Fast Reactor Fuel Development in Japan

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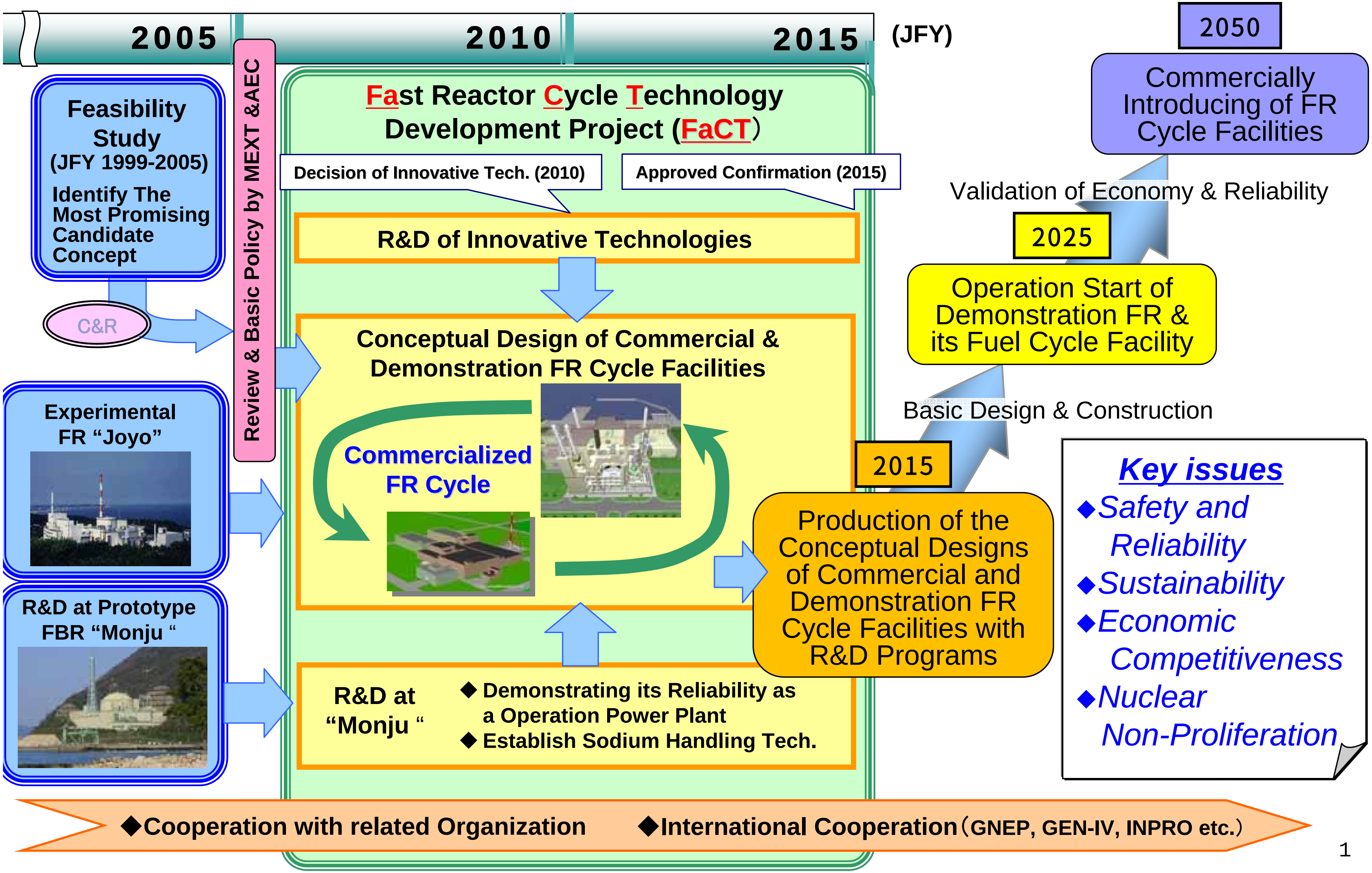
FR Cycle Development Program in JAPAN



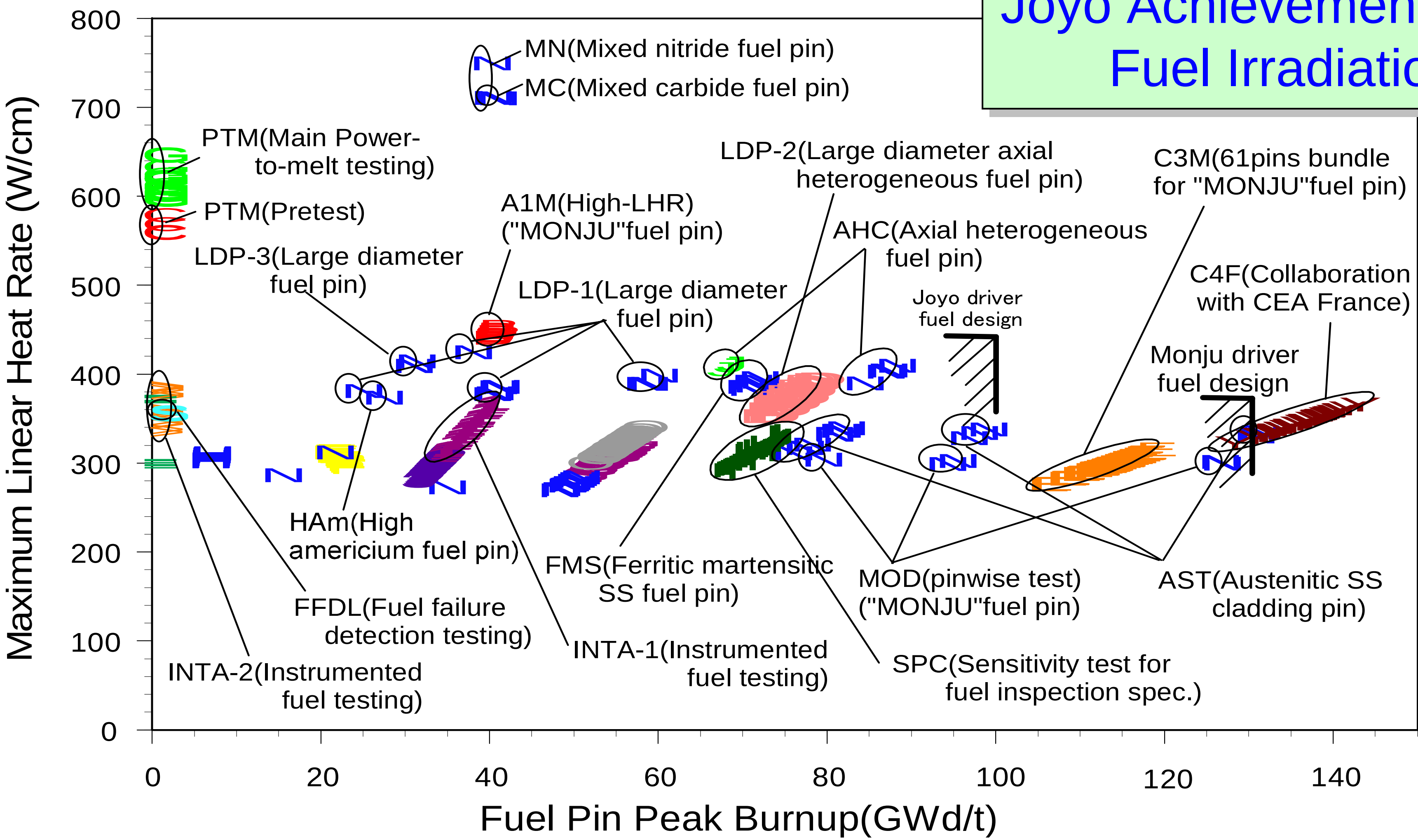
Driver fuels of Joyo and Monju

		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

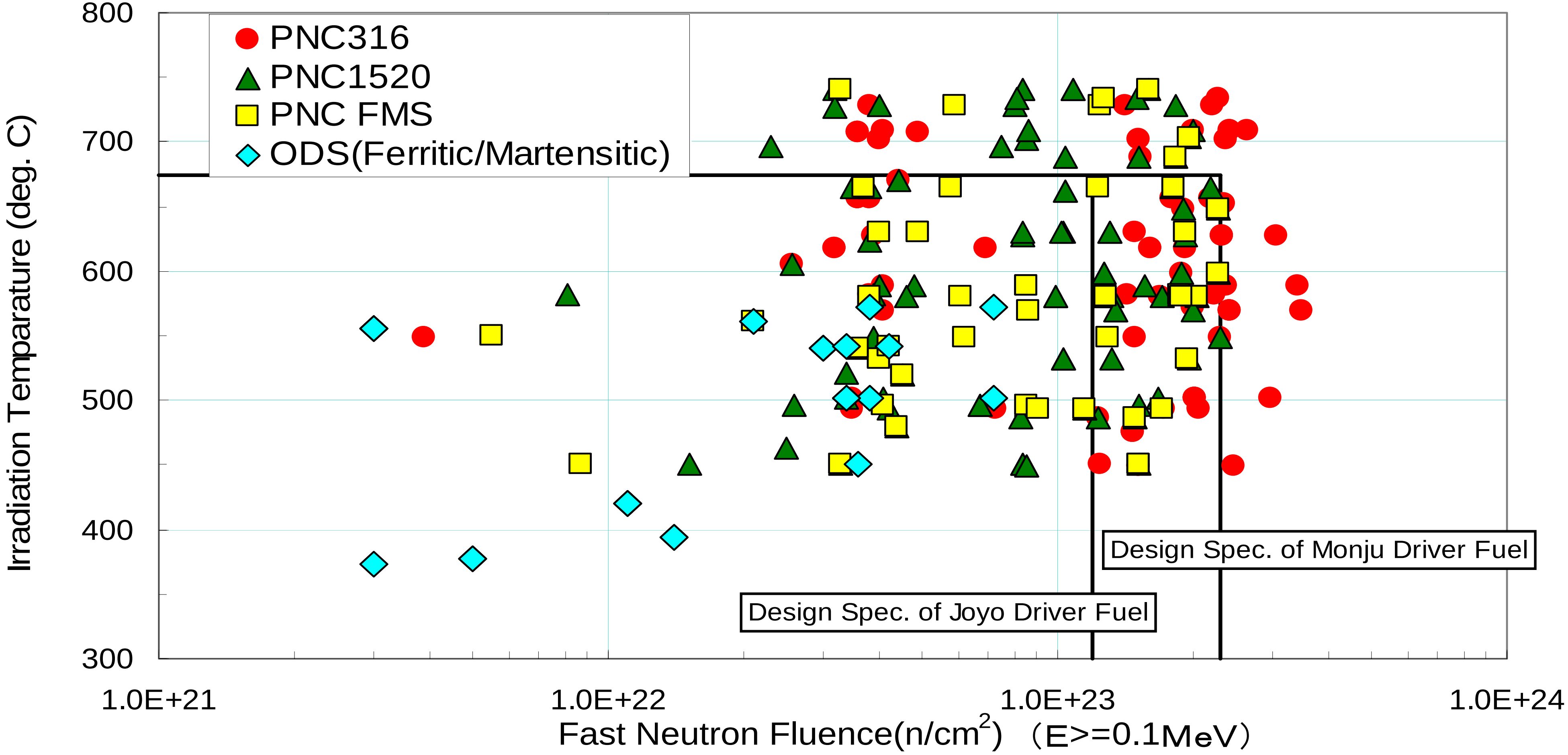
Joyo and Monju

- Joyo has been being accumulating irradiation test data
- Monju is expected to demonstrate high burnup fuel in S/A scale and core scale

Joyo Achievement : Fuel Irradiation



Joyo Achievement : Material Irradiation



Main Features of JSFR

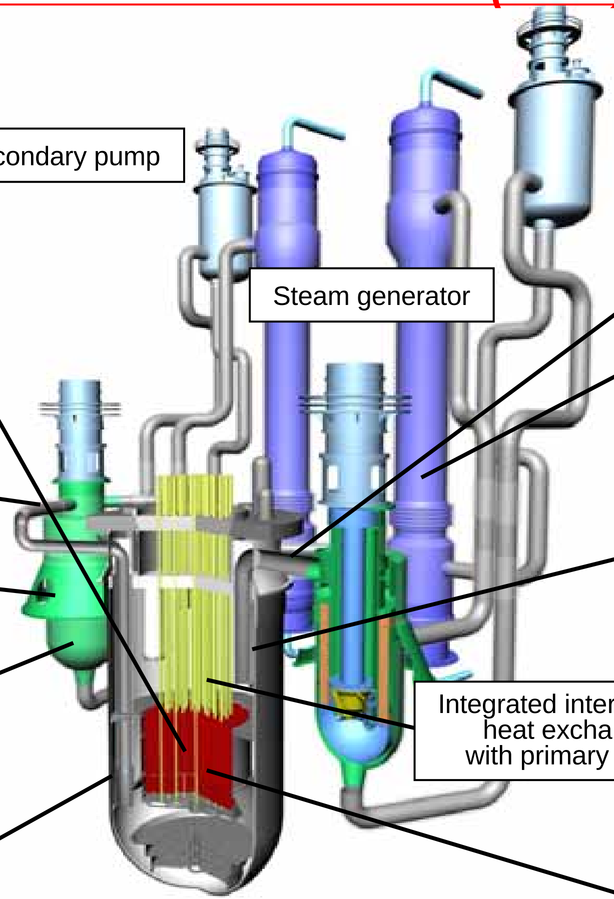
- 1,500 MWe large-scale loop-type SFR with MOX fuel,
- Innovative technologies for enhancement of reactor core safety, high economic competitiveness and countermeasures against specific issues of sodium

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

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

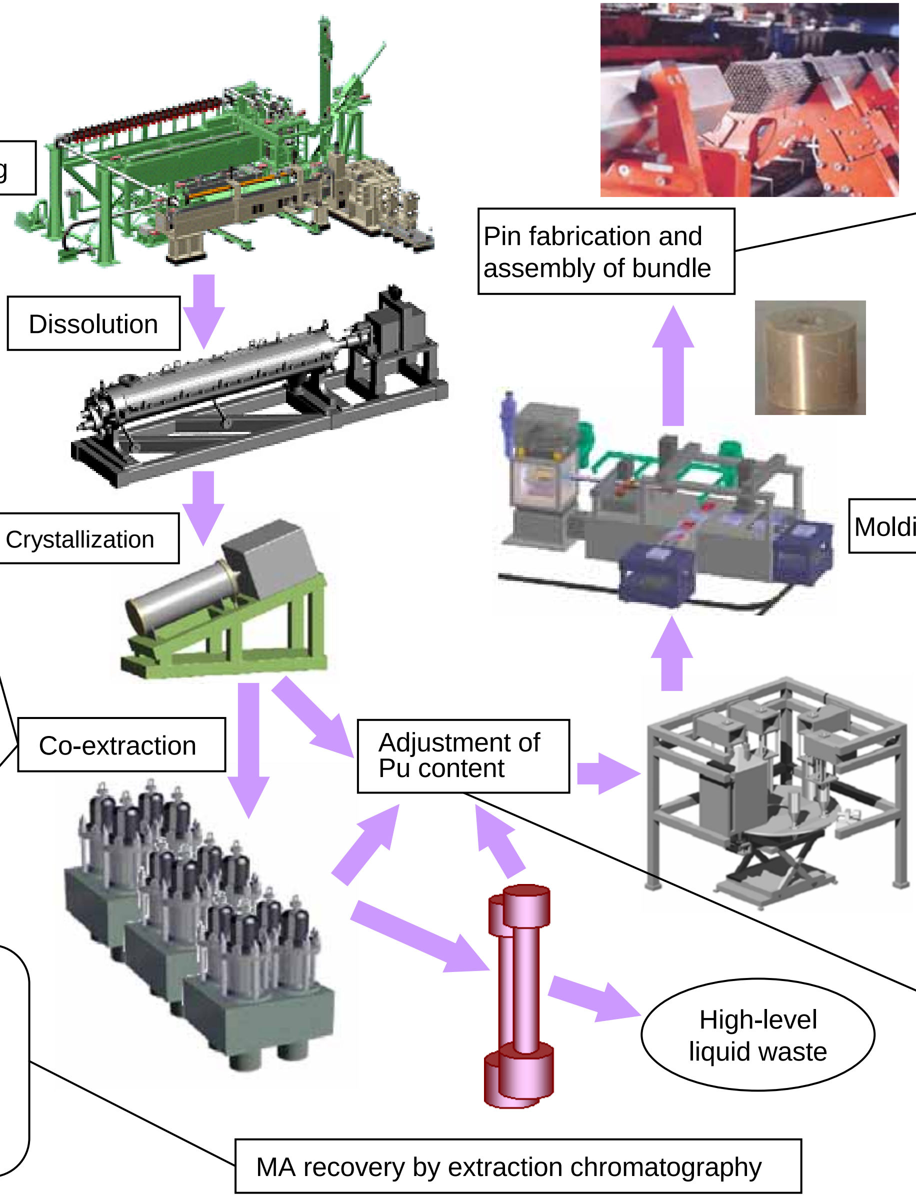
Advanced Aqueous Reprocessing

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

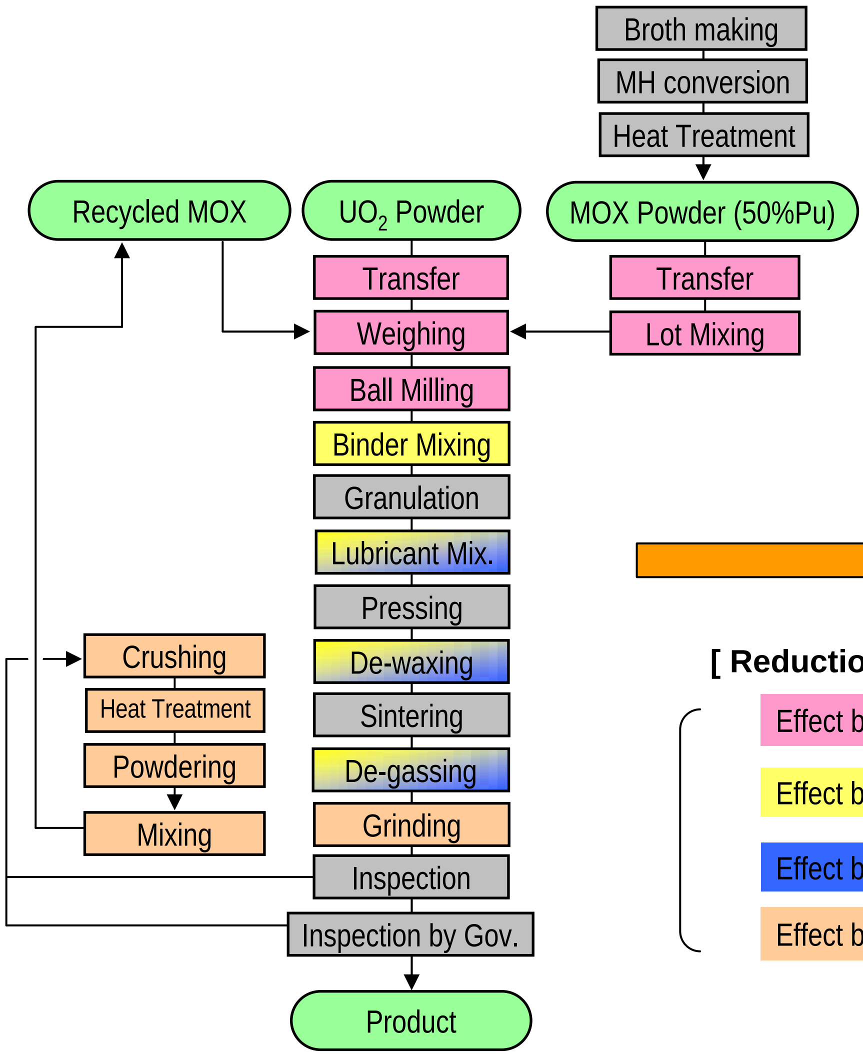
Die lubricating-type molding without lubricant-mixing

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

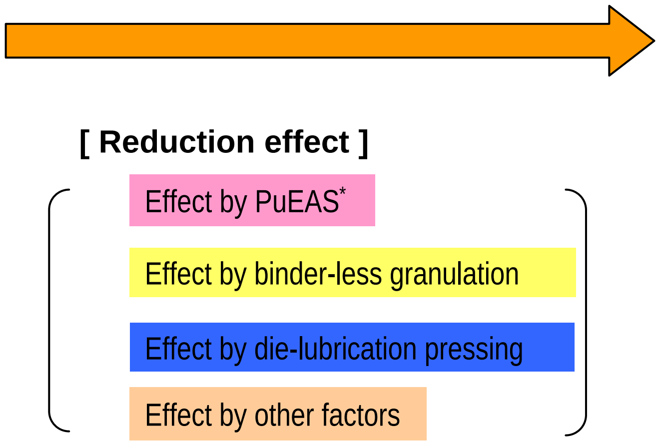
Adjustment of Pu content at solution state is enabled by integrating reprocessing and fuel fabrication plant

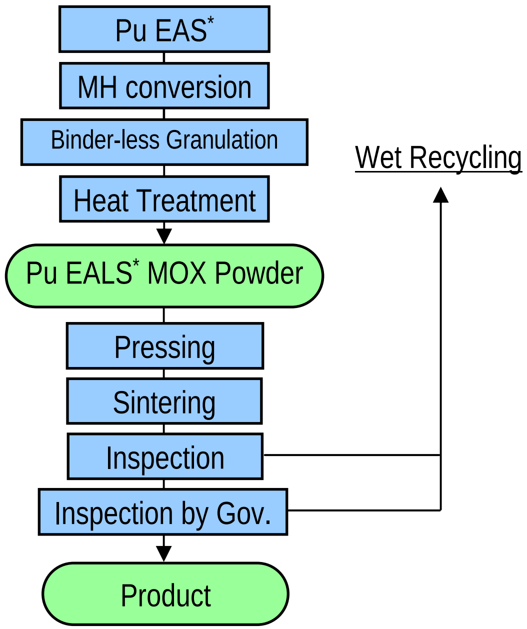
Simplified Pelletizing Process

- 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





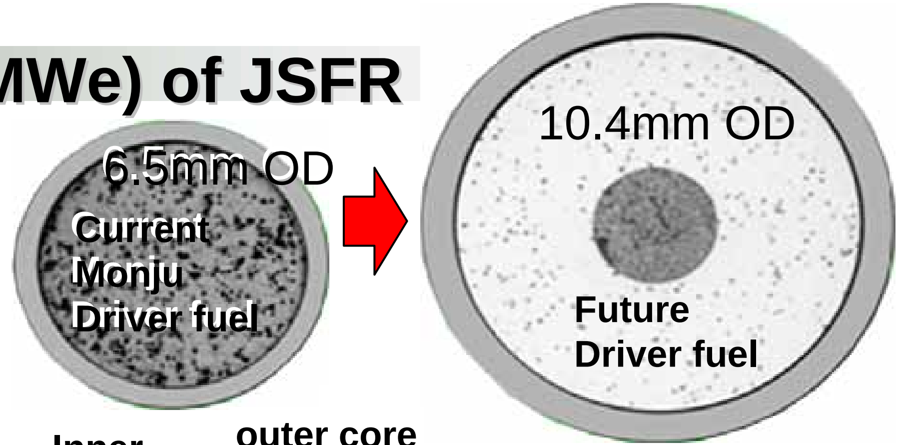
Simplified Pelletizing Process (SPP)

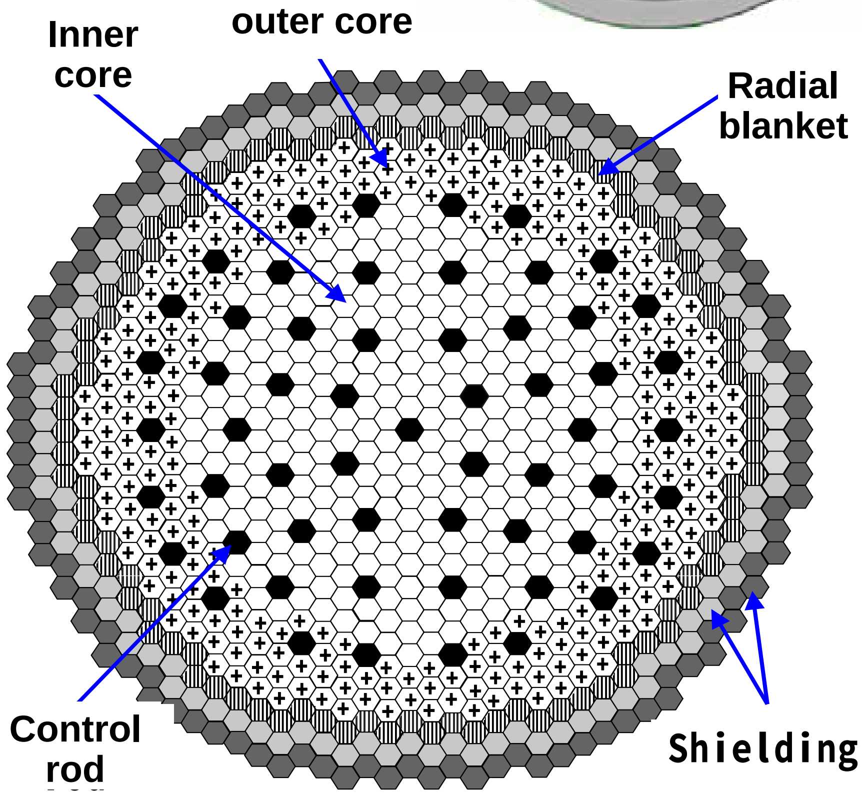
* **Pu** **E**nrichment **A**djustment in **S**olution

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

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)

Fuels for SFR (1/2)

- **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 for SFR (2/2)

- 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]

Future Evolution of SFR driver fuel

	Current	Interim	Future
Burnup	80 GWd/t	100-150 GWd/t	150GWd/t
Core materials	PNC-316	PNC-316 Advanced austenitic ODS / PNC-FMS	ODS clad. PNC-FMS S/A duct
Fuel pin diameter	6.5mm	8-10mm	10.4mm
Fuel pellets	Solid 85%TD	Solid / Annular High density	Annular 95%TD
Fuel compositions	(U,Pu)+decay Am Pu from LWR	(U,Pu)+decay Am Pu from HB-LWR and LWR-MOX	Pu/TRU from HB-LWR and LWR-MOX FR recycle FR equilibrium
Fuel fabrication technologies	Conventional pelletizing	(Simplified pelletizing)	Simplified pelletizing

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)

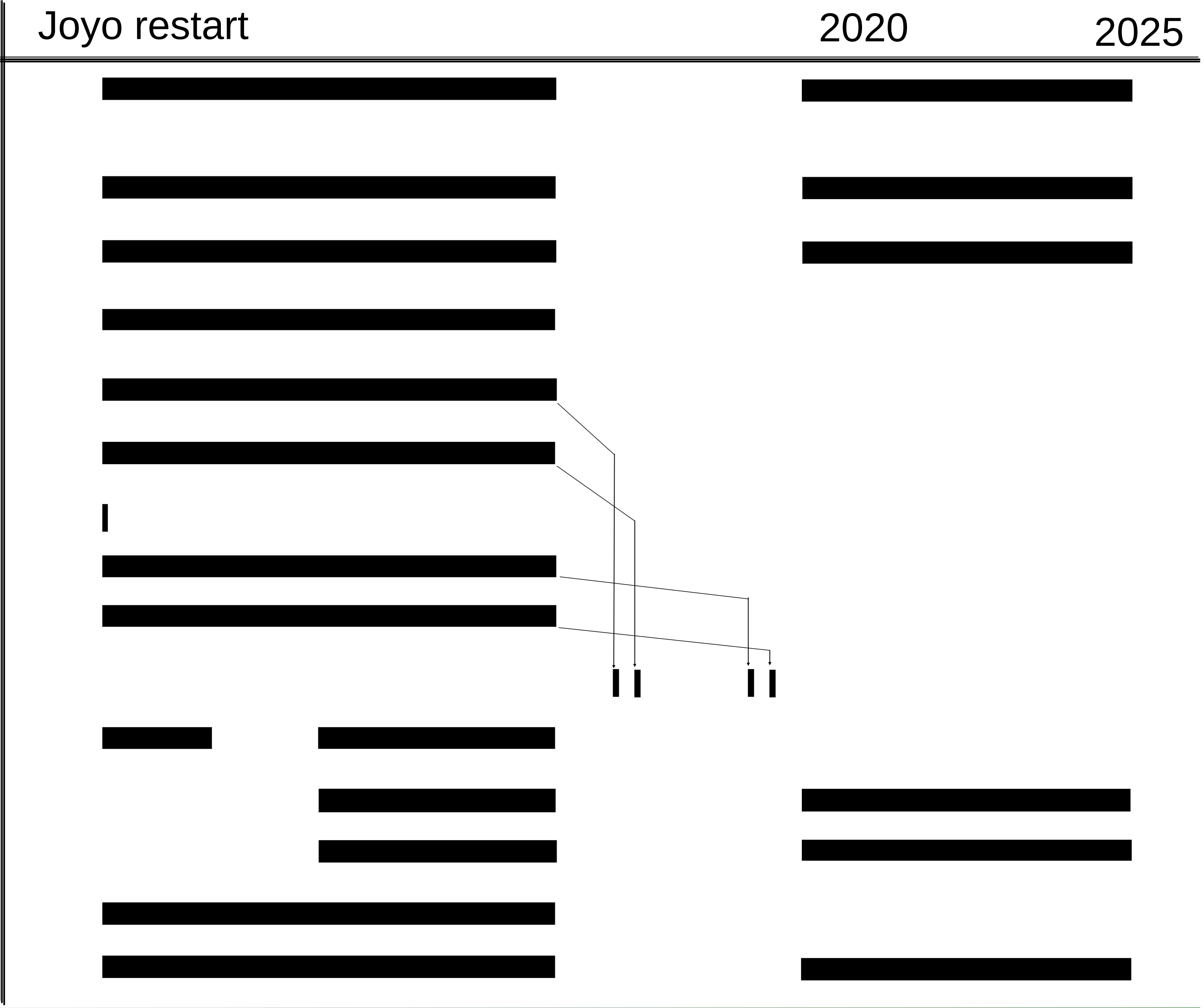
etc.

xxxx : already started in Joyo

Irradiation tests

Irradiation items

- ◆ ODS, PNC-FMS material
- ◆ ODS fuel pin irradiation*
- ◆ ODS fuel pin bundle irradiation
- ◆ PNC-FMS SA duct irradiation
- ◆ Large diameter fuel pin (Annular)
- ◆ Large diameter fuel pin (Annular)
- ◆ Annular fuel PTM
- ◆ Irradiated fuel PTM
- ◆ Am+Np bearing oxide fuel
- ◆ Am+Np+Cm oxide fuel
- ◆ Am+Np+Cm oxide fuel (high BU)
- ◆ Zr-H shielding
- ◆ Long life control rod (B_4C)



* : Includes simplified pelletizing fuel

Basic scheme of SFR fuel 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

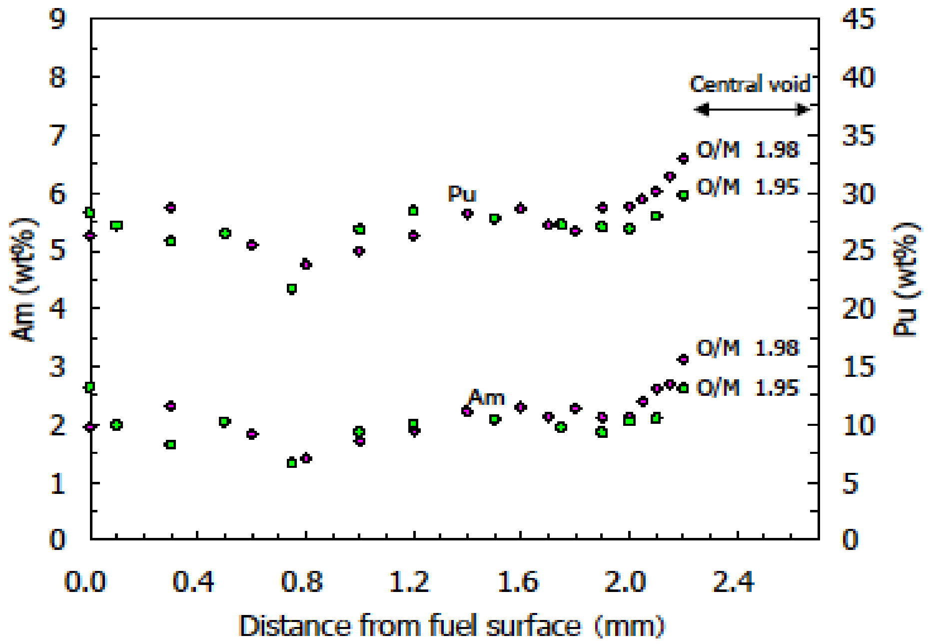
- Fuel fabrication
  tech. development

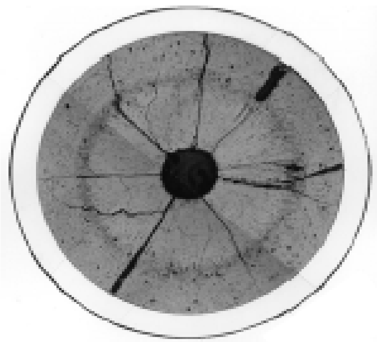
Mass production system
Fuel pin/bundle scale fabrication
Bench-scale development

MA bearing oxide fuel test in Joyo
Current outcomes of Am-1/B11 (5%Am, 2%Am+2%Np)

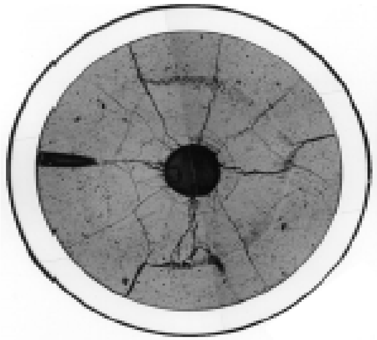
Radial distribution of Am and Pu content in Np/Am-MOX

Japan Atomic Energy Agency





second test,
x/L=0.5, O/M 1.98



second test,
x/L=0.5, O/M 1.95

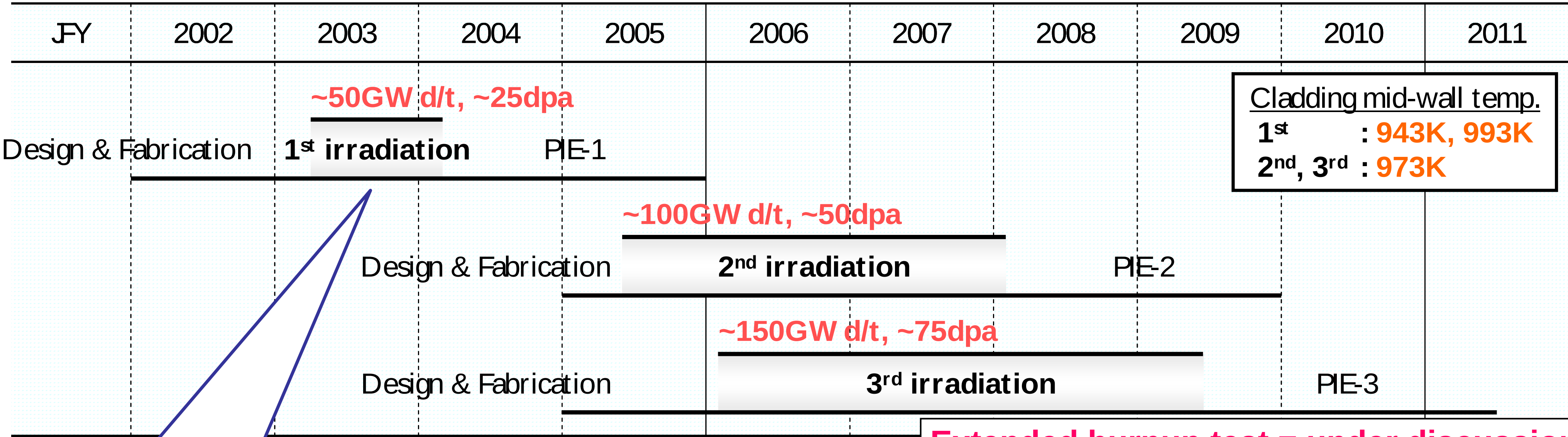
・The radial redistributions of Am and Pu were to a large extent a direct consequence of the mechanisms generating the formations of the columnar grains and central void,

・dominant dependence of the fuel O/M ratio on the radial redistributions of Am and Pu was indicated.

Steady state irrad.
In Joyo
= ready

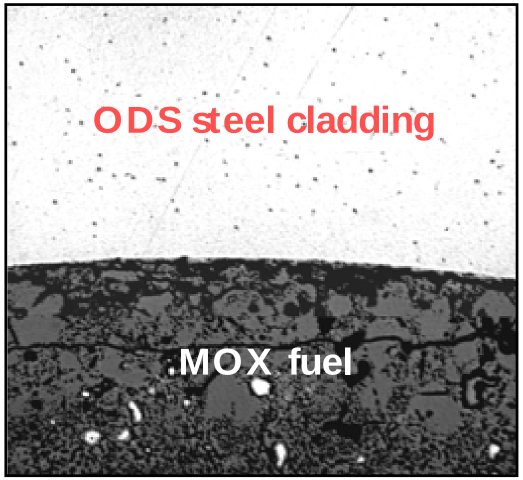
ODS Fuel Pin Irradiation Test in BOR-60

Joyo test
= under preparation



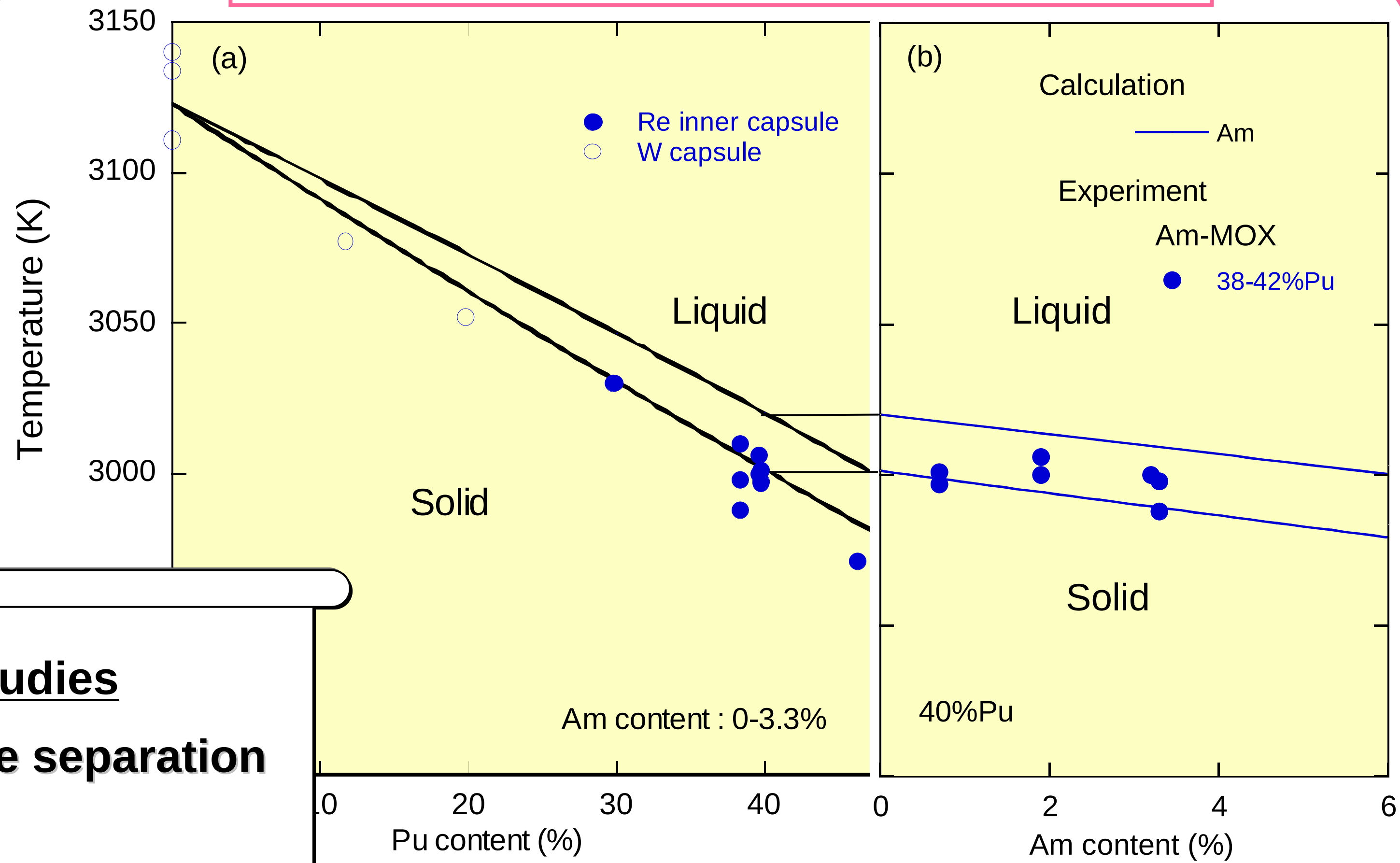
Extended burnup test = under discussion

- **Objectives**
  - To attain the cumulative damage fraction (CDF) value similar to the end of life condition
  - To obtain the inner surface corrosion (FCCI) data at the higher temperature
- **Results**
  - Irradiation results of **CDF up to 0.3** were achieved without fuel pin failure
  - Maximum corrosion depth observed was **10 μm**



Extended Studies of Oxide Fuel Property

Melting Temperature of Am bearing oxide fuel



◆Solidus temperature = -4 K/%Am

◆Modeling = Ideal solution model

Evolution of technology

✓Fuel fabrications
✓Fuel performance analyses
✓Fuel designs

Current fuel property studies

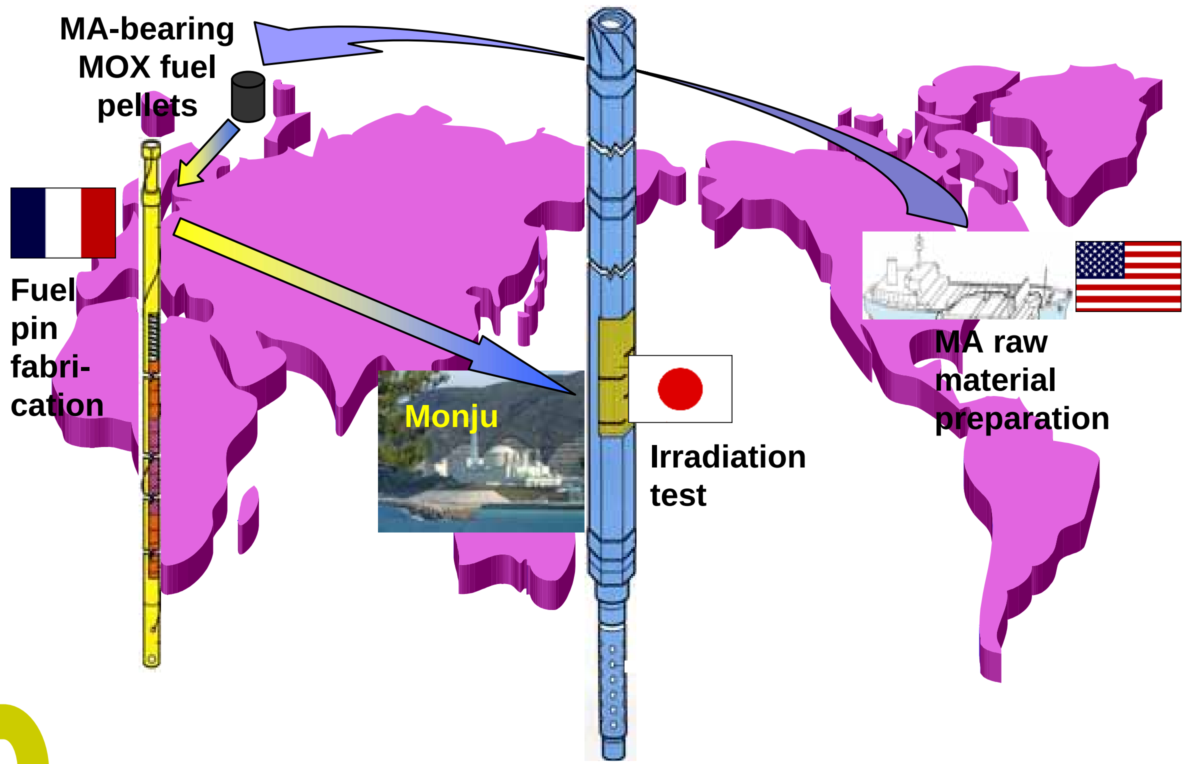
- **Phase state and Phase separation**
- **Lattice parameters**
- **Oxygen potentials**
- **Melting temperatures**
- **Thermal conductivities**
- **Homogeneous sample preparation**
- **Simulations by analytical method**

International Collaborations

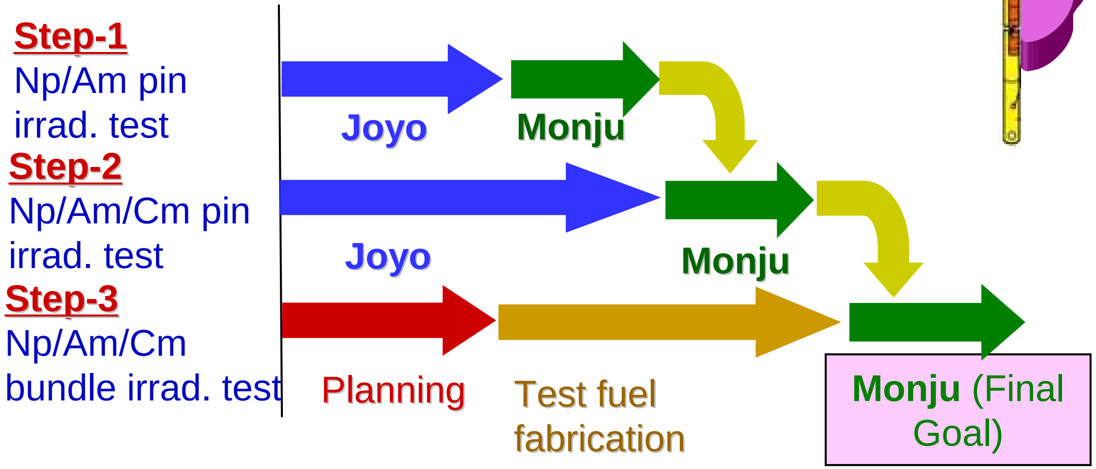
CEA/DOE/JAEA GACID Project

- ***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.***

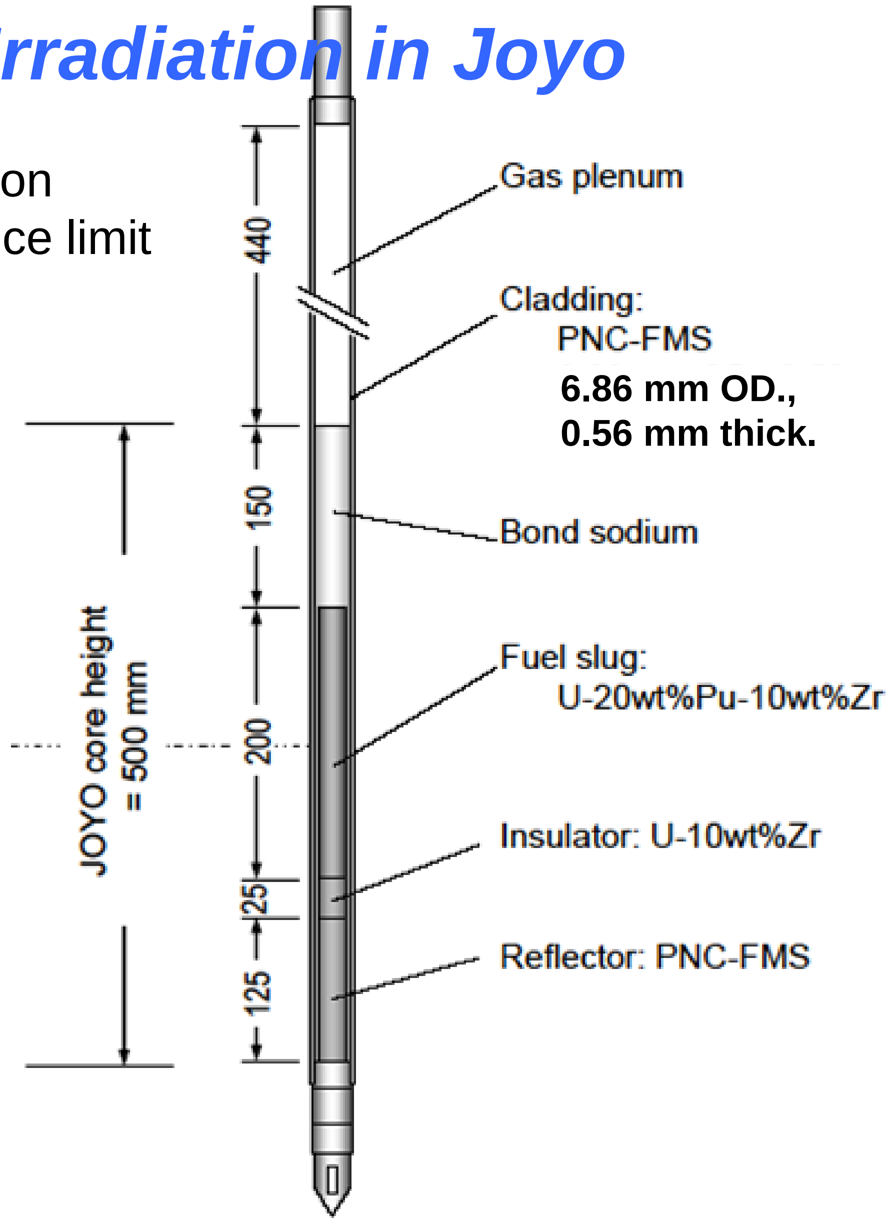
GACID: Global Actinide Cycle International Demonstration

U-Pu-Zr Metallic Fuel Pin Irradiation in Joyo

- High clad. temp. = fuel-clad. Compatibility evaluation
- High smear density = FCMI evaluation in a tolerance limit
- Begin with ferritic-martensitic steel clad.
- To be extended to ODS steel clad.

Major parameters of test fuel pins

Pin No.	Slug OD [mm]	Smear density [%TD]	Peak linear heat rate (target) [W/cm]	Clad. temp. (clad. inner surface) [°C]	Peak burnup [GWd/t]
#1	5.05	77.4	>450	650	30
#2	4.95	74.4	>450	650	30
#3	5.05	77.4	>450	620	80
#4	4.95	74.4	>450	620	80
#5	5.05	77.4	>450	620	>100
#6	4.95	74.4	>450	620	>100



Conclusions

- Fuel development for future fast reactors are in progress as a part of FaCT project in Japan.
- Developmental effort includes irradiation tests, fuel fabrication technology development and out-of-pile studies such as fuel property investigations.
- Future fuels will be realized through Joyo irradiation tests and Monju demonstrations.
- International collaborative effort is also an important part of such activities.