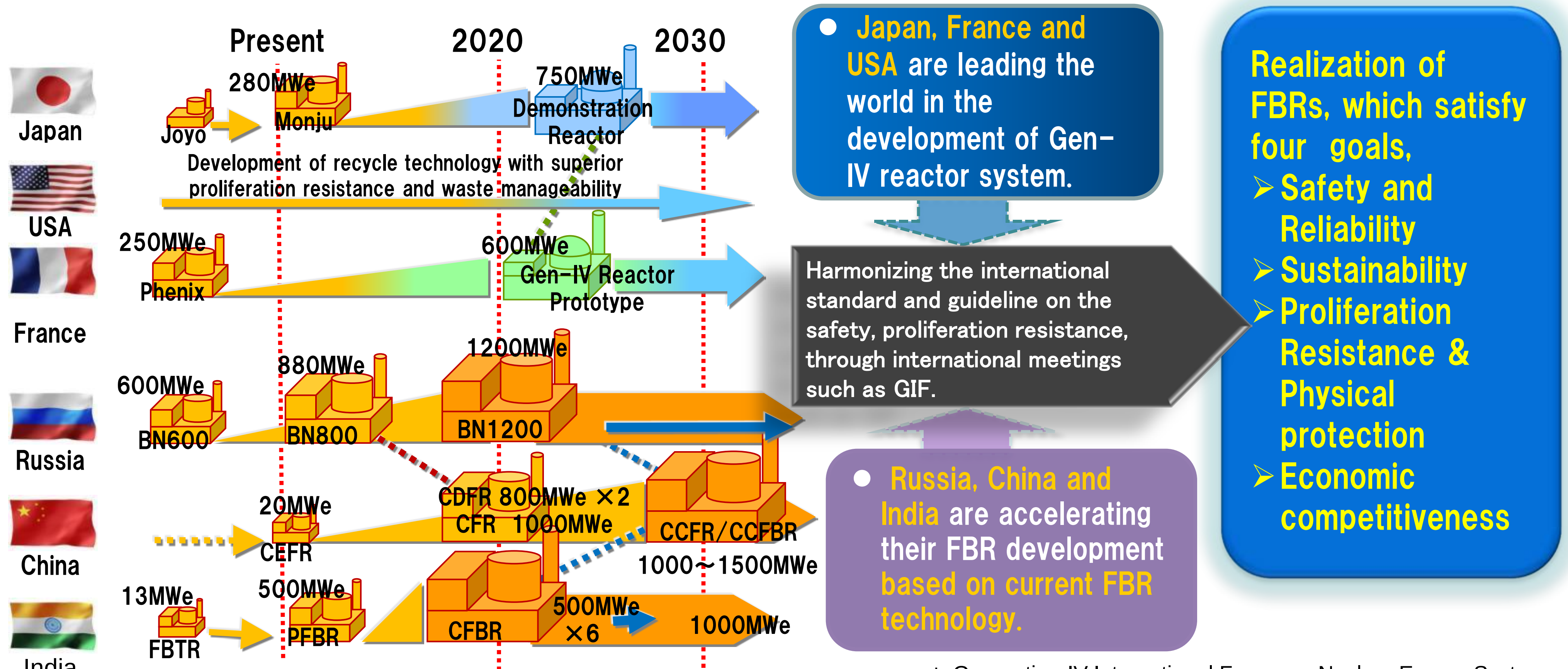


Example of TRU management in a LWR fuel cycle with FRs (Recycling use of SFs from Pu use in LWRs)

(Reference) Amount of nuclear fuel elements was roughly estimated referring to the document 2 in the 10th Workforce meeting of Monju research planning held on July 2013 by MEXT.

Current situation of FR development in the world

- Russia, India, China : Construction and start of operation → Breeding mode, Sustainable mode.
- France : Development plan for a demonstration reactor（ASTRID Project）→ TRU management mode, Sustainable mode.
- USA: Broad range of R&D for management of used fuel → TRU management mode



＊ Generation-IV International Forum on Nuclear Energy System

Global trends for FR development and a Japanese plan

- Fast reactor developing countries are promoting R&Ds for commercial reactors which satisfy the requirements with regard to safety, economy, environmental impact and utilization of resources etc., comprehensively and at a high level.
- In Japan, based on the "Strategic energy plan", compilation of the results of the FBR development, research on the reduction in volume and toxicity of radioactive waste and R&Ds for improving safety will be carried out preferentially, as well as FR development through international cooperation with USA and France etc.

Global trends for FR development

Current

- Establised basic technologies for sodium cooled fast breeder reactor with MOX fuel
- Accumulated experience of pant operation, verified performance
- Progressed new plans

Development subject

- TRU recycling technologies
- International consensus on safety
- Innovative technologies and innovative plant concept

Development Goal(Gen-IV FR)

- ✓ Realize safety, economic competitiveness, minimum environmental impact and resource utilization at a high level
- ✓ Priority depends on status of countries

Japanese plan

Current status of FR technology development

- Establised basic technologies for sodium cooled fast breeder reactor with MOX fuel
- Monju was shutdown during performance test and has been in a long-term shutdown condition

Strategic energy plan

- Compiling the result of the development of the FBR
- Reduction in volume and the toxic level of radioactive waste
- Improvement of the safety of FBR
- FR development through international cooperation

Purpose of development

- ✓ Apply the potential of FR for reduction in volume and toxicity of radioactive waste to the promotion of nuclear fuel cycle and to the settlement of SF issues
- ✓ Reflect the results to future Gen-IV FR development

Progress of R&D (Relationship with Goals)

Start ▽1966 | Nuclear Power National Plan ▽2006 | Strategic Energy Plan ▽2014

Development goal

FBR
Short-term breeding capability

Commercial reactor (Stationary mode)
Safety, Economics, Environmental effect, Resource utilization efficiency, Proliferation resistance, and Coexistence of LWRs and FRs

Gen IV FR

TRU management reactor (TRU management mode)
Environmental effect, Coexistence with LWRs

Development area

- Core, Fuel
- Reactor
- Power Plant

Verification with Joyo
- Breeding capability
- MOX fuel performance
- Na handling technology
- Basic technologies for Na cooled FRs

etc.

High performance, Long life fuel tests and MA tests with Joyo

Verification with Monju
- Core characteristics (partial)

Verification of Pu- & MA-burnig with Monju

Verification with Monju
- Breeding capability
- MOX fuel performance
- Na handling technology
- Basic technologies for Na cooled FRs
- Operation and maintenance technologies
- Performance evaluations

etc.

- Fuel Cycle

Pu Cycle Technology (Degraded Pu, Enriched Pu fuel etc.)

MA Cycle Technology (MA separation., remote fuel fabrication etc.)

Key international cooperation

Gen IV International Forum (GIF)

US-Japan Cooperation (CNWG)

France-Japan Cooperation (ASTRID)

Monju Research Plan

- Monju is positioned as an international research center for technological development, such as reducing the amount and toxic level of radioactive waste and technologies related to nuclear nonproliferation, and results will be compiled as expected in Monju Research Plan. (Strategic Energy Plan)

Interim Evaluation

Overall Evaluation

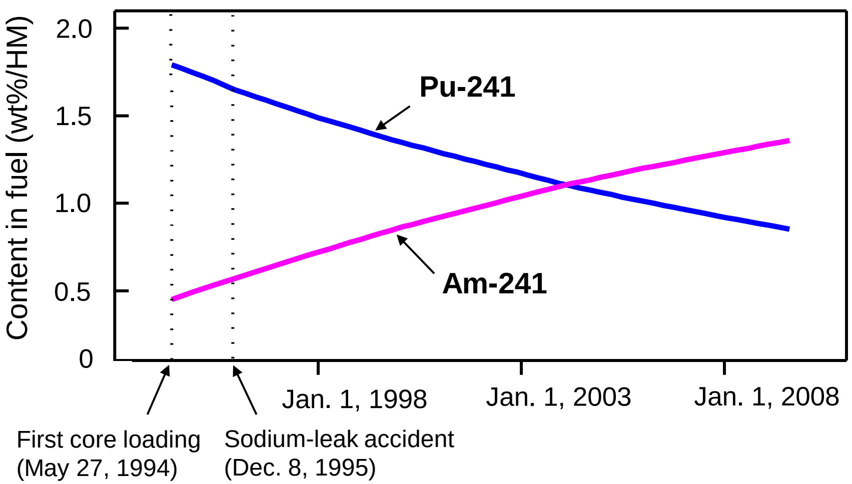
Schedule of Monju	Performance test (40-100% of full power) / Performance test &1st cycle operation	Rated Operation (Initial core) / 2nd cycle - 5th cycle operation		Rated Operation (fr equilibrium core) / From 6th cycle
Compiling the result of the development of the fast breeder reactor Goal: Verification of technical feasibility as a fast breeder reactor plant	➢ Verification of feasibility of generating system	➢ Verification of reliability of generating system ➢ Demonstration of reliability of core fuel	Compiling research results	• Verification of secular change characteristic/integrity of generating system through long-term full scale operation
	➢ In-Service Inspection (ISI) technology development & Preparation for application to real machine	➢ Application		• Verification of secular change characteristic/integrity of a large scale sodium facility
	➢ Improvement of maintenance methodology using experience of facility inspection and addressing machine trouble			
Reduction in volume and the toxic level of radioactive waste Goal: Verification of effectiveness in reducing environmental burdens by the fast breeder reactor/fast reactor system	➢ Verification of initial core characteristic bearing much Am (critical property, output characteristic)	➢ Verification of burning characteristic of initial core bearing Am		• Demonstration of high burning fuel
		➢ Irradiation tests of Am- and Np-bearing MOX fuel		• Irradiation test of initial loading fuel of French demonstration reactor (ASTRID)
	➢ Technology development of MA-bearing fuel fabrication and MA separation ➢ Experiments to verify MA-bearing fuel pellet's irradiation behavior (Joyo)	➢ Irradiation test for long-life materials (Joyo)		• Global Actinide Cycle · Global Actinide Cycle International Demonstration (GACID) experiment
Improvement of the safety of fast breeder reactors Goal: Establishment of safety technology system for fast breeder reactors/fast reactors	➢ Identification of measures to improve safety and elaboration of SA evaluation techniques (Natural circulation heat removal test)	➢ Improvement and demonstration of SAM		
	➢ Establishment of international standard Safety Design Guideline (SDG) ➢ Development of technology to maintain core cooling and terminating event within reactor vessel on SA			

: Conducted at Monju

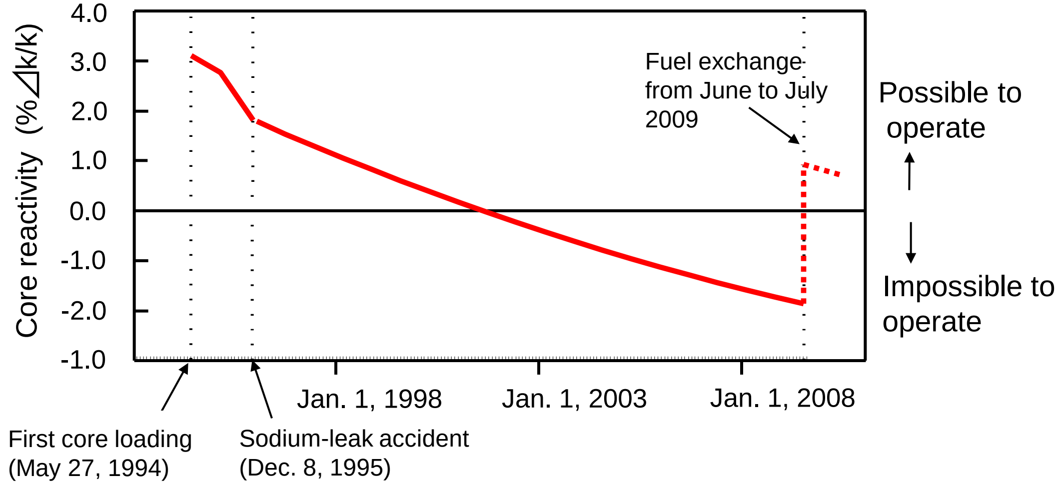
Red items : Conducted or may be conducted in international cooperation

Am-containing Core in Monju

- The main MA element, Am, accumulated in the Monju core during a long shutdown period.
- In the system start-up test in 2010, it was confirmed that the core neutronics characteristics data on the zero-power critical state for the fast reactor core containing 1.5% of Am on an average.
- In the future experiments, the core neutronics and burnup characteristics data are to be obtained in the Am-containing actual core on the operation status.



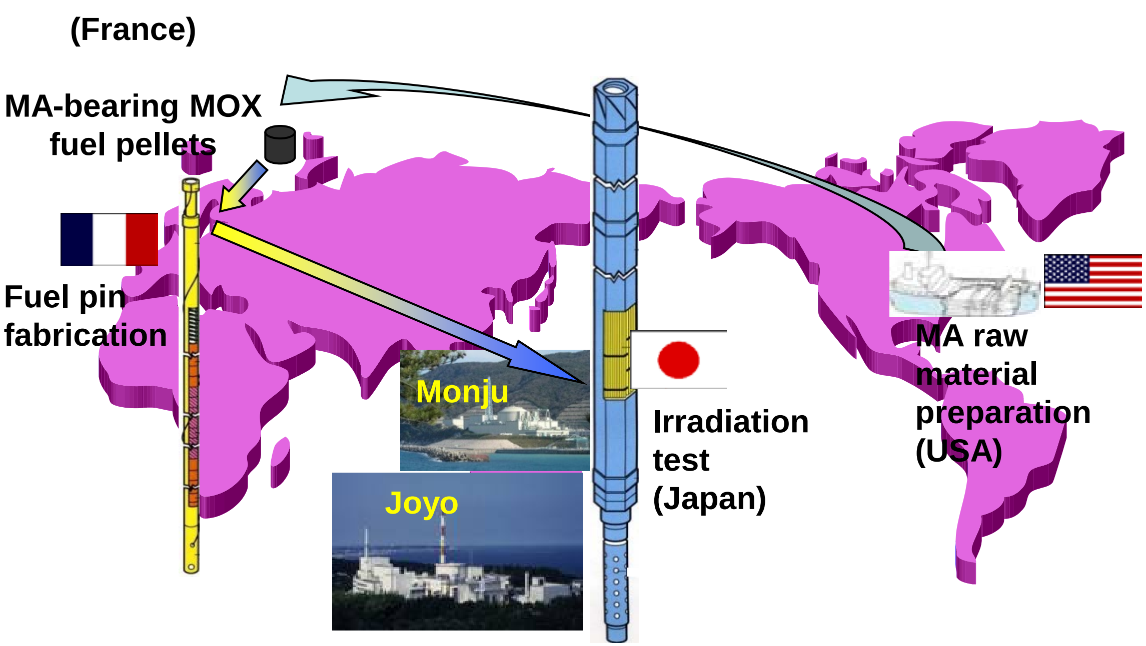
Am-241 creation due to the beta decay of Pu-241



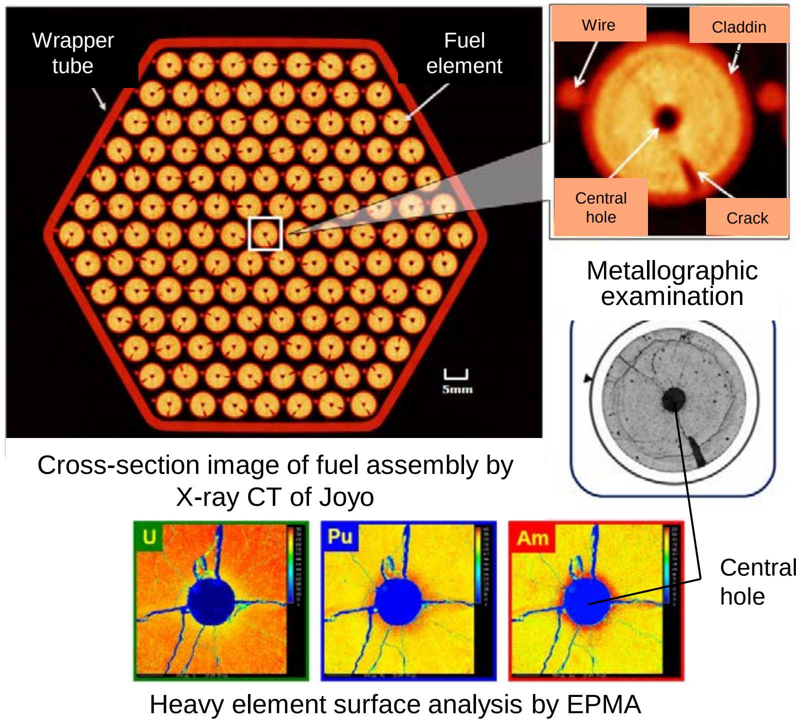
Core reactivity (at the temperature of 180 ℃)

Irradiation Test of MA-bearing MOX Fuel in Monju

- The world's only fast reactor that allows full-scale fuel irradiation
- Fully-equipped with facilities for MA-bearing fuel fabrication and post irradiation tests in Japan
- Irradiation test plans in international cooperation are under consideration
  - Irradiation tests of MA-bearing fuel by the collaboration of Japan, U.S. and France (GACID)
  - MA-bearing fuel tests by the collaboration of Japan and U.S.



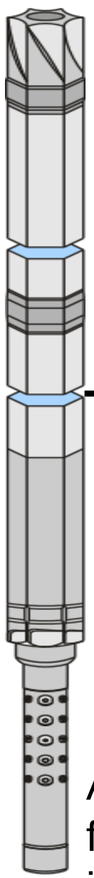
GACID (Global Actinide Cycle International Demonstration) program



Example of post irradiation examination of fuel in Joyo

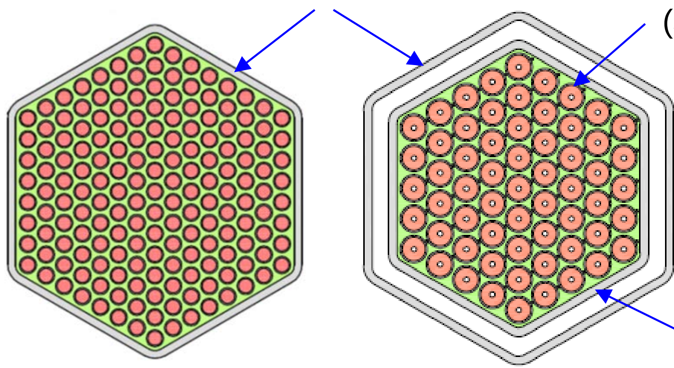
Irradiation Test of ASTRID Fuel in Monju

- CEA in France has expressed the hope to conduct irradiation of simulated MOX fuel assembly and to test the validity of design and performance.
- Details of tests available in Monju are under discussion with CEA and the feasibility of irradiation tests will be evaluated.



Appearance of fuel assembly in Monju

Enlargement of fuel assembly cross-section with MOX fuel



Fuel in Monju

ASTRID Test Fuel
(example under consideration)

One or a few assemblies are assumed to be replaced by ASTRID test fuel within 198 fuels in Monju core

Structure of fuel assembly for irradiation test of ASTRID fuel

Irradiation Test

Protorype Fast breeder reactor "Monju" (Tsuruga)

Post Irradiation Examination (PIE)

Fuels monitoring facility (Oarai)

Conclusion (1/2)

- U, Pu and MA can be utilized as nuclear fuels in the FR system due to its prominent nuclear characteristics. By developing Pu and MA recycling technologies combined with FR, we will have possibility to contribute significant increase of utilization of U resources and decrease of waste volume and its toxicity.
- Then, several countries are steadily developing Gen-IV fast reactors which will satisfy the requirements to the sustainable nuclear power system including safety, economy, environmental impact etc. at a higher level.
- Strategic energy plan in Japan states to compile the results of the FBR development, to do research on the reduction in volume and toxicity of radioactive waste and to perform R&Ds for improving safety as well as to carry out FR development through international cooperation with USA and France etc.
- Such activities will allow us to clarify the effect and feasibility of the reduction in waste volume and its toxicity with the FR system, to contribute promotion of nuclear fuel cycle and settlement of SF issues and to obtain R&D results which can be reflected to future Gen-IV FR.

Conclusion (2/2)

- “Monju” plays a pivotal role in such development. In Monju, integrated demonstration data for MA recycling in FR are planned to be acquired through verifying the characteristics of MOX core containing much amount of Am, one of major MA elements, and irradiation tests with Am-bearing MOX fuel.
- Since “Monju” is highly expected as an international research center with a valuable field for fast neutron irradiation, JAEA will provide maximal effort to respond its mission and such a global expectation.