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# Design Study of Minor Actinide Bearing Oxide Fuel Core for Homogeneous TRU Recycling Fast Reactor System

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# Introduction

## *FBR development program in Japan*

**FS (1999-2005)**
Feasibility Study on Commercialized Fast Reactor Cycle System

→

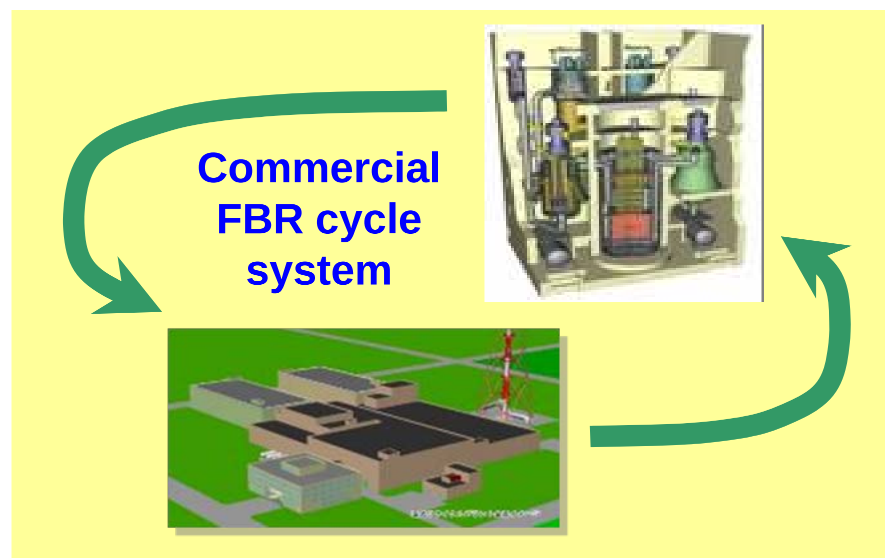
**FaCT Project (2006-2015)**
Fast Reactor Cycle Technology Development Project

- Clarification of several promising candidates for FBR cycle system

- Establishment of the most prominent FBR cycle system technologies

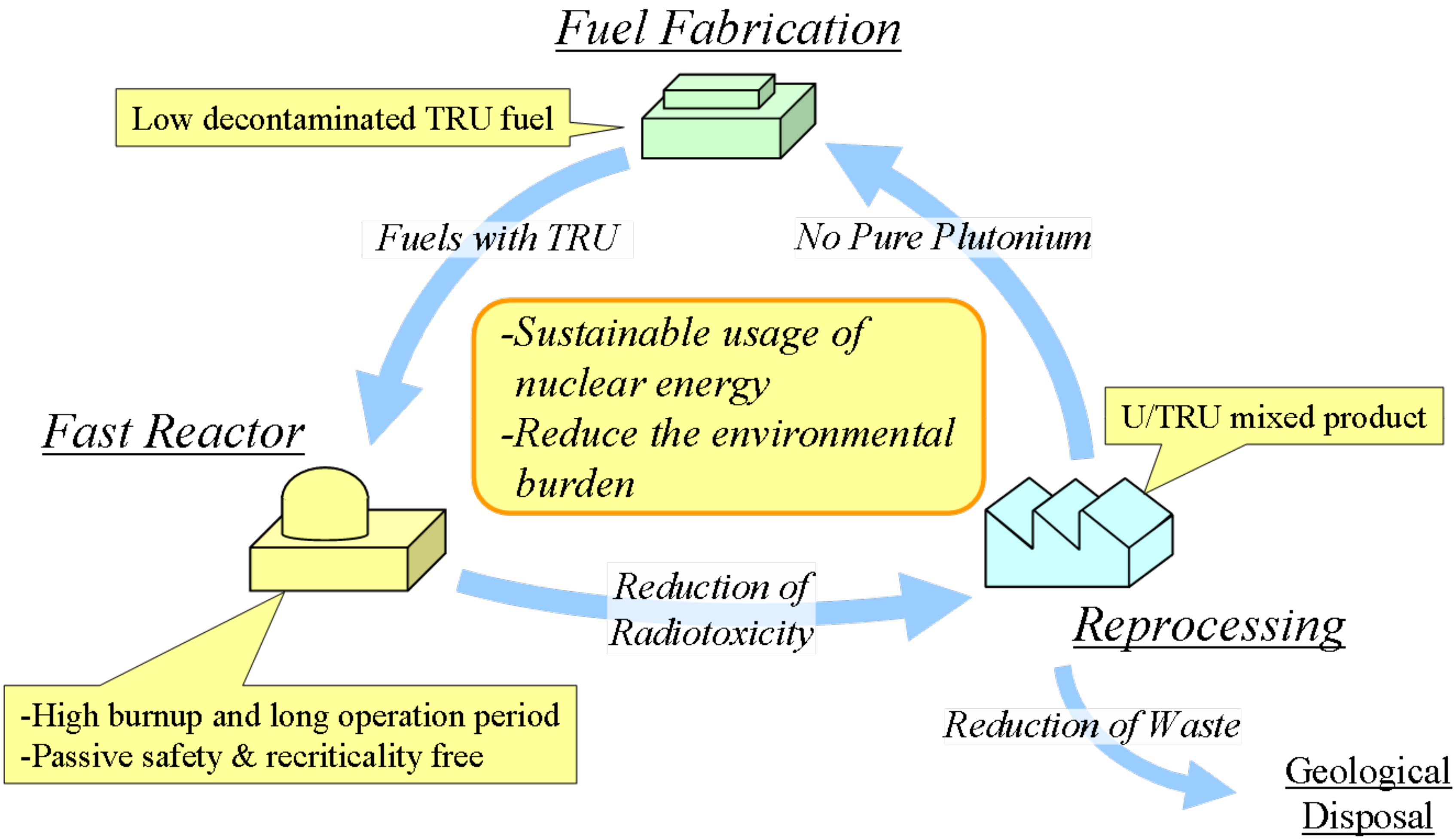
## *The reference concept*

- The reference core concept: JSFR MOX fuel core **"High internal conversion" type**
- TRU recycling mode: **Homogeneous**



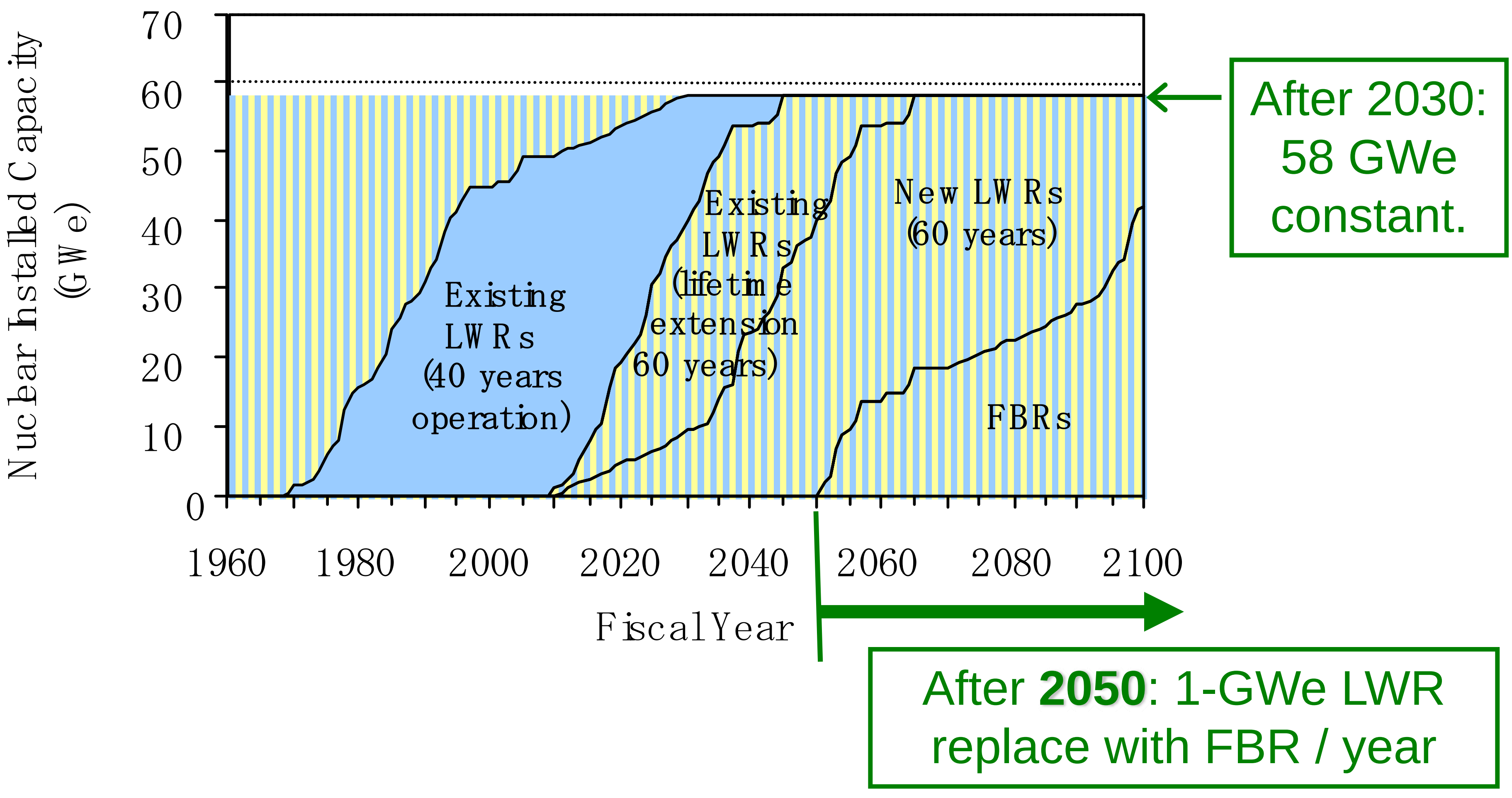

JSFR: Japan Sodium-cooled Fast Reactor

# Concept of FBR cycle system in FaCT Project



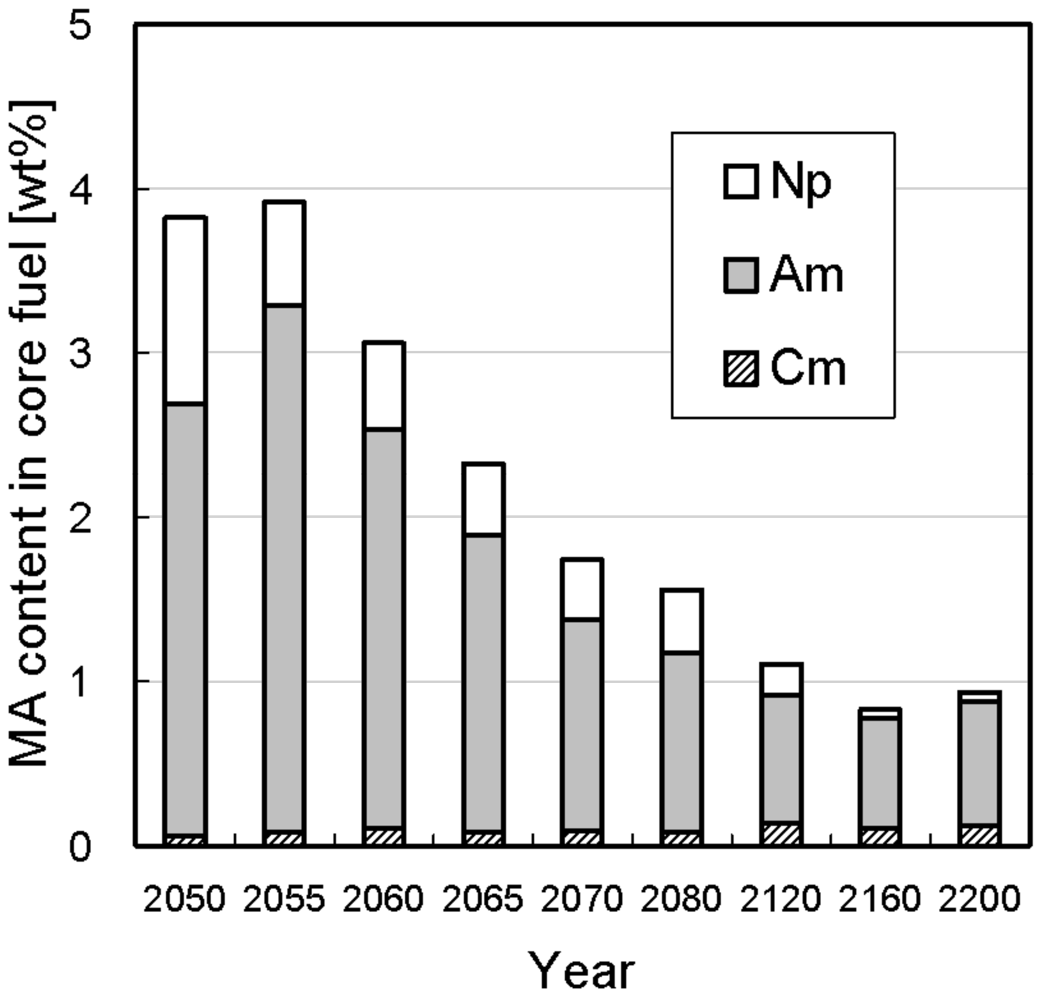

**Homogeneous TRU Recycling**

# Typical Japanese nuclear installed capacity




- TRU composition will change dynamically in the LWR-FBR transition stage.

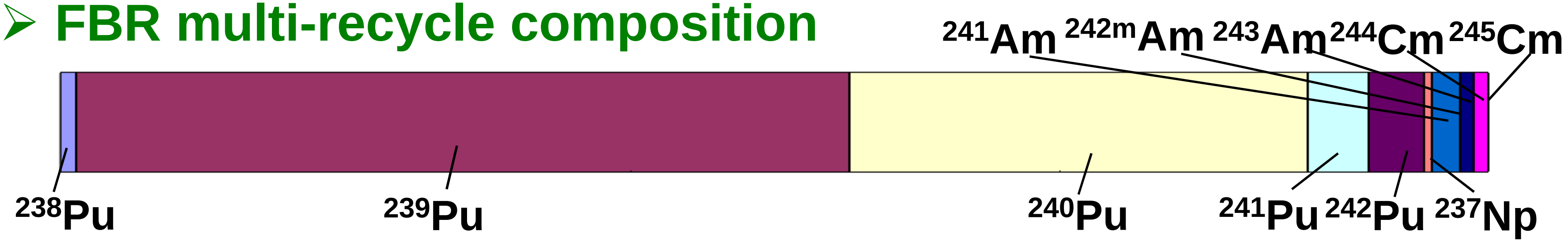
# MA content in the LWR-FBR transition stage




**An example of MA content change after the start of FBR deployment in 2050**

- MA content in the fuel will vary from 1 wt% to approximately 5 wt%.
- Two representative TRU compositions were selected for core design study:
  - FBR multi-recycle composition
  - LWR spent fuel composition

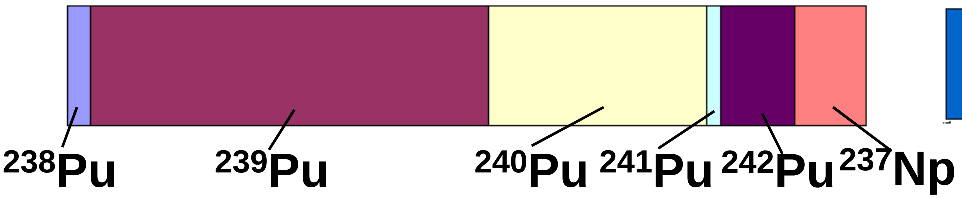
## FBR multi-recycle composition




## LWR spent fuel composition

- Conditions of LWR spent fuel
  Reactor type: ALWR, Burnup: 60 GWd/t, Storage period: 40 years
- Am and Cm were recovered separately from Pu and Np.

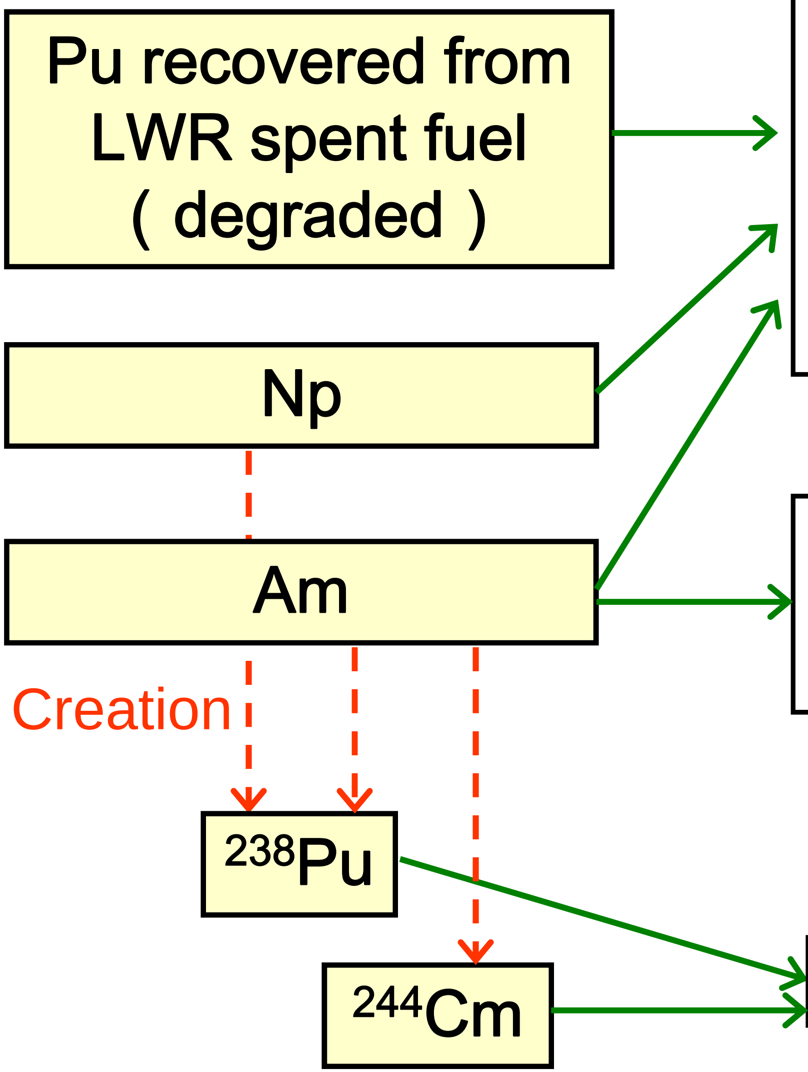
**[Pu + Np]**




**[Am + Cm]**


- Am and Cm were blended to Pu and Np so that the total MA content in heavy metal would be **3 wt%**. (typical content; the first design target)

# Effect of TRU on FBR core and fuel design




## Core design

- **Improvement of burnup characteristics**
  (burnup reactivity, breeding ratio, power mismatch)
- **Influence on safety-related reactivity coefficients**
  (sodium void reactivity, Doppler coefficient)

## Fuel design

- **Increase of inner gas pressure by helium production**
- **Reduction of linear power limit**

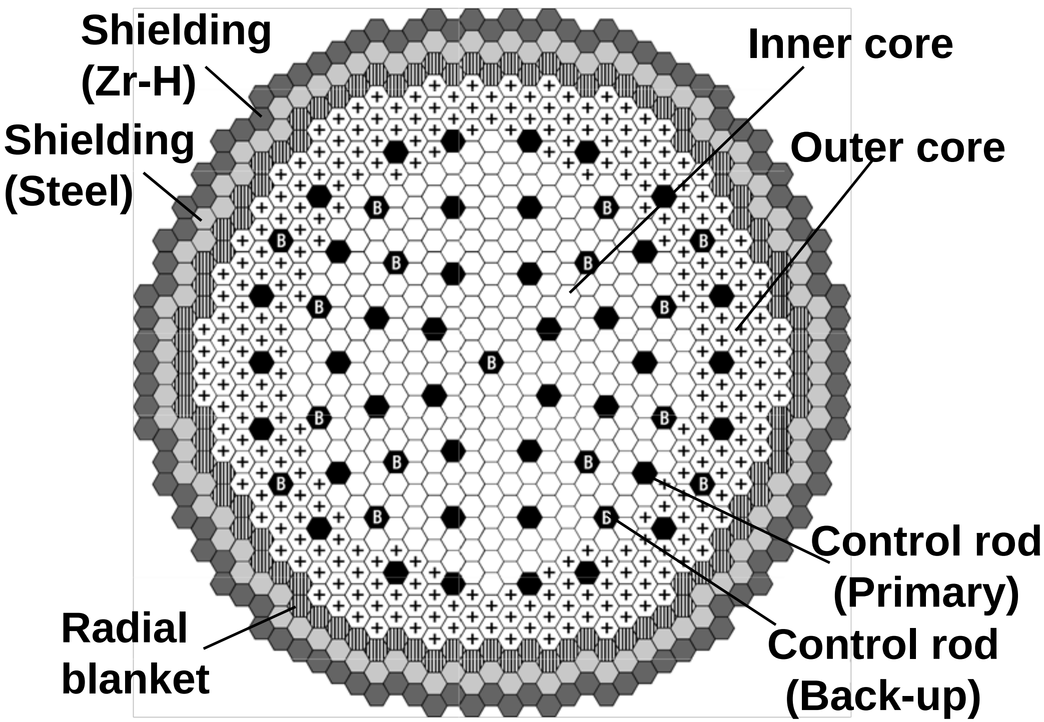
*cf. Naganuma, et al., this conference*

## Fuel fabrication and transport

- **Increase of fresh-fuel decay heat**

< JSFR MOX Fuel Core >

# "High Internal Conversion" type core




**Core configuration of large-scale HIC type core (1500 MWe)**

Breeding ratio: 1.03 ~ 1.1

Large fuel pin diameter (**10.4 mm**)

↓

Increasing fuel volume fraction

↓

Increasing internal conversion rate

↓

Reducing the amount of blanket

↓

Increasing total average discharge burnup (including blanket) (90-115 GWd/t)

Long operation cycle length (26.3 month (800 d))

**Economical advantages**

# Design conditions for MOX fuel core in the FaCT Project

## ◆ Safety and Reliability

- Sodium void reactivity: less than 6$
- Core specific power: more than 40 kW/kg-MOX
- Core height: less than 100 cm
- Recriticality-free: FAIDUS type subassembly

## ◆ Sustainability (*waste management, efficient utilization of nuclear fuel resources*)

**Current interest** →

- MA contents in the fuel: <u>from 1 to 5 wt%</u>
- Breeding ratio: 1.03~1.1 (for low breeding core)
  1.2 (for high breeding core)

# Development Targets for MOX fuel core in the FaCT Project (Continued)

## ◆Economic Competitiveness

- Operation period: more than 24 months
- Average discharge burnup

  for driver fuel: 150 GWd/t

  for whole core including blanket:

  80 GWd/t (for low breeding core)

  60 GWd/t (for high breeding core)

## ◆Nuclear Non-Proliferation

- Low decontaminated fuel
- Options to limit the generation of high-grade Pu

# Other design conditions for large-scale MOX fuel core

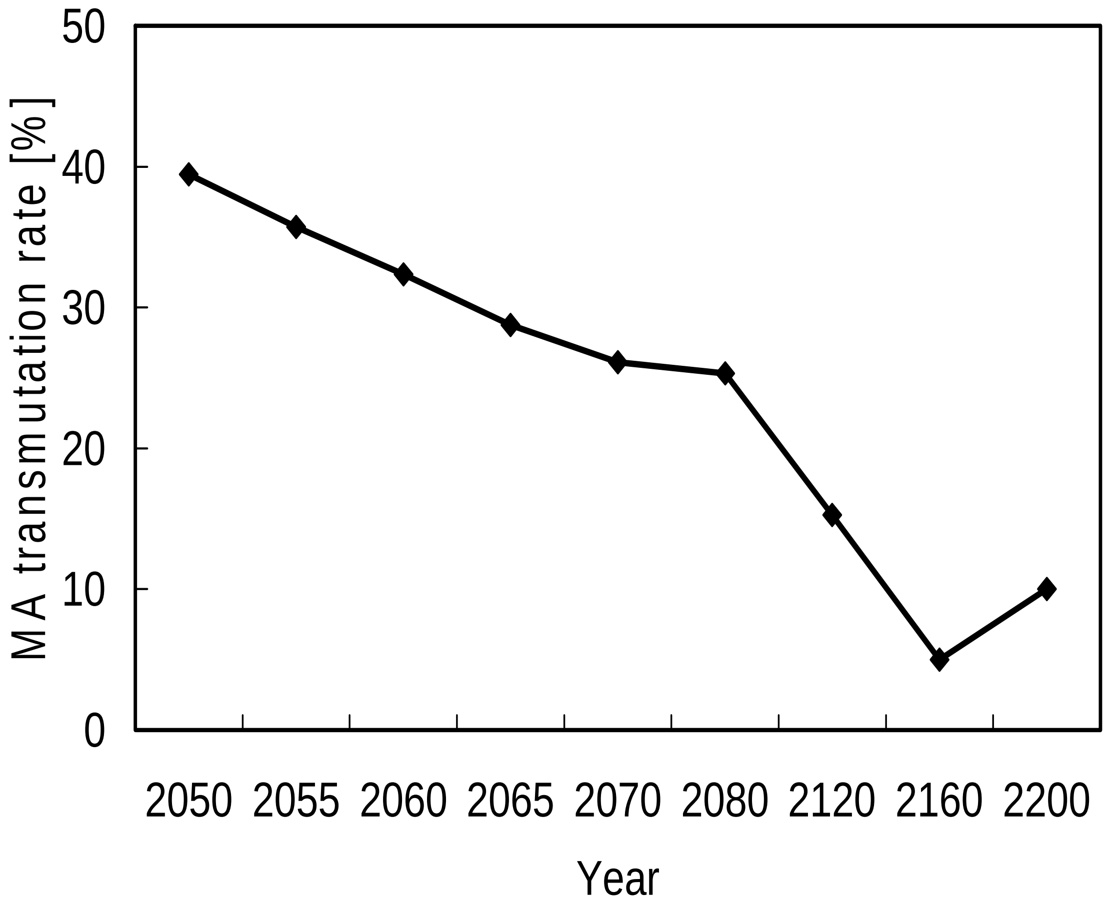
- Plant conditions
  - Power output : 1500 $MW_e$ / 3530 $MW_t$
  - Coolant temperature (outlet / inlet): 550 $^oC$ / 395 $^oC$
  - Shielding region diameter: less than about 7.0 m
- Thermal hydraulic condition
  - Maximum cladding mid-wall temperature: 700 $^oC$
  - Bundle pressure drop: less than about 0.2 MPa
- Fuel integrity limits
  - Maximum linear power: less than about 430 W/cm
  - CDF (steady state): less than 0.5
  - Maximum fast neutron fluence (E>0.1 MeV):
    less than about $5\times10^{23}$ n/cm$^2$

# Results of MA bearing fuel core design

| Item | Reference core | MA bearing fuel core |
|---|---|---|
| **TRU Composition** | **FBR multi-recycle** (MA: 1 wt%) | **LWR spent fuel** (MA: 3 wt%) |
| **Core height [cm]** | **100** | **100** |
| **Axial blanket thickness (upper / lower) [cm]** | **20 / 20** | **15 / 20** |
| **Gas plenum length (upper / lower) [mm]** | **100 / 1100** | **100 / 1150** |
| **Pu enrichment (IC / OC) [wt%]** | **18.2 / 20.6** | **19.6 / 22.1** |
| **Burnup reactivity [%dk/kk']** | **2.5** | **1.8** |
| **Breeding ratio** | **1.1** | **1.1** |
| **Sodium void reactivity (EOEC) [$]** | **5.2** | **5.9** |

The HIC type core enables to accept the typical MA containing fuel (up to 3 wt% of MA content) with slight modifications of core specification.

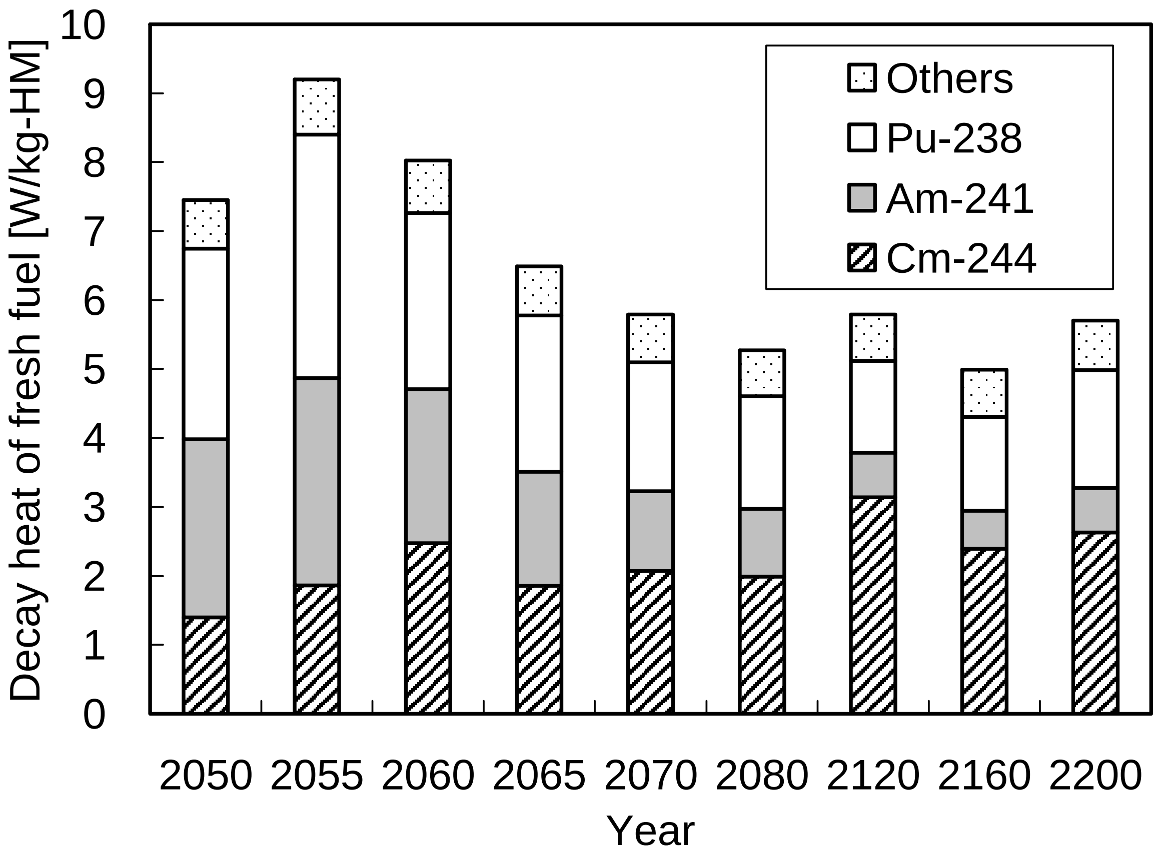
# MA transmutation rate during the LWR-FBR transition stage




**MA transmutation rate after the start of FBR deployment in 2050**

- MA transmutation rate is about **30~40 %/fuel life** if the MA content in fresh fuel is 3~5 wt%.
- The transmuted MA amount corresponds to the MA from 3~4 LWRs of the same reactor power.

# Fresh-fuel decay heat during the LWR-FBR transition stage (an example)




**Fresh-fuel decay heat after the start of FBR deployment in 2050**

- The present results have enough allowance to the tentative upper limit (20 W/kg-HM).
- If the recycle system is designed not to concentrate the heat source nuclides on particular fuel, the actinide management could be feasible.

# Conclusion

- In the FaCT project, conceptual design studies of sodium-cooled MOX fuel core for JSFR have proceeded with focusing on the TRU composition change during the reactor transition stage from LWRs to FBRs.
- The reference “high internal conversion” type core enables to accept a typical MA containing fuel with slight modifications of core specification.
- The MA transmutation rate is found to be about 30~40 % per fuel life if the MA content in fresh fuel is 3~5 wt%.
- The homogeneous TRU recycling has the advantage that it can provide a feasible solution to the increase of fresh-fuel decay heat due to the source nuclides ($^{244}Cm$, $^{238}Pu$, etc.).

< JSFR MOX Fuel Core >

## Fuel Assembly with Inner Duct Structure (FAIDUS)

- FAIDUS has inner duct installed at a corner, and a part of upper shielding element is removed.

- At CDA (Core Disruptive Accident), molten fuel enters the inner duct channel and goes out into the outside through the upper shielding.

FAIDUS has superior performance for discharge of molten fuel to prevent compaction of it.