Nuclear transmutation technology using the Fast Reactor

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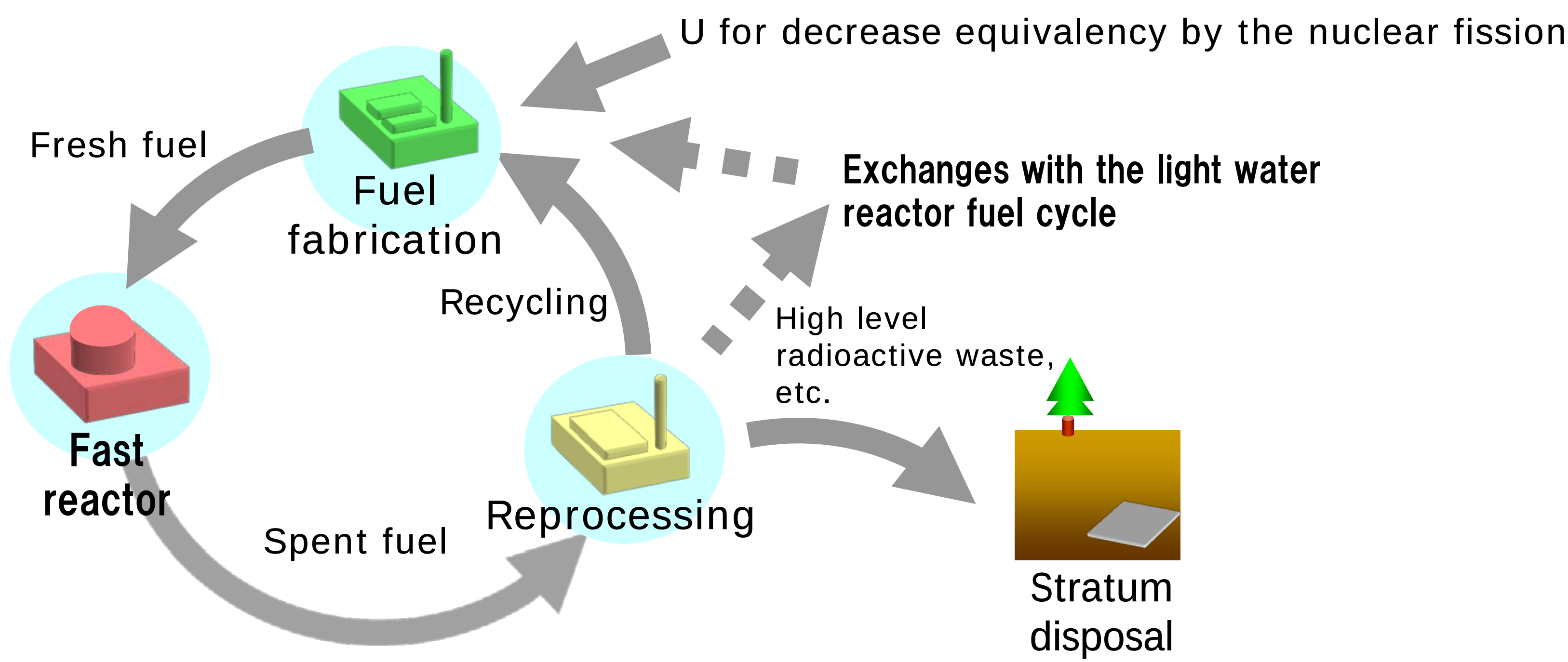
Significance of fast reactor cycle system for radioactive waste disposal

- Pu, MA can be recycled in a system flexibly and Pu, MA included in the radioactive waste to exhaust outside a system can be minimized.
- By the change of core, It is useful to breed Pu and to burn Pu, MA, and the inventory of Pu, MA can be regulated in the system.
- Significance of the fast reactor cycle depending on social needs, the technology development situation
  - Sustained mode
  - TRU management mode（Higher order Pu？、Np/Am？、Total MA？）



R&Ds in the Monju Research Plan as separation/transmutation study

Notes as separation/transmutation study

- Many options are suggested, and there are problems that should be developed in each option and the common research and development problems.
- There are many research and development problems in the wide field, and a long-term study is necessary.
- The fast reactor homogeneous cycle option is advanced as a part of the research and development of the fast breeder cycle for generation and almost finishes fundamental researches stage.
- For a general evaluation, the examination using a series of facilities, such separation, fuel fabrication, irradiation, PIE, is necessary.
- Without enough facilities about the MA separation, MA raw materials procurement is a bottleneck in a series of examination enforcement.

Notes from R&Ds enforcement

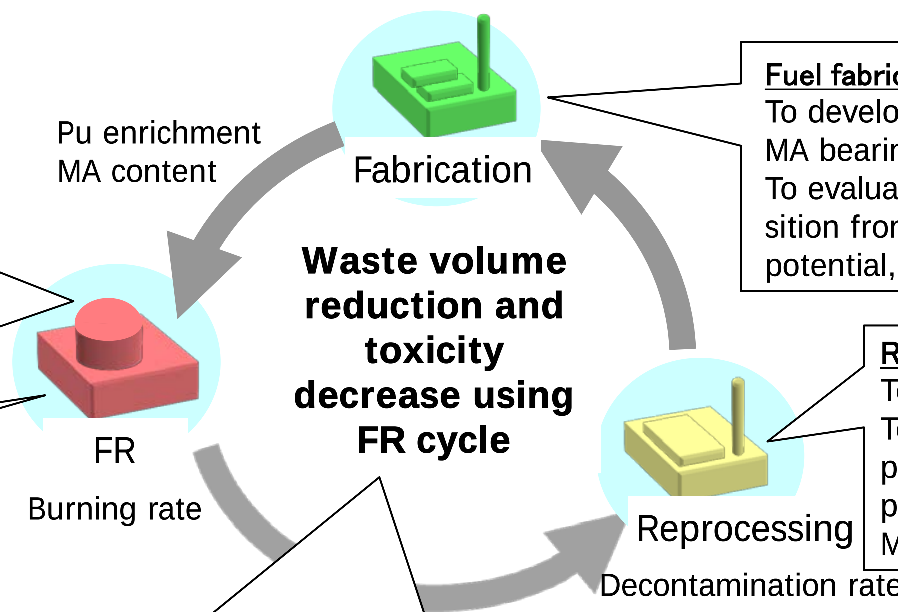
- Full scale irradiation utilizes possible "Monju" to the maximum
- A condition to carry out an examination safely in "Monju“ has to be satisfied, and it is necessary to fit with operation plan.
- Supplement of "Monju" is possible using Joyo.
- Associated cycle facilities (fuel fabrication, PIE, and reprocessing) are available for Am, Np-bearing MOX fuel, but are limited quantitatively.
- Correspondence for the supply of MA raw materials and higher order Pu raw materials is necessary.
  - Utilization of Am-241 generated from Pu-241
  - International cooperation

R&Ds in “Monju” aiming at volume and hazardousness reduction of radioactive waste

- The homogeneous Pu/MA cycle of the Na cooling plutonium-uranium mixed oxide fuel fast reactor is assumed to be a main study option concept, and a technique prospect and the effectiveness of this option at the associate engineering study stage are confirmed with result utilizing existing facilities as soon as possible.
- Confirmation of a characteristic behavior of MA-bearing fuel during irradiation by true scale irradiation in "Monju", increase and decrease inspection of Pu, MA by the nuclear transmutation is carried out with precedence, and supplement it by the systematic examination on a special condition in "Joyo“.
- Using research and development facilities, the prospect evaluation of the cycle technique necessary for the correspondence until an Am homogeneous cycle in the MOX fuel is carried out.
- By international collaboration, expands an irradiation examination plan by utilizing overseas MA raw materials and MA-bearing fuel, and pushes forward the information exchange in each field and a joint evaluation.

Homogeneous Pu/MA cycle in MOX fuel SFR

- Confirmation items to evaluate the technical feasibility and effectiveness of waste volume reduction and toxicity decrease using FR cycle
  - Technical possibility of FR plant concept → To confirm Pu recycle technic using MOX fuel SFR plant
  - Flexibility of Pu utilization → To confirm potential of higher Pu utilization and Pu burning
  - Utilization and burning of MA → To confirm potential of MA bearing MOX fuel
  - MA partitioning and transmutation → To confirm technical perspective of MA partitioning, fabrication, etc.



R&Ds and irradiation tests:
To conduct systematic irradiation tests of MA bearing MOX fuel and high enriched Pu fuel.
To obtain the knowledge about the fuel performance and transmutation property

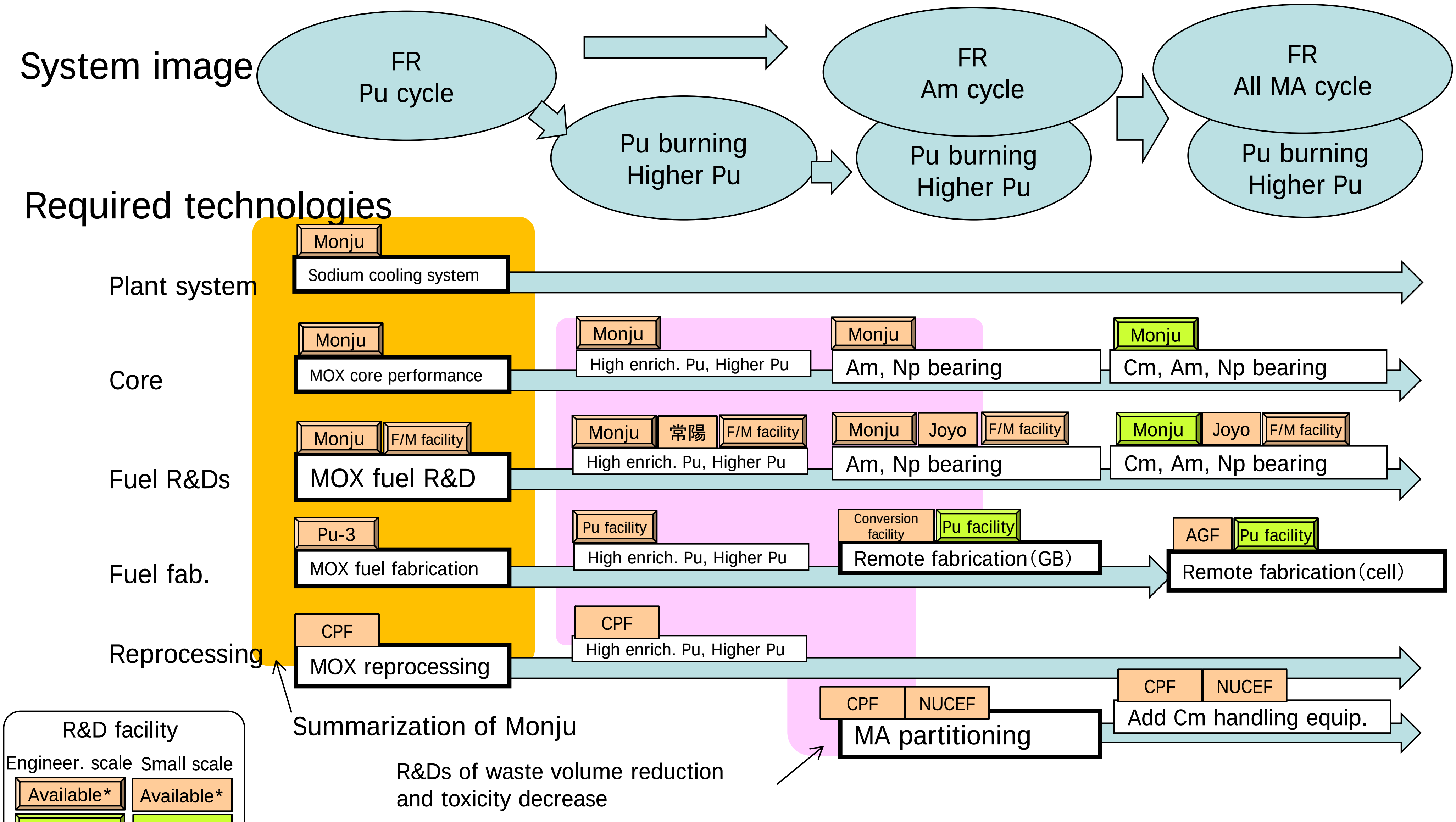
Core performance and system:
To demonstrate Pu cycle using MOX fuel SFR on engineering scale based on data from performance tests and operation of Monju.
To evaluate performance of MA bearing fuel core and select the core concept.

Fuel fabrication:
To develop remote fabrication technology of MA bearing MOX fuel, etc.
To evaluate possible range of TRU composition from technical feasibility, economic potential, etc.

Reprocessing
To develop MA partitioning process.
To evaluate feasible process and it's performance from reprocessing and partitioning properties of MA bearing MOX fuel, etc.

Total system evaluation:
To select a promising system concept from technical feasibilities of each field
To confirm effectiveness of waste volume reduction and toxicity decrease

Cycle concept and test scale considered in Monju project



- It is necessary to prepare test equipment.

R&Ds of waste volume reduction and toxicity decrease in Monju project

	R&Ds utilizing "Monju"	Basic technology necessary for system concept realization	Basic research
① Fuel fabrication technology	◎ Fabrication of irradiation test fuels	○MA−MOX pellet fabrication ○Advanced fabrication process ○R&Ds on simplified pelletizing method ○R&Ds on remote fabrication equipment	○Measurements of funda−mental material properties ○Preparation of database ○Simulation technique
② Fuel R&Ds and irradi-ation tests	◎ Design of irradiation test fuels ◎ Irradiation tests in Monju and Joyo (including PIE)	○R&Ds on evaluation techniques of fuel design and behavior ○ Long−lived core material ◇ FP target ◇ MA target	
③ Core perform-ance and plant system	◎ Performance tests and operation data of Monju	○R&Ds on core performance evaluation technique ○Study on core concept	○Differential measurements of nuclear data ○Integral measurements of nuclear data
④ Reprocessing technology	◎ Reprocessing tests using PIE specimens	○R&Ds on MA partitioning process ○Base technologies on solution and extraction	○R&Ds on new extractant

Total system evaluation

◎ To evaluate the technical feasibility and effectiveness of waste volume reduction and toxicity decrease

◎, ○: Issues for homogeneous cycle, or common issues of homogeneous/heterogeneous cycles

◇: Issues for heterogeneous cycle

① Fuel fabrication technology（Resarch plan）

Experience and current technology

In Tokai Pu-facility, 18 t-HM of FR MOX fuel has been fabricated

【Range of TRU comp.】
- ･Pu30%
- ･Am2% (from ^{241}Pu decay)
- ･Pu from LWR UO_2 fuel

【Plant concept】
- ･Installation in GB
- ･Remote auto-operation
- ･Direct maintenance

R&Ds, base technologies, fundamental studies

Fabrication of irradiation test fuel

Pellet fabrication process tech-nology
- ･MA bearing rate increase
- ･Pu enrichment increase

Advanced fabrication process
- ･Measures for heating
- ･Inspection tech. under high radiation dose
- ･Dry reprocessing tech.

Expanding range of TRU composition

Fundamental material property Measurement, research

Remote fabrication

Development of process appro-priate to remote fabrication
- ･Simplified pelletizing method

Improvement of maintenance and repair

Remote fabrication equipment technology

Technologies required to realize the concept

Fabrication of homoge-neous MA cycle MOX fuel

【Range of TRU comp.】
- ･Pu40%
- ･MA5%
- ･Pu from LWR MOX fuel

【Plant concept】(*)
- ･Installation in cell
- ･Remote auto-operation
- ･Remote maintenance

(*) There is possibility of GB and direct maintenance depending on MA composition.

①Fuel fabrication technology (Development of automated and remote fabrication)

Development of fabrication technology(Present issue in near future)

- Development of fabrication process suitable for automated and remote fabrication(Simplified Pelletizing Process)
- Improvement of automated and remote fabrication facilities

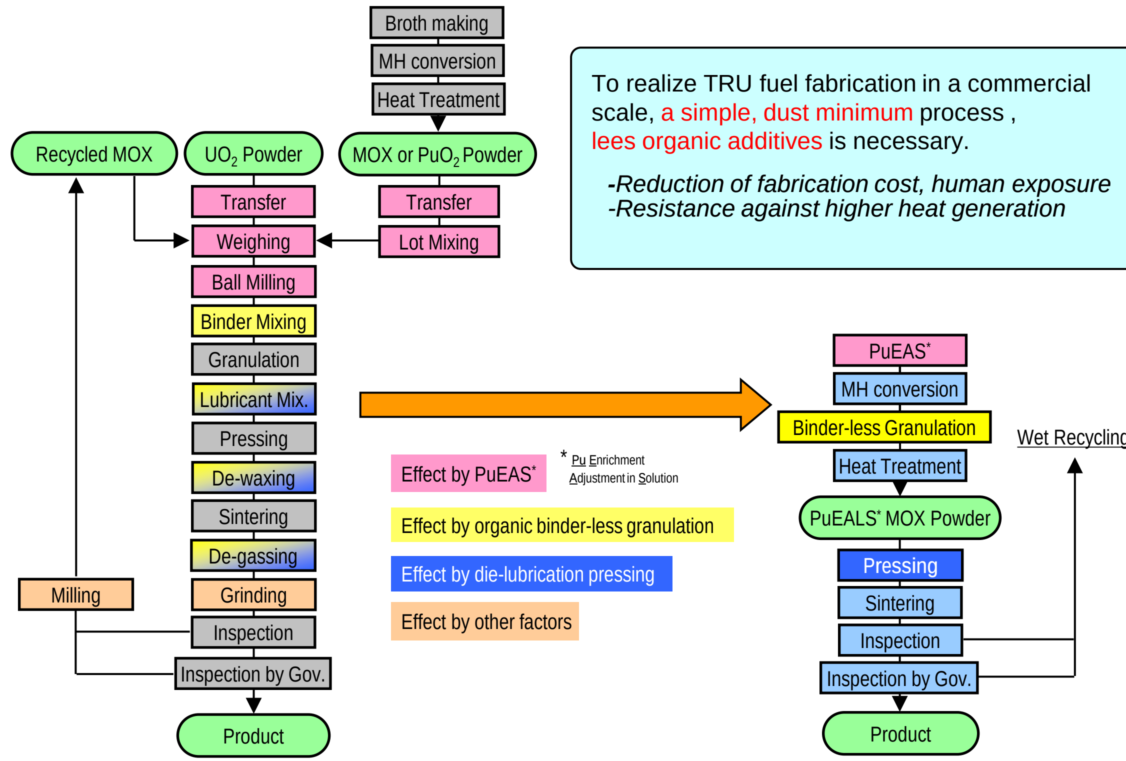
Apply to Am-Bearing MOX fuel fabrication

Fully automated and remote fabrication facilities(Long term in future)

- Realization of remote maintenance
- Confirmation of Curium influence

To realize TRU fuel fabrication in a commercial scale, a simple, dust minimum process , lees organic additives is necessary.

-Reduction of fabrication cost, human exposure
-Resistance against higher heat generation

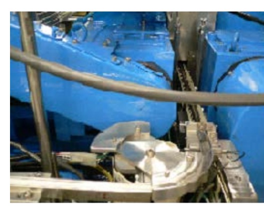


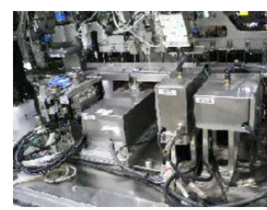
Present MOX Pellet Fabrication Process **Simplified Pelletizing Process**

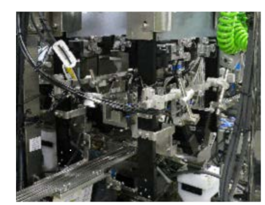
Development of fuel fabrication process for automated and remote fabrication


Molybdenum plate


Parts feeder


Grinder


Diameter and weight test


Appearance inspection

Flow of the pellet in the equipment of pellet grinding and inspection process that expected reliability improvement by solving malfunction of the pellet conveyance

②Fuel development and irradiation examination (Research plan)

Results and Current technology

○Loaded MOX fuel assemblies
- Joyo 614 assemblies
- MONJU 287 assemblies

~700 W/cm,~144 GWd/t

○Post irradiation examination
- Joyo; 103 pins,
- Irradiated abroad; 49 pins

○MA-MOX fuel irradiation tests
- Joyo（Am-1, B14）
- France（SUPERFACT）
- U.S.（AFC）

○High Pu content MOX fuel irradiation tests
- France（CAPRIX1）
- U.S.（HEDL/ANL 08）

○Target fuel
Concept study stage

Research and development, fundamental technology, fundamental researches

Nuclear data

Research of physical properties

Confirmation of irradiation behavior of MONJU fuel

Evaluation of irradiation behavior and method of fuel design

Accumulation of MOX fuel irradiation data and development of fuel design method

Irradiation test（M1-4, J1-4）
- Helium effec
- Cladding inner surface corrosion
- power-to-melt ,etc.

Fuel composition influence of irradiation behavior

High burnup fuel material

Improve of fuel performance

Development of FP target

Heterogeneous cycle, Shortened life of FP

Necessary technology of the concept realization

【Homogeneous cycle】

○Development of fuel design method based on irradiation test results of demonstration scale MOX fuel assembly

○ Extensive fuel composition
（Pu40%, MA5%,Pu recovered from spent LWR-MOX fuel)

○Improve of fuel performance

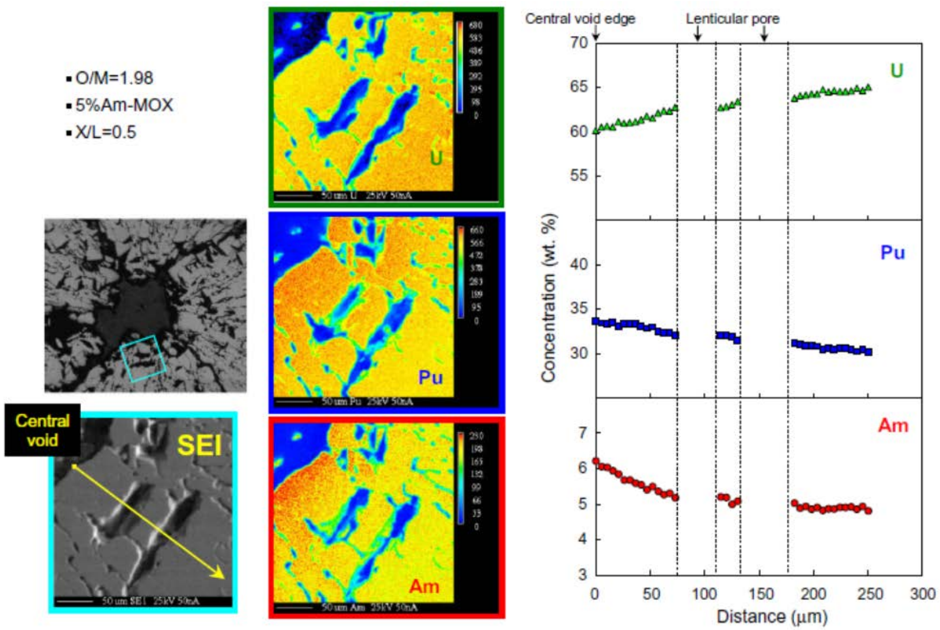
○Evaluation of radioactive waste reduction effect

【 Heterogeneous cycle 】

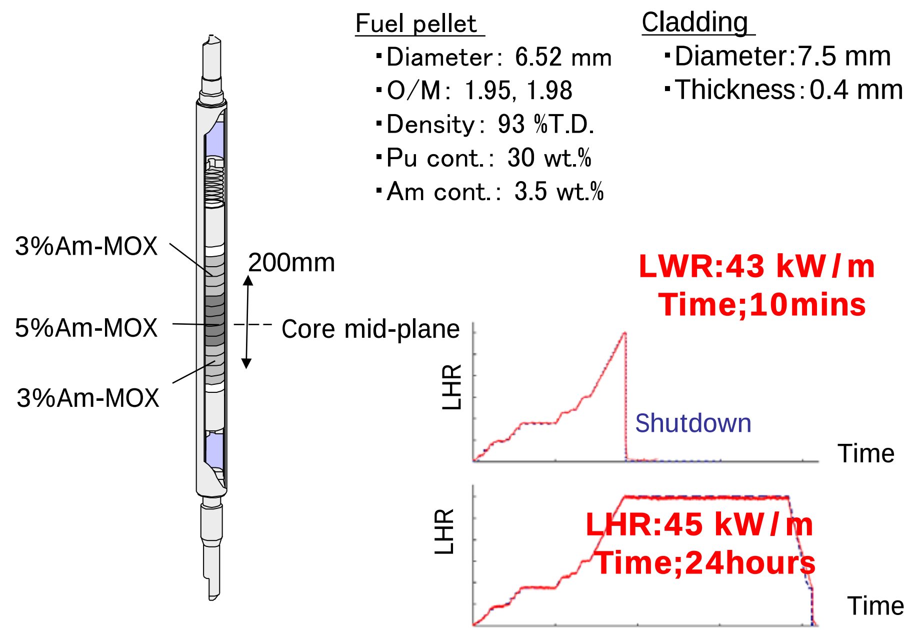
○Target life time, evaluation of heterogeneous cycle, development of heterogeneous cycle tecnology

②Development of MA-MOX fuel and irradiation examinations（Am-bearing MOX fuel irradiation）

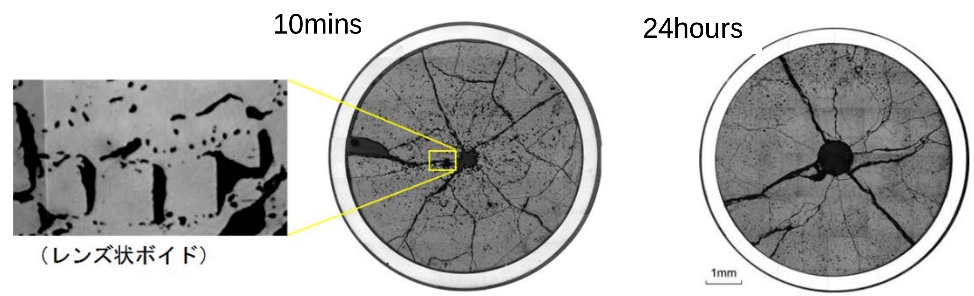
- In a Joyo short term irradiation examination of the MOX fuel which contained up to 5% of Am, the Am behavior data at BOL were acquired and the Am content effect was confirmed to be a small.
- In future, the range of burnup and linear power of the data would be expanded, and by true scale irradiation in Monju, it will be confirmed that the Am-bearing MOX fuel could be used through the operation periods without any problem.



Distribution of U, Pu and Am concentration around central void (Am-1 irradiation test)



Speciation and irradiation condition of Am-1 irradiation test fuel



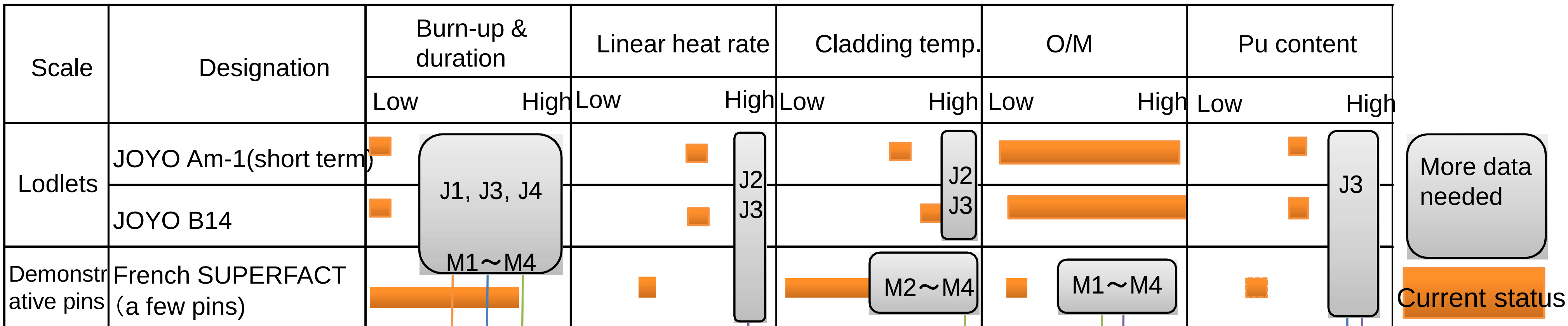
Pellet ceramography (Am-1 irradiation test)

* Central void is extended with irradiation progress.

②Fuel development and irradiation examination (Irradiation in Monju and Joyo）

Test code	Test	Achievement	Outline
M1	Irradiation test MOX fuel assemblies (with accumulated Am)	Validation of Monju fuel design. Confirmation of steady-state irradiation behavior and helium effect for Am-bearing MOX fuel.	Irradiation tests on MOX fuel assemblies in which Am storage Early stage burnup and medium burnup
M2	Irradiation test of MOX fuel assembly with degraded Pu	Confirmation of irradiation behavior and helium effect of degraded Pu-MOX fue.l Demonstration of usage of degraded Pu in FR.	Irradiation tests on MOX fuel assembly with degraded Pu recovered from spent Fugen-MOX fuel
M3	Irradiation test of MA-bearing MOX fuel	Confirmation of irradiation behavior for a real-scale MA-bearing MOX fuel pin	Irradiation test on MOX fuel assembly including MA-bearing MOX fuel pin with low density fuel
M4	Irradiation test of MA-bearing MOX fuel [GACID-1]	Confirmation of irradiation behavior for a real-scale MA-bearing MOX fuel pin (different from M3 in fuel specification and fuel fabrication procedure)	Irradiation test by international collaboration. MA raw material is supplied from US and MA-bearing MOX fuel pins will be fabricated in France. The MA-bearing MOX fuel pin will be installed in MOX fuel assembly in Japan and irradiated in Monju.
J1	Am-1 long-term irradiation	Confirmation of burnup dependence of cladding corrosion for MA-bearing MOX fuel pin	Continuous irradiation of 5%Am-bearing MOX fuel pin and 2%Am-2%Np-bearing MOX fuel pin
J2	Am-1 short-term high power irradiation	Confirmation of element redistribution and restructuring of MA-bearing MOX fuel at the beginning of irradiation	Higher power irradiation as the 2nd examination of the previous short-term irradiation od 5%Am-bearing MOX fuel pin and 2%Am-2%Np-bearing MOX fuel pin
J3	Systematic irradiation examination of MA-bearing high Pu-MOX fuel	Confirmation of the effect of fuel composition and fuel specification on irradiation behavior at the high Pu content	Power-to-melt (PTM) at the beginning of irradiation and long-term steady-state irradiation as parameters of Am, Np, Pu content, O/M ratio, pellet density, pellet/cladding gap size
J4	Lead irradiation of GACID-1	Confirmation of the effect of pellet density and the scale-effect by comparing with M3	Irradiation of MA-bearing MOX fuel with the same fuel specification as M3 except pellet density

②Fuel development and irradiation examinations （MA-MOX fuel evaluation plan）



①**Acquisition of MA transmutation data** Necessity for obtaining each MA integral data of transmutation in reactors

②**Helium effect** Necessity for the influence of He gas increase inseparable from MA-containing and highly-Pu-containing fuel (especially demonstrative fuel pin)

③**Prevention of fuel failure** Necessity for the verification of the behaviour of cladding inner corrosion taking O/M dependence into account in the range of high burn-up and at high cladding temperature

④**Prevention of fuel melting** Necessity for the verification of the behaviour and fuel melting under high LHR in consideration of the decrease of the melting point and the thermal conductivity attained with either MA content and high Pu content. It is important to verify the O/M dependence in consideration of both the redistribution of Pu and MA and its sensitivity to thermal conductivity.

⑤**Fuel cycle technology** Necessity for the evaluation of realization of both the fuel fabrication technology of MA-containing and high Pu containing MOX and reprocessing technology, and the processes of MA-separation and recovery.

③Core properties and core system（Research plan）

Experience and current technology

【MOX core】
〇Core-loaded MOX fuel assemblies of 614 for JOYO and 287 for MONJU
・LWR-Pu has been used in JOYO

【Na-cooling power plant】
〇accumulation of operational performance records every nation
〇MA homogeneous cycle practical plant concept

【Transmutation core conceptual study】
〇Much of MA-homogeneous cycle core design
〇Little of Pu-burner design

R&D・Development of fundamental technologies・Fundamental studies

Nuclear data measurement

MONJU performance test, operation data

Irradiation tests (nucleus analysis)

Reprocessing test for irradiated fuel

Methodology of evaluation of core properties

Real MOX core properties, Pu/MA in-core consumption properties

MONJU performance test, operation and maintenance data

Operational experiences of power plant

Pu/MA burner concept study

Transmutation core concept

Required technologies to realize the concepts

【MA-MOX core】
〇Evaluation of the properties of homogeneous cycle core and fuel-burning, and core safety
〇Integral verification for transmutation

【Na-cooling power plant】
〇Performance verification and accumulation of the results of operation and maintenance of MONJU

【Transmutation core conceptual study】
〇Narrowing down the each concepts

③Core properties and core system (Research procedure)

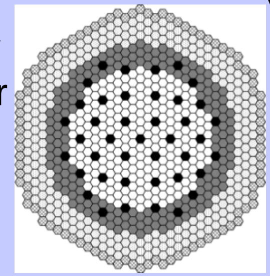
R&Ds utilizing "Monju"

◎MONJU performance test, operation data
- Neutronics of MOX core containing degraded Pu and Am
- Temperature and burn-up properties data available only in actual core

◎Irradiation tests of MONJU & JOYO
- PIE data of high-Pu content, degraded Pu, MA-MOX fuel (fuel design evaluation data, variation of isotopic composition)

Basic technology necessary for system concept realization

○Core conceptual study
- Study for Pu/Am burner adaptable to a nuclear energy scenario



- Core safety evaluation: Evaluation of the applicability of passive shutdown system and the change of things at severe accidents

○Core-system conceptual study
- Effect evaluation to plant
- Study how to treat high power fuel off core

Basic research

○Nuclear data measurement
- High-precision measurement of MA capture cross sections for fast neutrons

○Nuclear data integral measurement
- Sample irradiation of degraded Pu and MA at JOYO (Isotopic composition change)
- Development for high-precision measurement

○Understanding of Pu・MA burner properties (5 years) (making use of MONJU performance test and JOYO irradiation test data)
○Materialization of Pu・MA burner system (10 years) (making use of the MONJU operation and irradiation data)

④Reprocessing technique（Research plan）

R&Ds・Basic Technology Development・Basic Research

Results and Current Technique

【MOX fuel reprocessing】
・Reprocessing examinations for MOX fuels from 72 Joyo fuel pins and 11 foreign test fuel pins（MA concent: ～1.5%）

【MA separation】
・Choice of extractant （TODGA,R-BTP）
・Am,Cm response rate （more than 95%）
・FP decontamination factor （roughly more than 100）

Reprocessing examination of Monju and Joyo irradiation test fuels

Basic research of dissolution/extraction
・Dissolubility, Residue properties
・Extractability, Solvent depletion

Reprocessing properties of MA-MOX, High Pu-MOX fuel

New extractant creation research

Data accumulation of MA separation process

Development of MA separation process
・Extraction chromatography
・Solvent extraction

Technique necessary for concept realization

【MA-MOX/High Pu-MOX fuel reprocessing】
・Flow-sheet actualization

【Dissolution・Extraction】
・Dissolubility, Residue behavior
・Extractability

【MA separation】
・MA response rate
・Decontamination performance （DF）
・Waste fluid quantity
・Separation flow-sheet

④Reprocessing technique（Research procedure）

R&Ds utilizing "Monju"

"Monju"

"Joyo"

Reprocessing examination by using PIE samples

・Confirmation of separation performance with high MA-bearing MOX fuel (Reprocessing waste fluid of “Monju” fuels)

Basic technology necessary for system concept realization

"Joyo"

CPF(Nuclear Fuel Cycle Engineering Laboratories)

Base data acquisition

・Evaluation of created extractant
・Optimization of the carrier structure
・Improvement with the examination
・Sludge behavior, Dissolution behavior, Extraction/Separation behavior (cold, Reprocessing waste fluid of “Joyo” fuels)

Basic research

NUCEF (Nuclear Science Research Institute)

New extractant research

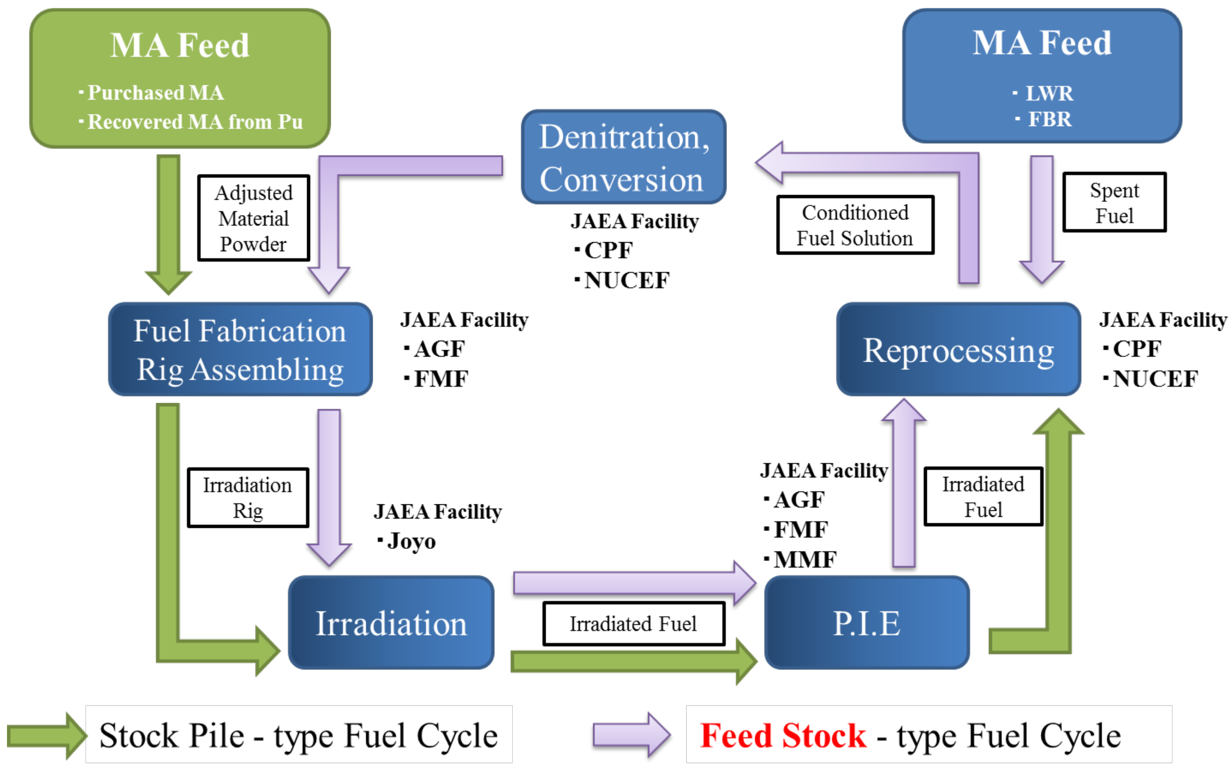
MA extractant creation
・Collection agent of MA/Ln
・Separation agent of MA/Ln
(cold, Tracer RI etc.)

○Data accumulation of MA separation process, Reprocessing properties of MA-MOX・high Pu-MOX fuel (about 5-6 years)
・Construction of MA separation/collection flow-sheet
・Understanding of dissolution/separation performance of high Am・high Pu-bearing MOX fuel
・Base data acquisition to develop the simulation code

○Verification of reprocessing flow-sheet of MA, high Pu-bearing MOX fuel by using the spent fuels (about 10 years)

Recycle Examinations with Feed Stock from Spent fuels

- The MA raw materials used for the irradiation examinations carried out and to be used for the irradiation examinations in the Monju research plan are limited to Np and Am purchased from the foreign countries or Am collected from a Pu product, and the knowledge such as the material income and expenditure in each process to reach the fuel fabrication from separation, the influence of the FP is not provided until now.
- The plan that it is small amount, but by utilizing existing facilities, the processes of the series of the examination after separation from spent fuel, conversion, fuel fabrication, irradiation and PIEs will be carried out.（SmART：Small Amount of Reused fuel Test)



Summaries

- By a report of the result of the fast breeder development in "the Monju research plan", recycling of the nuclear reactor grade Pu with the Na cooling plutonium-uranium mixed oxide fuel fast reactor would be demonstrated on "Monju" core scale.

- As a R&Ds aiming at volume and hazardousness reduction of radioactive waste in "the Monju research plan", the data of the Am-rich the MOX core would be acquired in "Monju“, the examinations of fuel fabrication, irradiation, PIEs and reprocessing concerning the homogeneity cycle of higher order Pu and Am and the Np would be carried out at a level to be able to foresee a true scale, and the effectiveness about the volume and hazardousness reduction of radioactive waste of the system for a Na cooling plutonium-uranium mixed oxide fuel fast reactor cycle would be confirmed. R&Ds for dissolution, the extraction flow sheet construction would be pushed forward while cooperating with R&Ds of the new extractant about the MA separation technology.

- Actions to get the knowledge such as the material incomes and expenditures in facilities for a cycle using existing facilities would be pushed forward by examining the series of MA separation and collection from spent fuel, conversion, fuel fabrication, irradiation and PIEs.

- Irradiation examinations in Monju, production of the examination fuel, raw materials procurement, and PIEs would be performed as international collaboration, and concerning the common technique with ADS cycles such as MA separation technology development, the remote fuel fabrication technology development, and basics base research, the cooperation with the research activities except the Na cooling plutonium-uranium mixed oxide fuel fast reactor would be planned.