MINOR ACTINIDE BEARING FUEL STUDY ACTIVITIES IN JAPAN FOR HOMOGENEOUS TRU RECYCLING FAST REACTOR SYSTEM

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MINOR ACTINIDE BEARING FUEL STUDY ACTIVITIES IN JAPAN FOR HOMOGENEOUS TRU RECYCLING FAST REACTOR SYSTEM

- FaCT project : FR cycle development program in Japan
- Fuel of the FaCT project
- Monju and its fuel with Am
- Am bearing fuel study
- Further development

FR Cycle Development Program in JAPAN

2005 | 2010 | 2015 (JFY) | 2025 | 2050

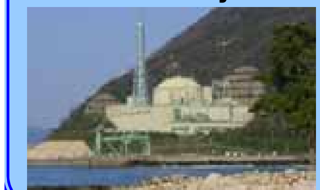
Feasibility Study
(JFY 1999-2005)
Identify The Most Promising Candidate Concept

C&R

Review & Basic Policy by MEXT &AEC

Experimental FR "Joyo"

R&D at Prototype FBR "Monju "



Fast Reactor Cycle Technology Development Project (FaCT)

Decision of Innovative Tech. (2010)

Approved Confirmation (2015)

R&D of Innovative Technologies

Conceptual Design of Commercial & Demonstration FR Cycle Facilities

R&D at "Monju "
- Demonstrating its Reliability as a Operation Power Plant
- Establish Sodium Handling Tech.

2015
Production of the Conceptual Designs of Commercial and Demonstration FR Cycle Facilities with R&D Programs

Basic Design & Construction

2025
Operation Start of Demonstration FR & its Fuel Cycle Facility

Validation of Economy & Reliability

2050
Commercially Introducing of FR Cycle Facilities

Key issues
- *Safety and Reliability*
- *Sustainability*
- *Economic Competitiveness*
- *Nuclear Non-Proliferation*

◆**Cooperation with related Organization** ◆**International Cooperation（GNEP, GEN-IV, INPRO etc.）**

FaCT Project : Main Features of JSFR

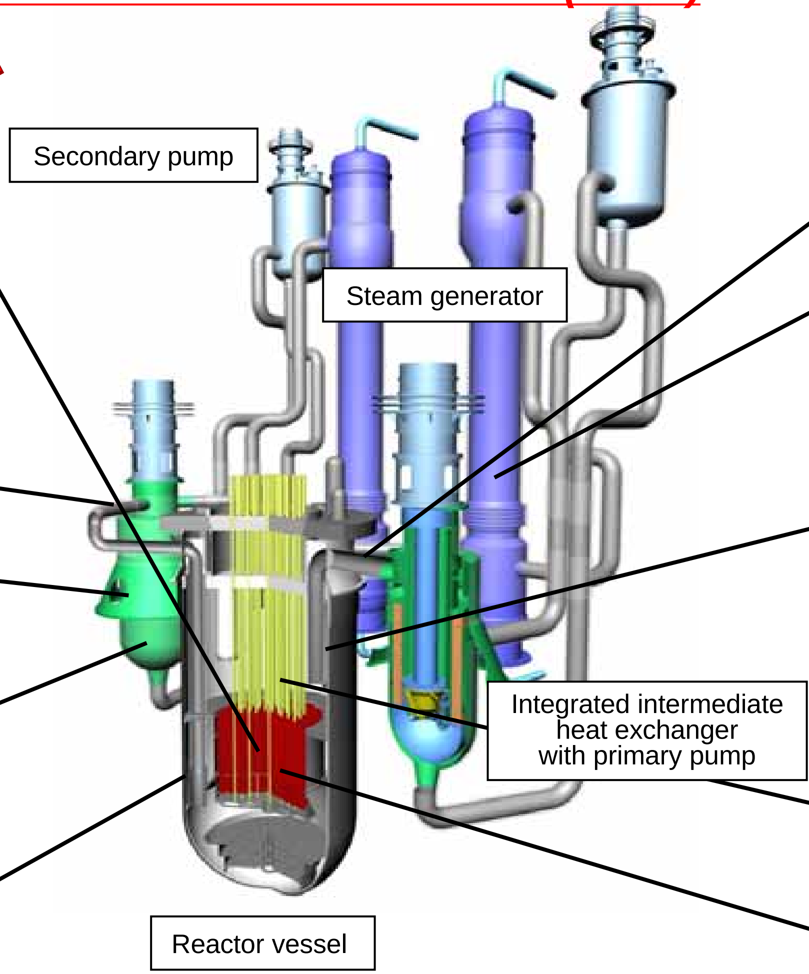
- 1,500 MWe large-scale loop-type SFR with MOX fuel,
- Innovative technologies for enhancement of reactor core safety, high economic competitiveness and countermeasures against specific issues of sodium

Japan Sodium-cooled Fast Reactor (JSFR)

ODS steel cladding tube for high burnup + **MA bearing fuel**

Reduction in material amount and building volume through the adoption of innovative technologies

- 2-loop arrangement for a simplified plant system
- High-chromium steel structural material for a shortened piping length
- Integrated intermediate heat exchanger with primary pump for a simplified primary cooling system
- Compact reactor vessel



Prevention of sodium chemical reaction

- Complete adoption of a double-walled piping system
- Steam generator with straight double-walled heat transfer tube

Inspection and repair technology under sodium

Enhancement of reactor core safety

- Passive reactor shutdown system and decay heat removal by natural circulation
- Recriticality free core concept during severe core damage

FaCT Project : Main Features of Fuel Cycle System

- Low decontaminated TRU fuel → Simplify process without U/Pu partitioning and purification

- Adjusting Pu content in solution → Reduction of powder treatment processes

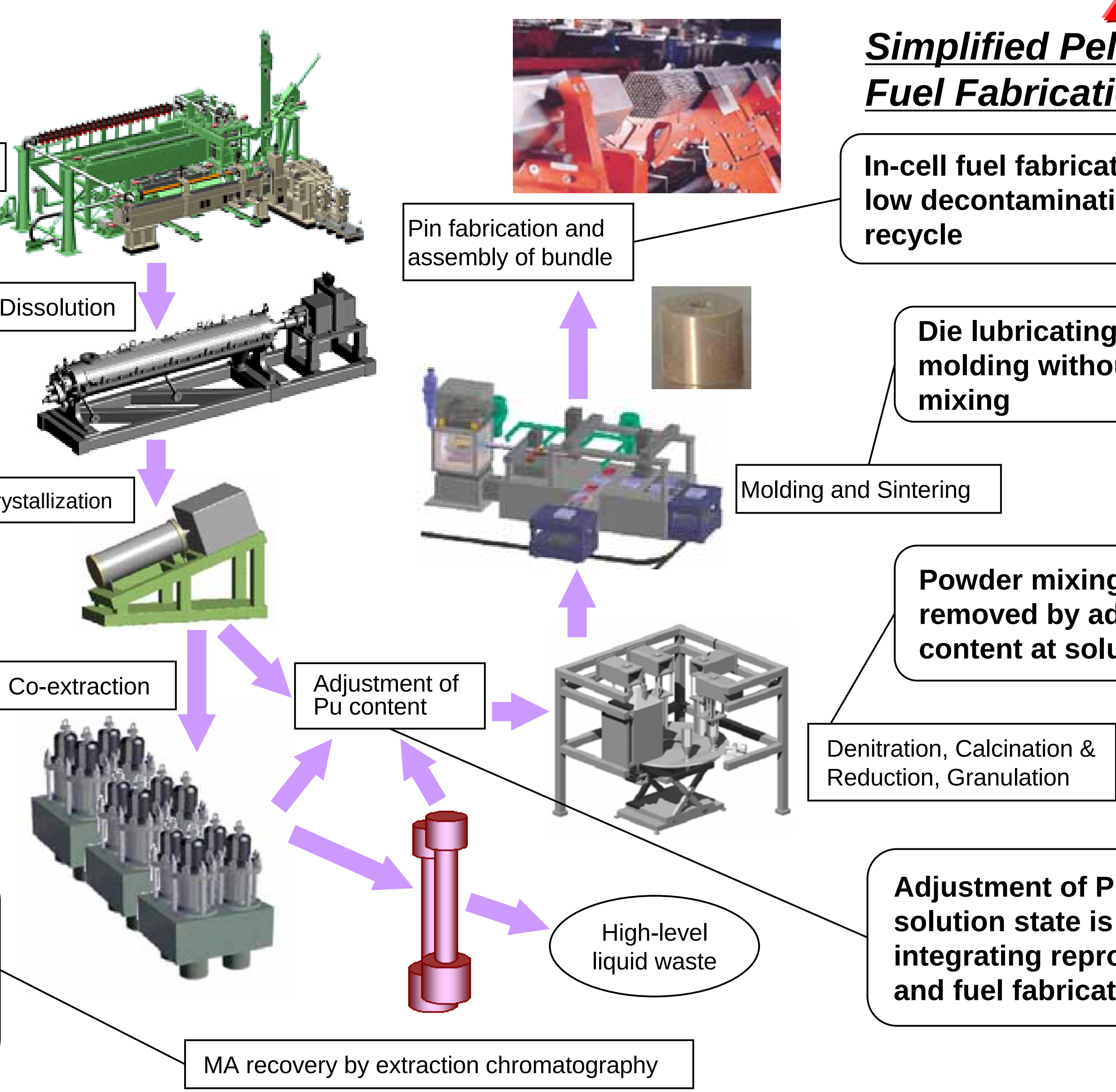
Advanced Aqueous Reprocessing

U crystallization process that can dramatically reduce the extraction process flow

Single cycle co-extraction of U, Pu and Np with low decontamination

No Purification processes of U and Pu because the recovery in low-decontamination process is permitted.

MA recovery by using extraction chromatography that allows the use of compact components and a lower amount of secondary waste



Simplified Pelletizing Fuel Fabrication

In-cell fuel fabrication enabling low decontamination and MA recycle

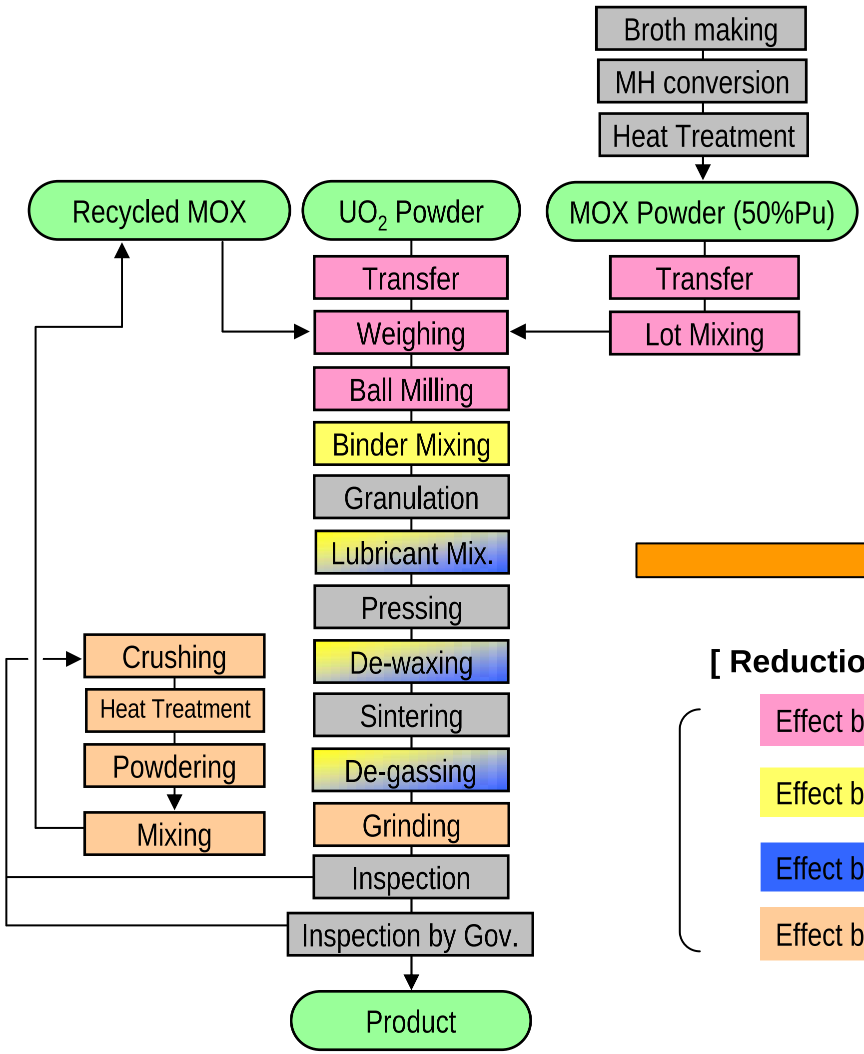
Die lubricating-type molding without lubricant-mixing

Powder mixing process is removed by adjusting Pu content at solution state

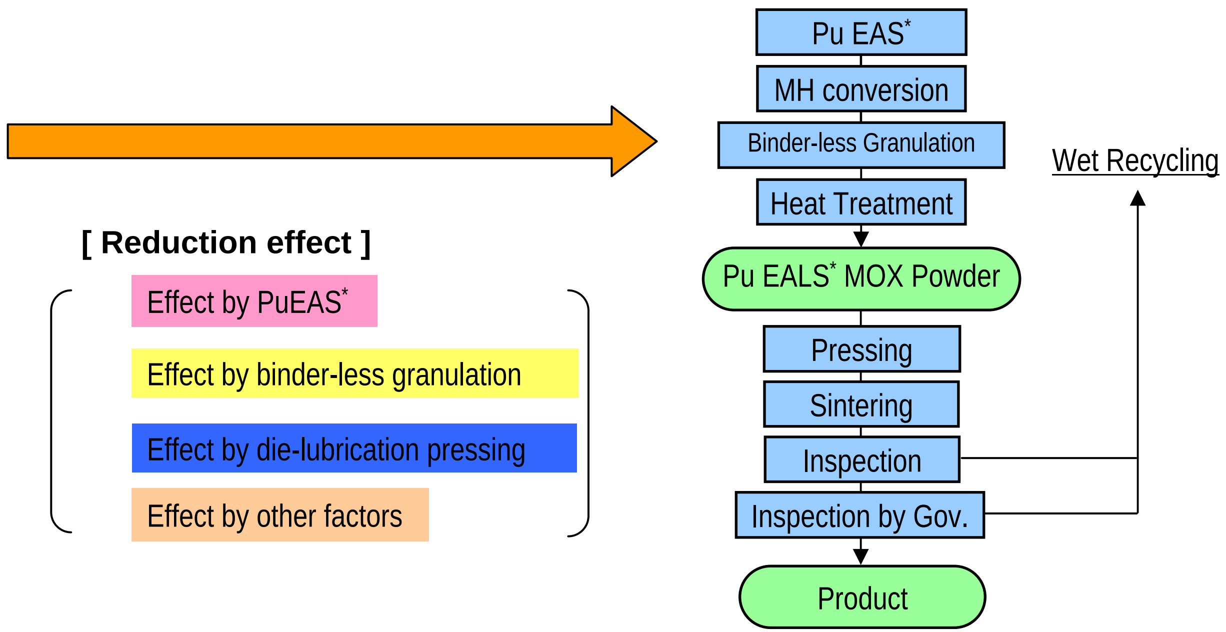
Adjustment of Pu content at solution state is enabled by integrating reprocessing and fuel fabrication plant

FaCT Project : Simplified Pelletizing Process

- **To realize low DF TRU fuel fabrication in a commercial scale, the simplified pelletizing method is adopted.**
- **The simplified pelletizing method expects**
  - **-dust minimum and *HM loss* minimum process because of less powder treating processes,**
  - **-to reduce fabrication process and cost because of less powder treating processes and less organic additives,**
  - **-to solve the problem of potential evaporation of additives caused by higher decay heat because of die wall lubrication method etc.**



Present MOX Pellet Fabrication Process



Simplified Pelletizing Process (SPP)

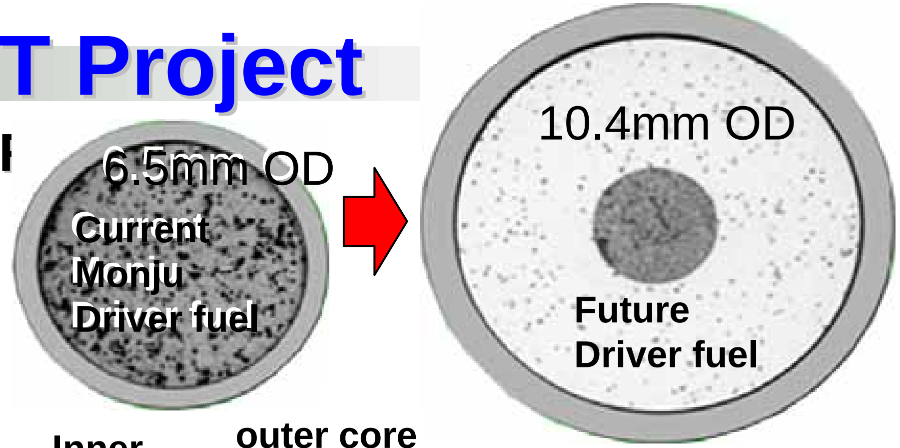
* Pu Enrichment Adjustment in Solution

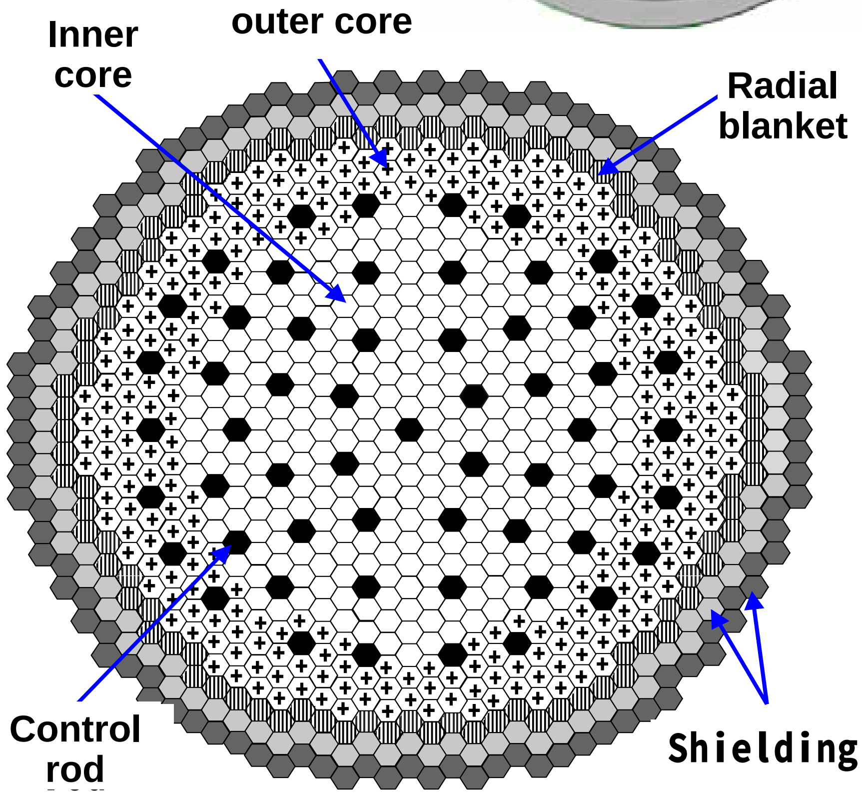
Fuel of the FaCT Project

Large Scale Oxide Core (1,500MWe) of JSF

Core and Fuel Specifications

Items	Breeding Core	Break Even Core
Nominal full power (MWe/MWt)	1,500/3,570	←
Coolant temperature [outlet/inlet] (°C)	550/395	←
Primary coolant flow (kg/s)	18,200	←
Core height (cm)	100	←
Axial blanket thickness [upper/lower] (cm)	20/20	15/20
Number of fuel assembly [core/radial blanket]	562/96	562/ —
Envelope diameter of radial shielding (m)	6.8	←
Fuel cladding outer diameter (mm)	10.4	←
Fuel cladding thickness (mm)	0.71	←
Number of fuel pin per assembly	255	←
Wrapper tube outer flat-flat width (mm)	201.6	←
Wrapper tube thickness (mm)	5.0	←





Core Configuration (Breeding Core)

Fuel of the FaCT Project

- **Oxide** fuel (Reference) and **metal** fuel (alternative)
- **Homogeneous TRU** recycling fuel composition

  ex. :fast reactor core equilibrium composition [oxide]
  Pu238/239/240/241/242/ Np237/Am241/243/Cm244
  =1.1/54.1/32.1/4.3/3.9/ 0.5/2.0/1.0/1.0
  (others : compositions of LWR spent fuels incl. LWR-MOX)
- **High burnup** fuel (ave. 150GWd/t : 200-250 GWd/t, 250 dpa at max.)
- High core outlet temperature (550 deg.C)
- **Simplified Pelletizing** Fuel Fabrication for oxide fuel

- Fuels
  - Oxide fuel : **MA bearing (<～5%HM) , Annular pellet, Low O/M, 82%TD of smeared density**
  - Metal fuel : MA bearing, U-TRU-Zr 75%TD or less of smeared density
- Core material (Swelling resistant and high strength)
  - Cladding : **ODS ferritic steel**
  - S/A duct : PNC-FMS(**ferritic martensitic steel**)
- Cladding maximum temperature
  - Oxide fuel : 700 deg.C (mid-wall)
  - Metal fuel : 650 deg.C (inner surface) [due to metal fuel-cladding compatibility]

Fuel of the FaCT Project : Irradiation tests

- ODS irradiation (material, fuel pin, fuel pin bundle)
- PNC-FMS irradiation (material, fuel pin, SA duct)
- Large diameter fuel pin
- Simplified process fuel pellets
- Annular fuel PTM (PTM=Power-To-Melt)
- Irradiated fuel PTM
- MA bearing oxide fuel (Am,Np-bearing, Am+Np+Cm bearing)
- Transient tests (reactor tests and hot cell tests)
- (Burnup extension of current fuels)

etc.

xxxx : already started in Joyo

Fuel of the FaCT Project : Development scheme

(U,Pu +Am) core = 2025
MA bearing fuel core = before 2050

Demonstration FR

- **Monju**
  upgrade cores

Core scale demonstration
Sub-assembly demonstration

- **Joyo**
  irradiation rigs

Fuel pin bundle irradiation
Fuel pin irradiation
Material irradiation

- Fuel fabrication
  tech. development

Mass production system
Fuel pin/bundle scale fabrication
Bench-scale development

Monju : Restart

at 10:36 am on May 6, 2010

- Withdrawal of Backup Control Rod No.1
- Restart of SST after 14 year and 5 month Suspension

at 10:36 on May 8, 2010

- Confirmation of Criticality Attainment

From May 6 to July 22, 2010

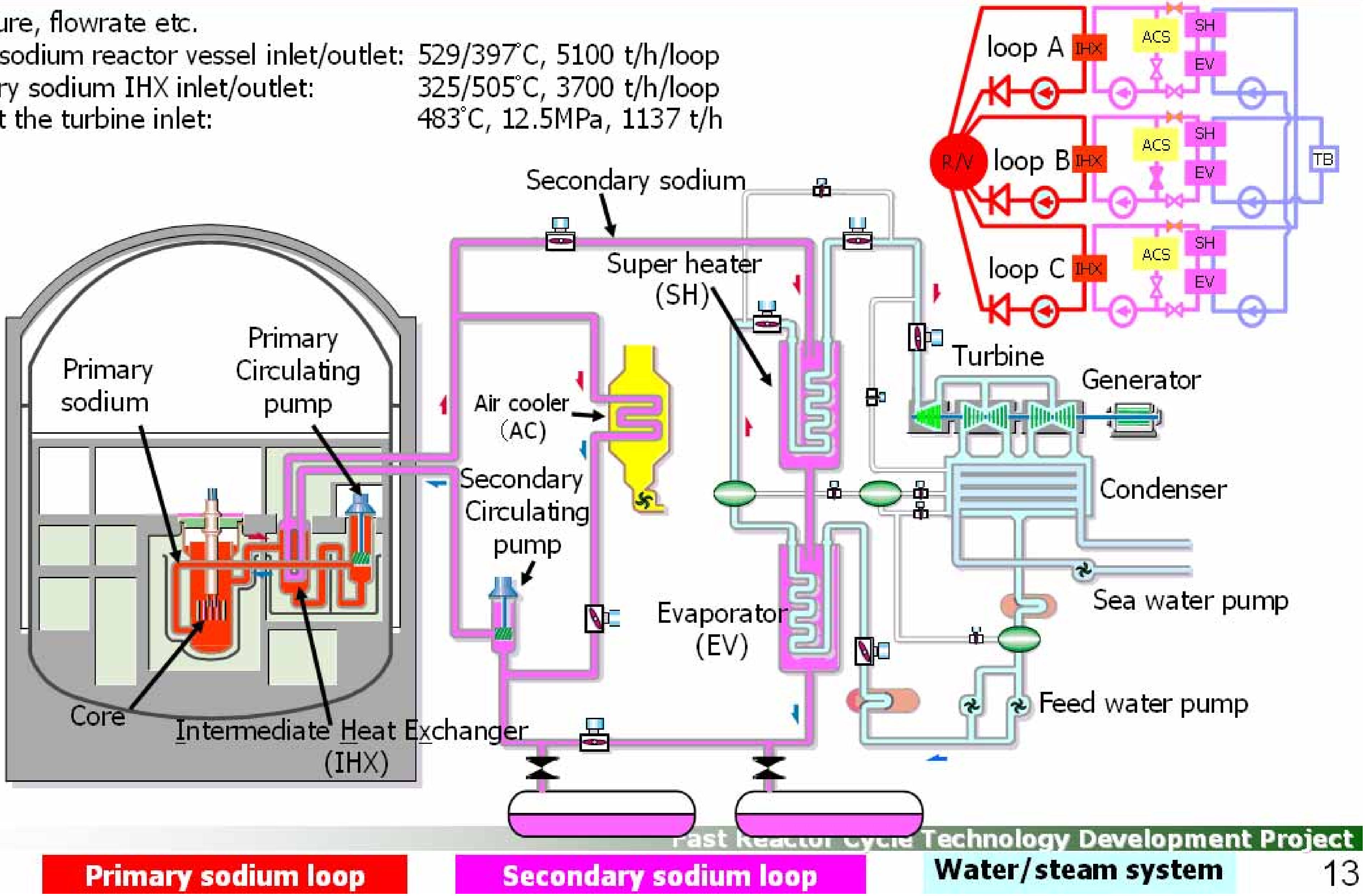
- Conduction of Core Confirmation Test which is the first step of SST

Monju : Power plant summary

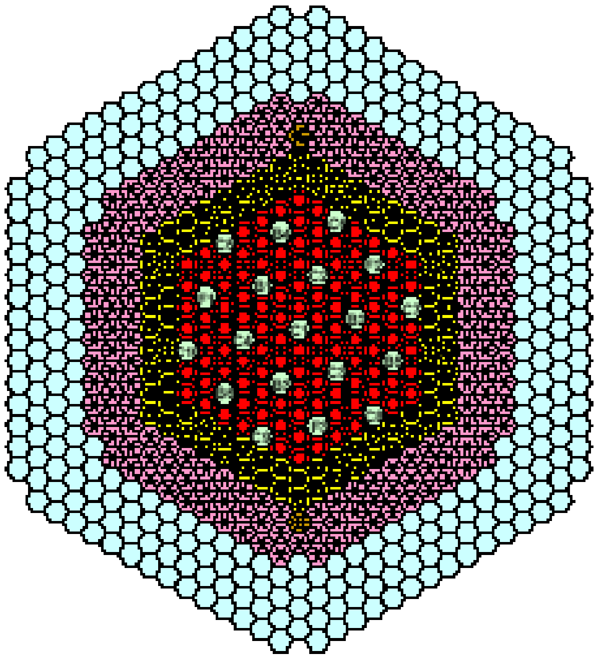
Electricity Output : 280MWe (714MWt), Sodium Coolant, MOX Fuel Core

Temperature, flowrate etc.

Primary sodium reactor vessel inlet/outlet:	529/397°C, 5100 t/h/loop
Secondary sodium IHX inlet/outlet:	325/505°C, 3700 t/h/loop
Steam at the turbine inlet:	483°C, 12.5MPa, 1137 t/h

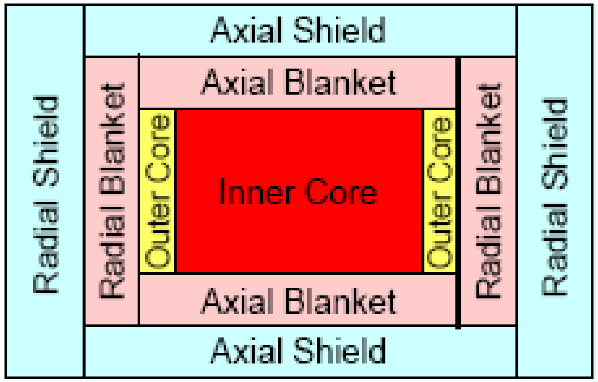


Monju : Current core



Horizontal Cross Section

Core Zone	Inner Core	108
	Outer Core	90
Radial Blanket		172
Control Rod	Fine Control Rod (FCR)	3
	Coarse Control Rod (CCR)	10
	Backup Control Rod (BCR)	6
Neutron Source		2
Neutron Shield		324



Vertical Cross Section

Principal Design and Performance Data of Monju

Reactor Type	Sodium-Cooled Loop-Type
Thermal Output	714 MW
Electrical Output	280 MW
Fuel Material	$PuO_2 - UO_2$
Core Dimension	
Equivalent Diameter / Height	1.8 / 0.93 m
Blanket Thickness	
Upper / Lower / Radial Equivalent	0.3 / 0.35 / 0.3 m
Plutonium Fissile Enrichment	(Inner Core / Outer Core)
Fuel of Initial Core (SST core) Type 1	15 / 20 wt%
Type 2	16 / 21 wt%
Type 3	16 / 21 wt%
Fuel of Equilibrium Core	16 / 21 wt%
Fuel Inventory	
Core (U+Pu+Am-241 metal)	5.9 ton
Blanket (U metal)	17.5 ton
Average Burnup	
Equilibrium Core	80,000 MWd/t
Cladding Material	SUS316
Cladding Outer (Diameter/Thickness)	6.5 / 0.47 mm

Monju : Current driver fuel

		Joyo (MK-III)	Monju
Sub-assembly			
	Overall length (m)	2.97	4.2
	Distance between flat (mm)	78.5	110.6
	Flow rate range (kg/s)	6.8 to 8.5	14 to 21
Pin			
	Overall length (mm)	1533	2813
	Fuel column length (mm)	500	930
	Diameter (Inner/outer) (mm)	4.8/5.5	5.56/6.5
	Spacer	wire	wire
	Triangular pitch (mm)	6.47	7.87
	Number of pins	127	169
Pellet			
	Type	solid	solid
	Diameter x Height (mm)	4.63 x 9	5.4 x 8
	Smeared density (% TD)	87	80

Monju : Am-241 in the driver fuel

- Fissile Pu-241 with half-life of 14 years has spontaneously decayed and turned into non-fissile Am-241 in the core fuel. **(Whole core fuel contains LWR SF – Pu)**
- The excess reactivity decreased approximately 4%⊿k/k during 14 year and 5 month suspension after the previous system start-up test (SST).
- The refueling was conducted in June to July, 2009. The following three-type of core fuel sub-assemblies constituted the reactor core at the restart of SST.
  - Type 1: 114 already-existing burnt fuel sub-assemblies which were used in the previous SST more than 14 years ago
  - Type 2: 78 already-existing aged but fresh fuel sub-assemblies, which were fabricated more than 14 years ago and stored outside the reactor core, and
  - Type 3: 6 fresh fuel sub-assemblies which were newly fabricated
- Approximately 1.5 wt% of Am-241 in core average was contained in the Monju restart core.

The reactor physics data of the core with such much amount of Am-241 is very hard to find in the world and valuable to verify nuclear data of Am-241 and reflected to the R&D of the transmutation technology of minor actinides.

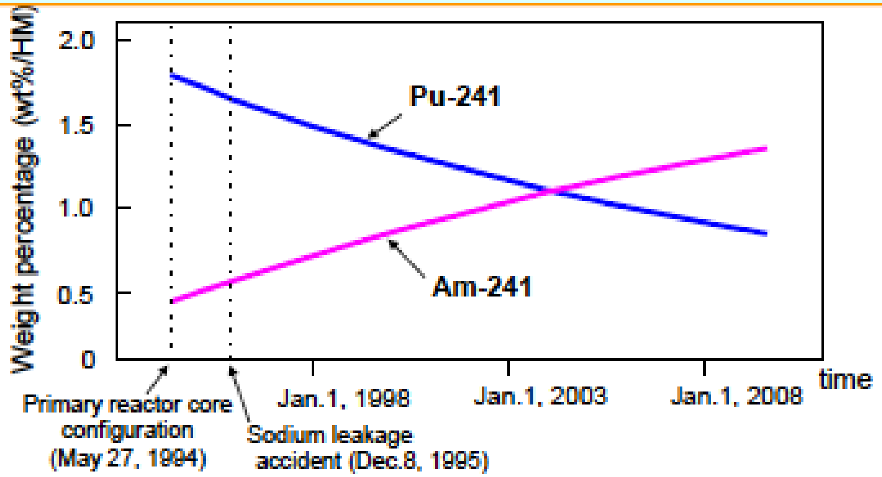


Fig.1 Weight % of Pu-241 and Am-241

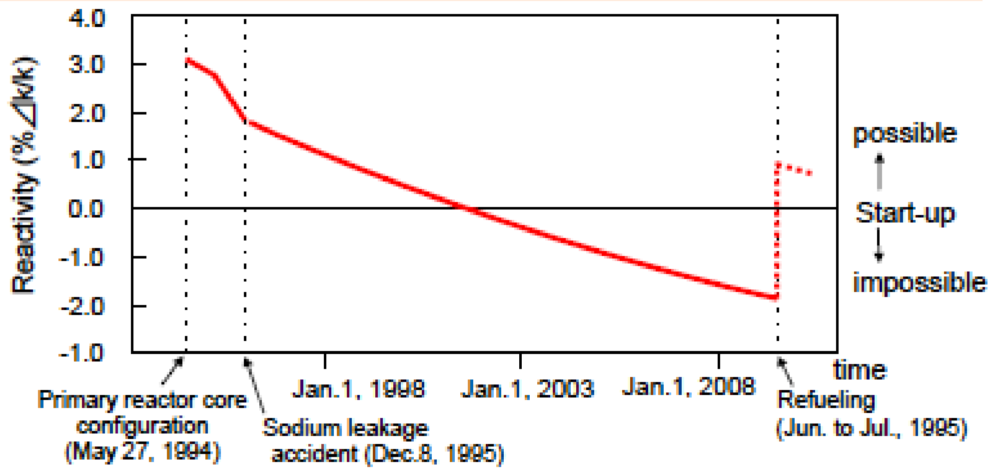


Fig.2 Core Reactivity (at 180 °C)

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Am bearing fuel study

- Fuel property
- Irradiation tests

  -> Fuel integrity evaluation

Am bearing fuel study : fuel properties

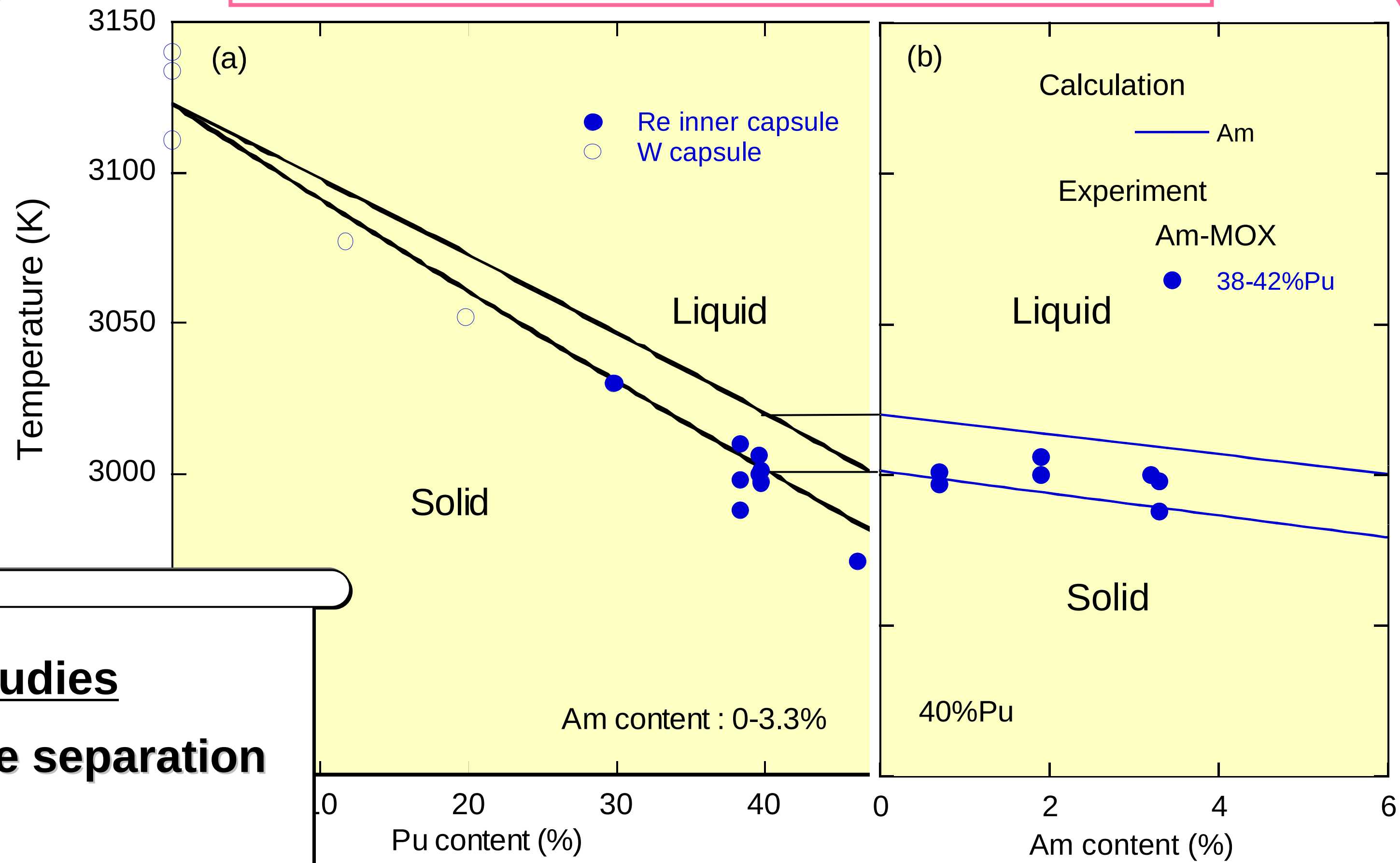
Evolution of technology

✓Fuel fabrications
✓Fuel performance analyses
✓Fuel designs

Current fuel property studies

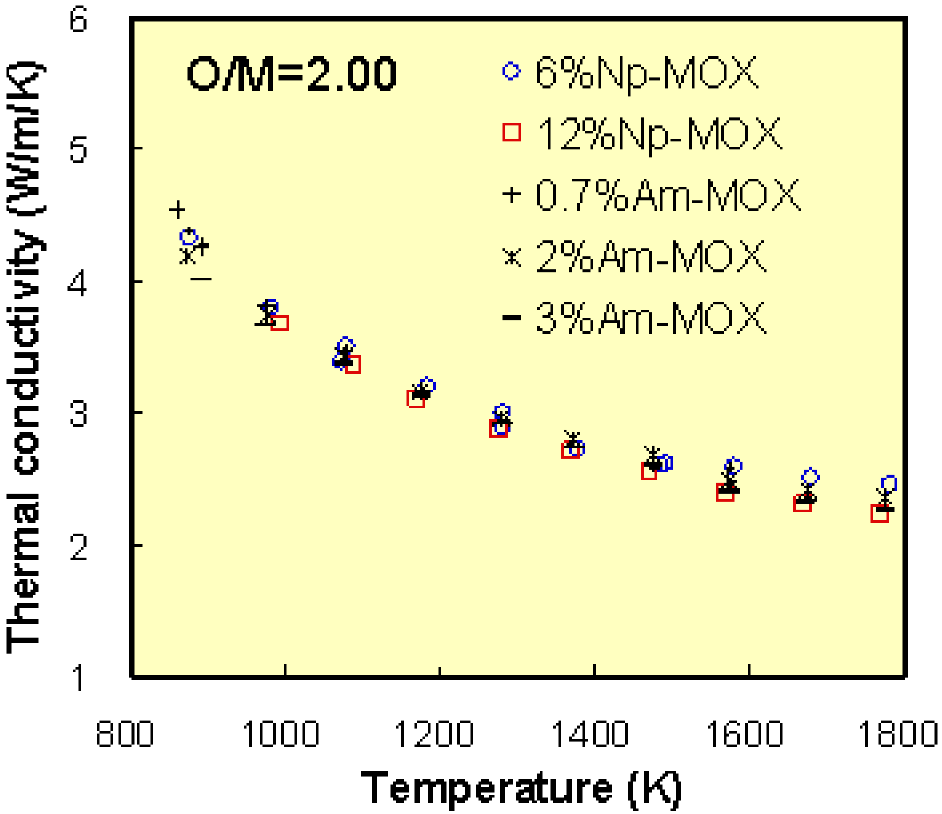
- ➢**Phase state and Phase separation**
- ➢**Lattice parameters**
- ➢**Oxygen potentials**
- ➢**Melting temperatures**
- ➢**Thermal conductivities**
- ➢**Homogeneous sample preparation**
- ➢**Simulations by analytical method**

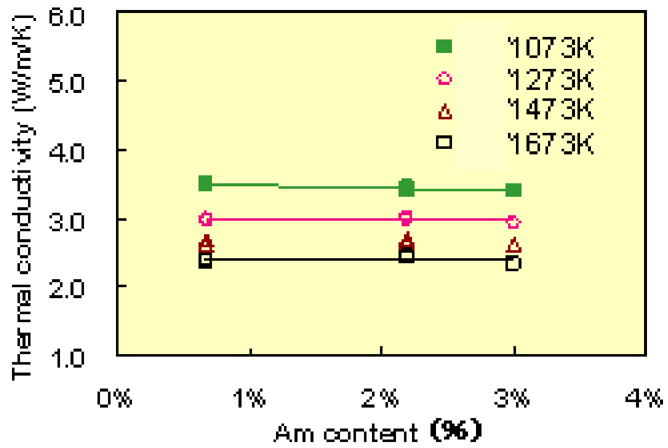
Melting Temperature of Am bearing oxide fuel

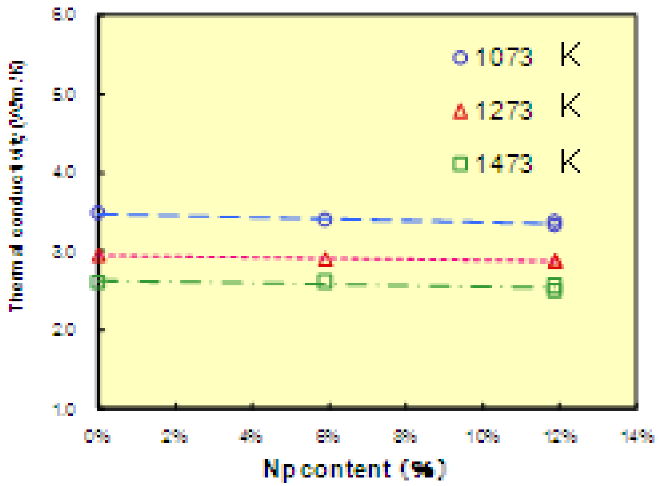


◆Solidus temperature = -4 K/%Am
◆Modeling = Ideal solution model

Am bearing fuel study : fuel properties

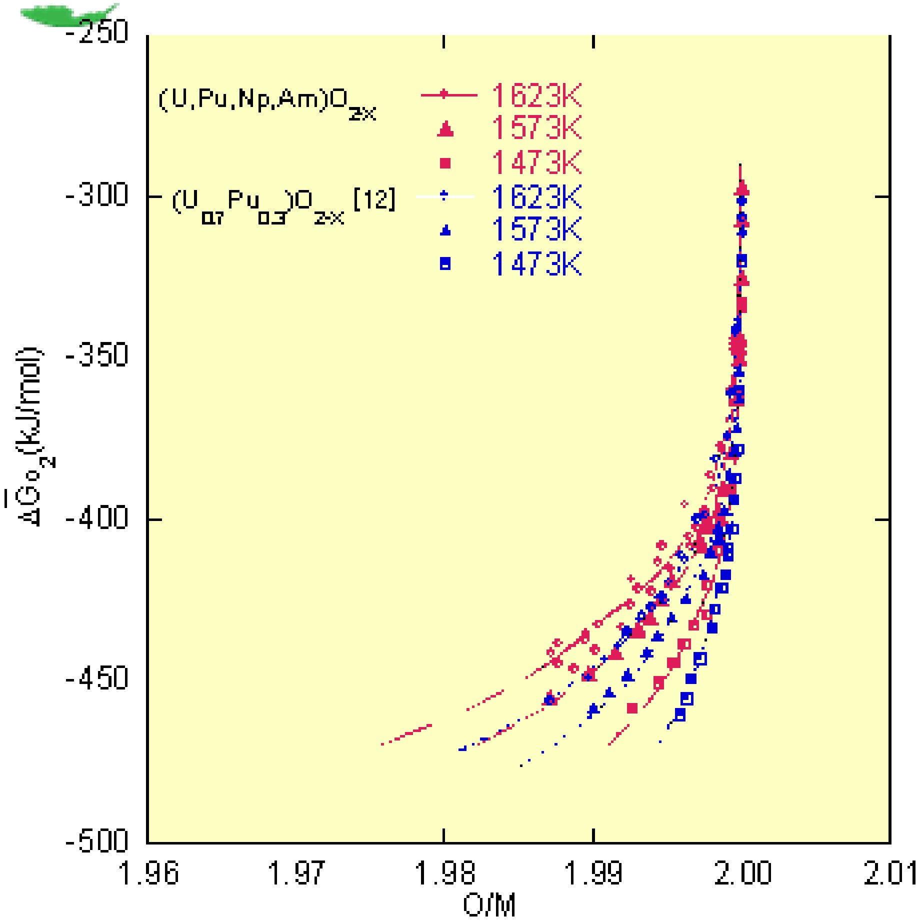




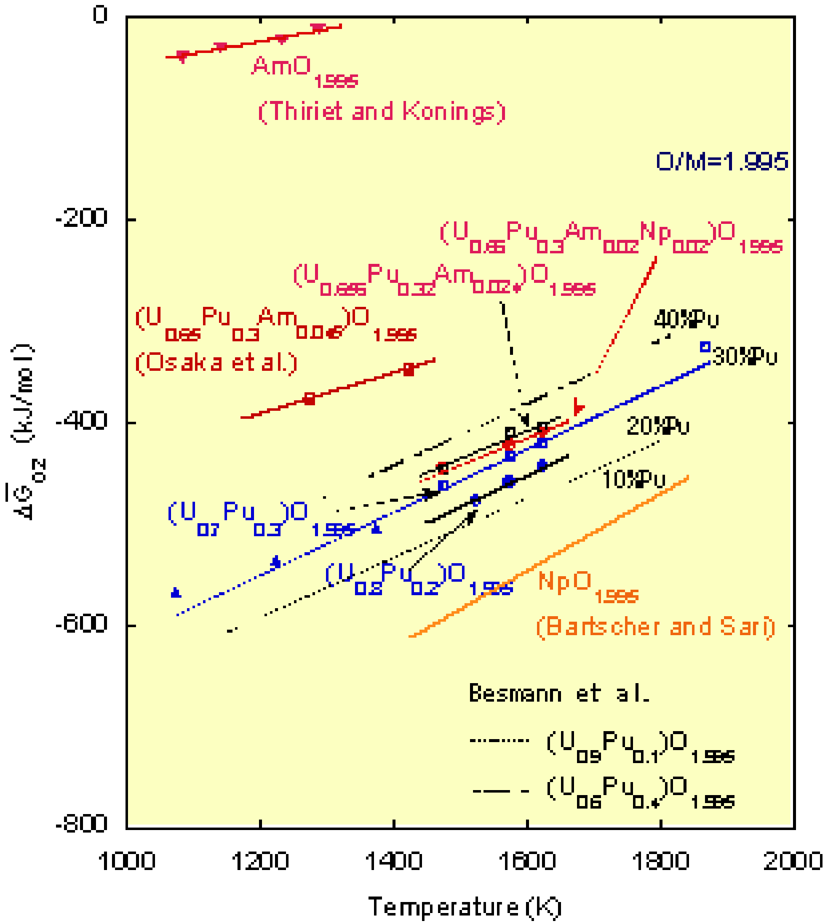


➢ **The addition of MA caused to decrease slightly the thermal conductivities in the temperature range of less than 1000K.**

Am bearing fuel study : fuel properties



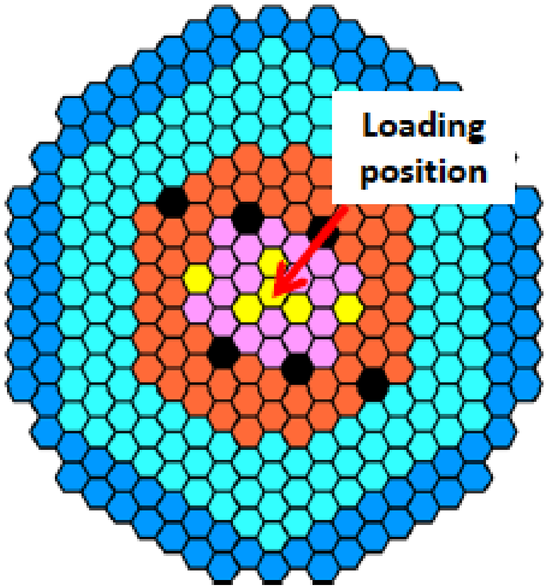
The change of the ΔG_{O2}



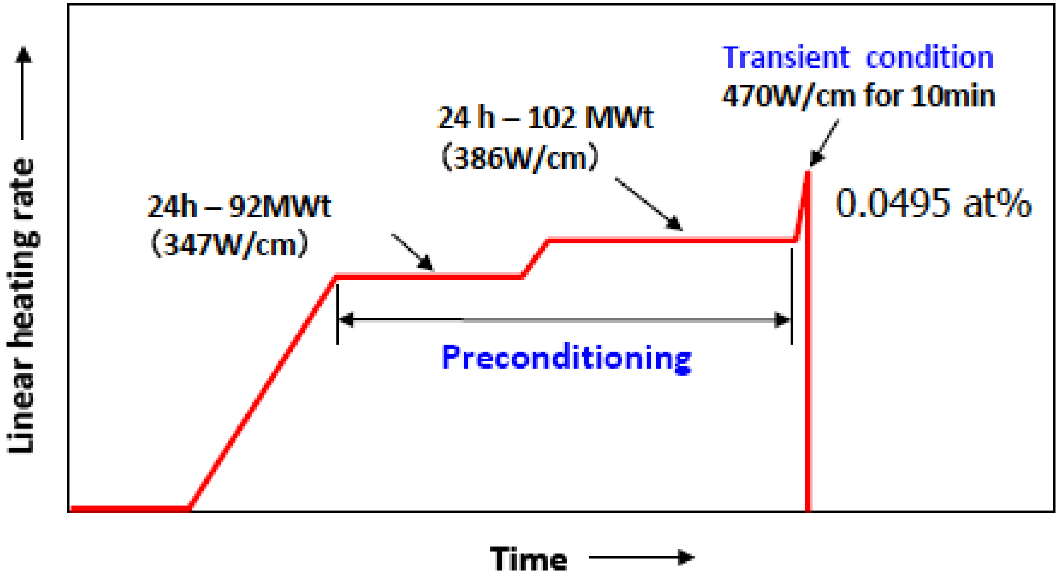
Comparison of the ΔG_{O2} of $MO_{1.995}$

- The ΔG_{O2} of $(U,Pu,Am,Np)O_{2-X}$ are slightly higher than those of MOX without MA.
- The slightly higher ΔG_{O2} is caused by Am content.

Am bearing fuel study : Irradiation test



Loading position: Center of Joyo MK-III core



Schematic diagram of irradiation history of linear heating rate for fuel pins.

Fuel : Monju size with 2.4%HM-Am

Irradiation

Preconditioning (2 step) → fuel restructuring, radial redistribution

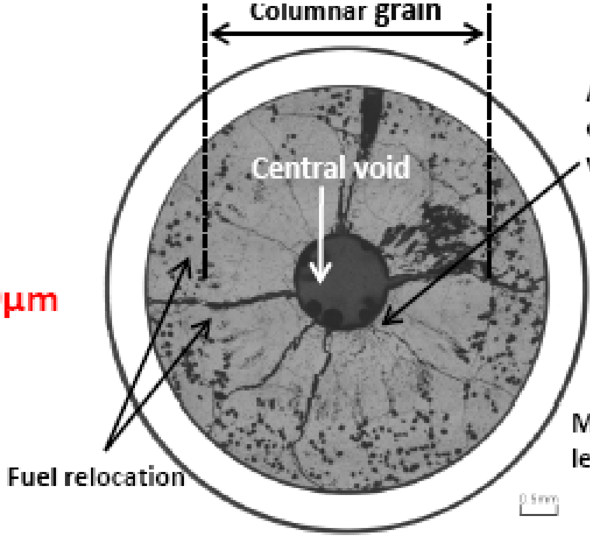
Reduction of fuel centerline temperature

Transient condition → no fuel melting

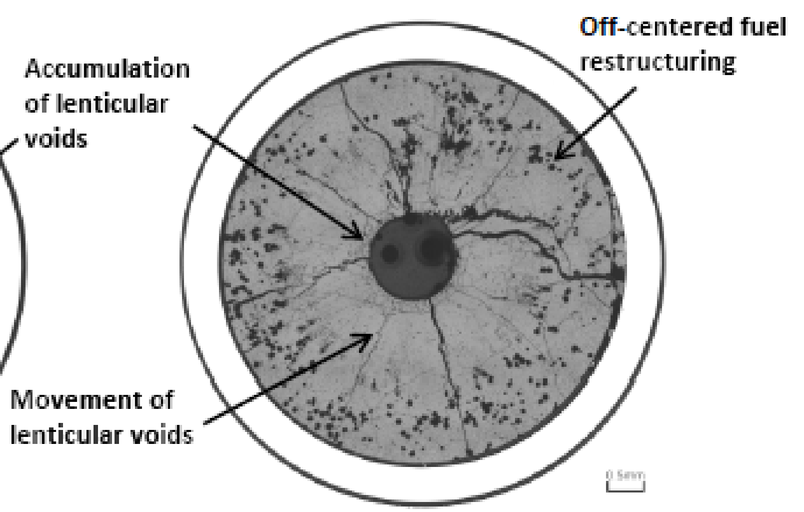
Verification of thermal design

Am bearing fuel study : Irradiation test

PTM002
gap width: 210μm
O/M: 1.98

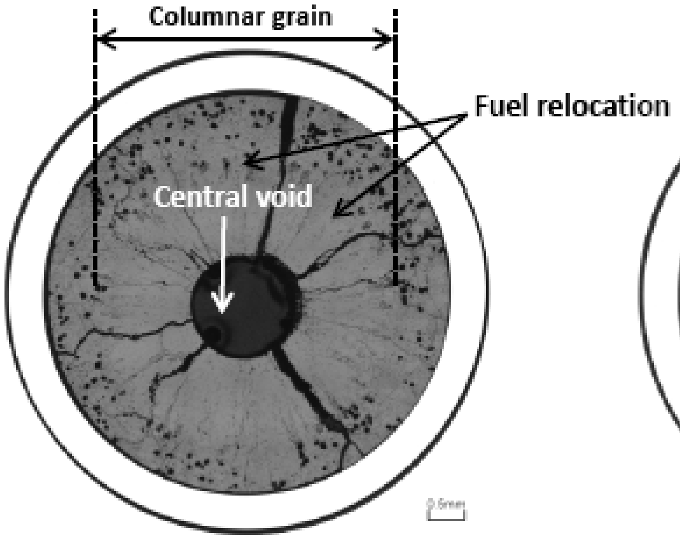


+27mm from the midplane

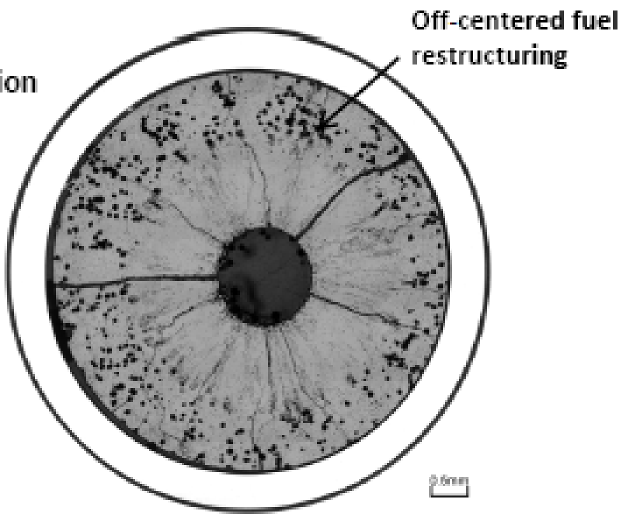


+99mm from the midplane

PTM010
gap width: 210μm
O/M: 2.00

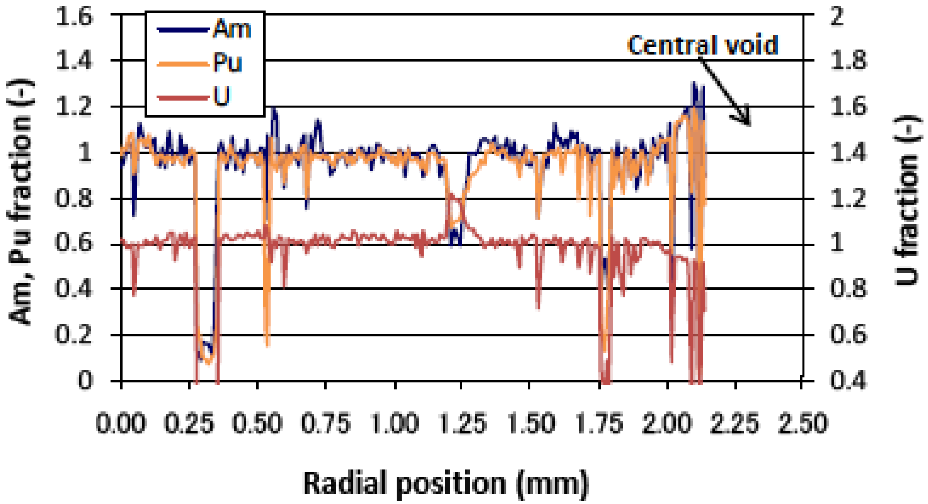


+25mm from the midplane

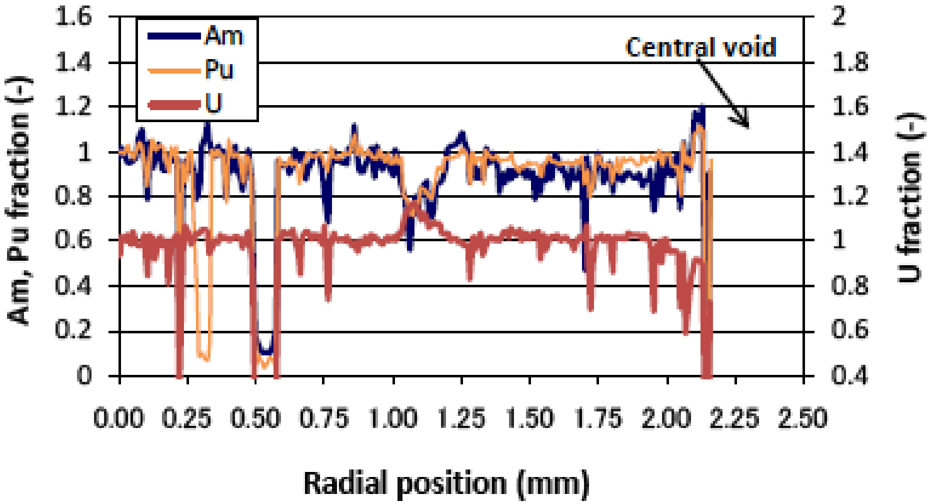


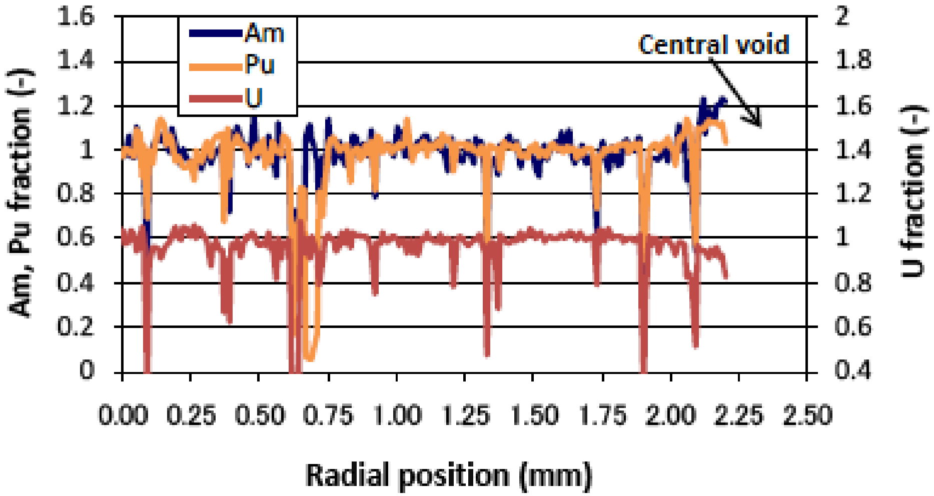
+97mm from the midplane

Am bearing fuel study : Irradiation test



PTM001 gap width: 160µm, O/M: 1.98





PTM003 gap width: 160µm, O/M: 1.96

PTM002 gap width: 210µm, O/M: 1.98

Further Development

(U,Pu +Am) core = 2025
MA bearing fuel core = before 2050

Demonstration FR

- **Monju**
  upgrade cores

Core scale demonstration
Sub-assembly demonstration

- **Joyo**
  irradiation rigs

Fuel pin bundle irradiation
Fuel pin irradiation
Material irradiation

- Fuel fabrication
  tech. development

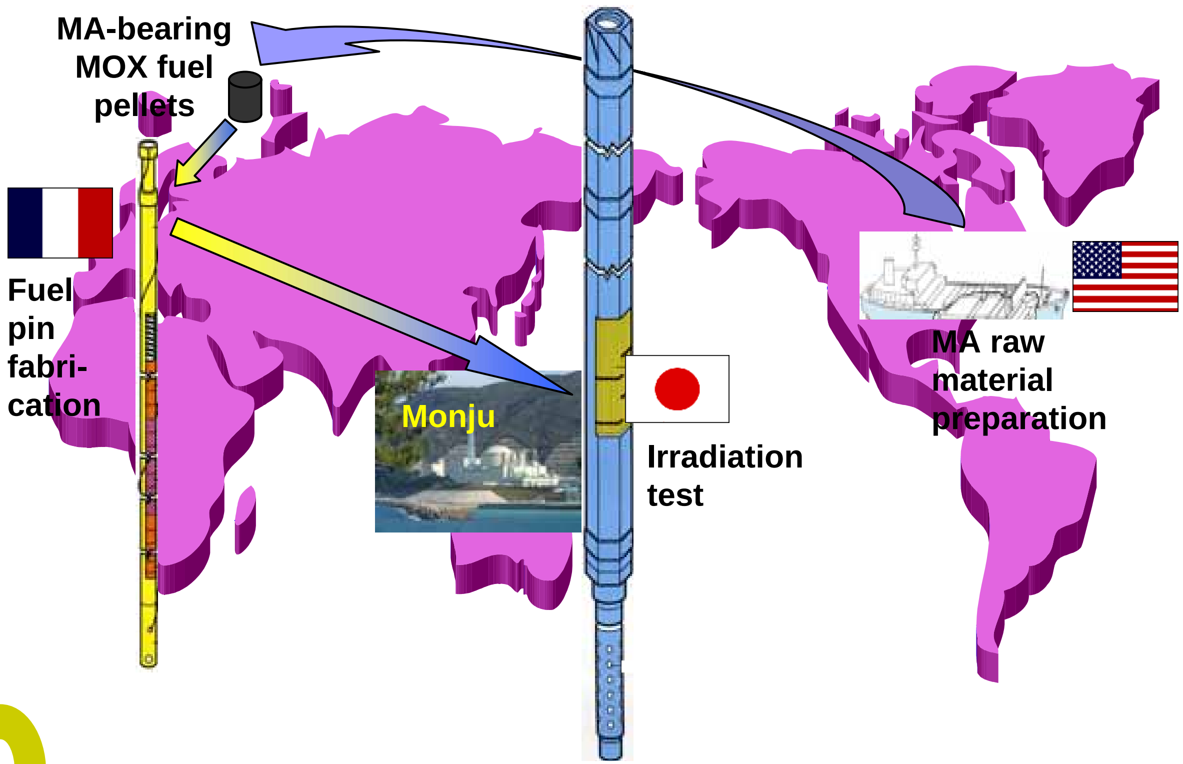
Mass production system
Fuel pin/bundle scale fabrication
Bench-scale development

Further Development

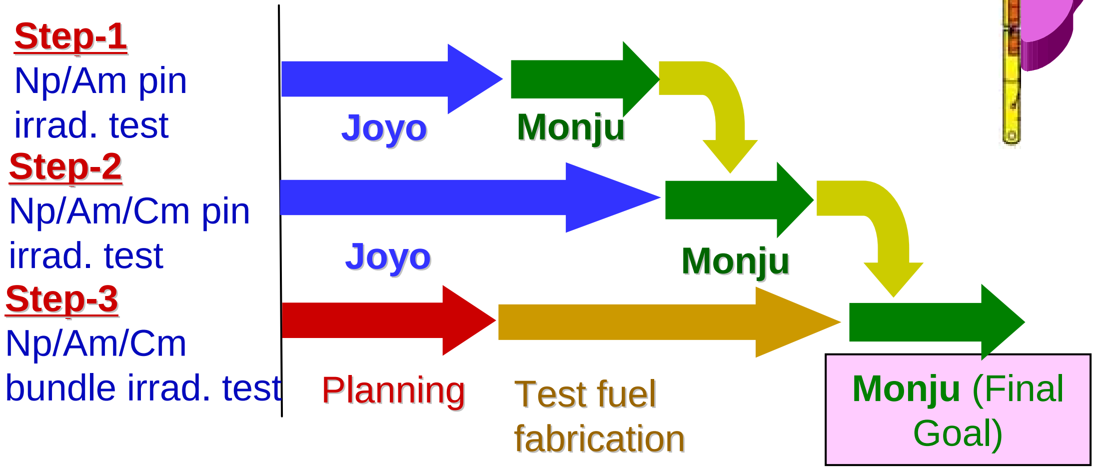
CEA/DOE/JAEA GACID Project

- ***Objective: to demonstrate, using Joyo and Monju, that FR's can transmute MA's (Np/Am/Cm) and thereby reduce the concerns of HL radioactive wastes and proliferation risks.***
- ***A phased approach in three steps.***
- ***Material properties and irradiation behavior are also studied and investigated.***

Tri-lateral collaboration in GACID pin-scale tests.



GACID overall schedule



- ***The Project is being conducted by CEA, USDOE and JAEA as a GIF/SFR Project, covering the initial 5 years since Sep. 27, 2007.***

GACID: Global Actinide Cycle International Demonstration

Conclusions

- Fuel development for future fast reactors are in progress as a part of FaCT project in Japan.
- The reference fuel of the FaCT project is MA bearing oxide fuel in homogeneous recycling
- Developmental effort includes irradiation tests, fuel fabrication technology development and out-of-pile studies such as fuel property investigations.
- Monju restarted its core with Am bearing fuel and its characteristics were experimentally evaluated.
- Further development will be promoted through Joyo irradiation tests and Monju demonstrations.
- International collaborative effort such as GACID is also an important part of such activities.