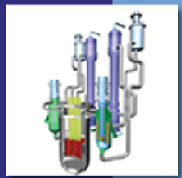
FR09, Kyoto, Japan, December 7-11, 2009



International
Nuclear
Recycling
Alliance

Enhancing Minor Actinide Transmutation in ARR

International Nuclear Recycling Alliance

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Outline

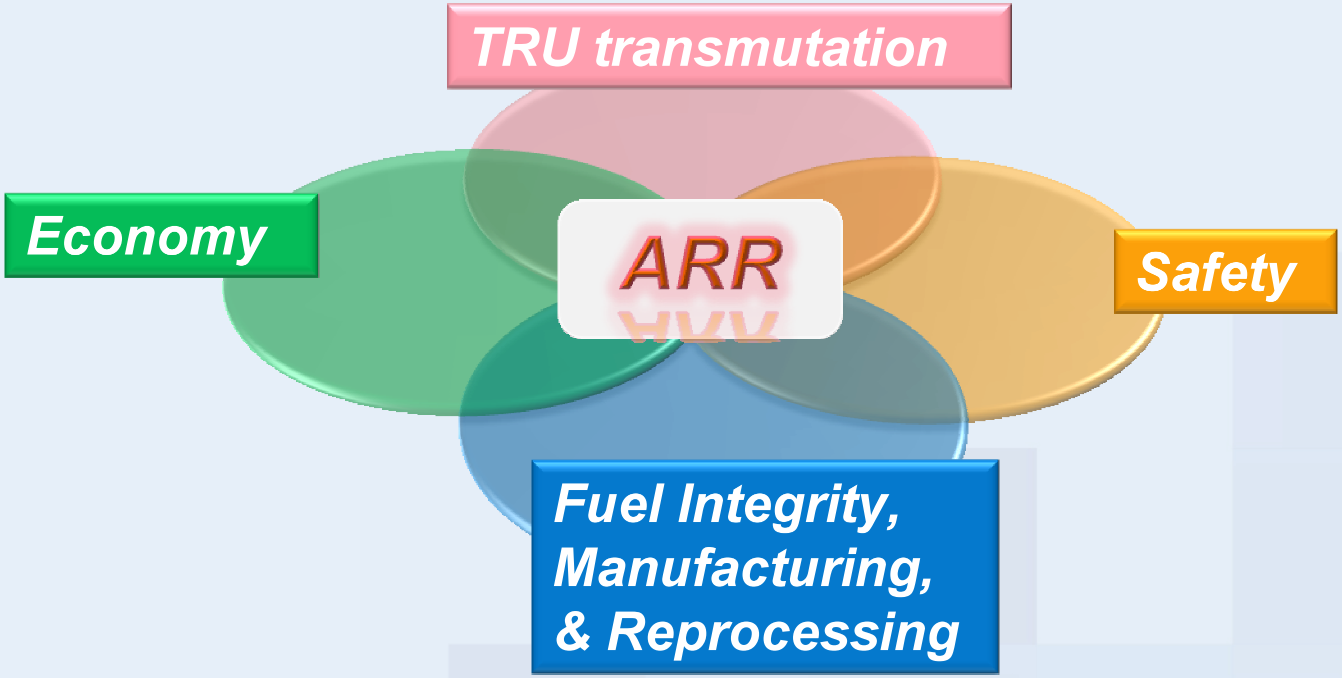
- ▶Objectives
- ▶Scope and Requirements of ARR core design
- ▶Optimization of Am blanket in ARR
  - Am type: Oxide and Nitride
  - Other parameters
    - Am blanket fuel life
    - Dimensions of Ax. and Rd. Am Blanket
  - ARR performance
- ▶Conclusions

Objectives

GNEP projects: For closed fuel cycle, Advanced Recycling Reactor (ARR) has been developed to enhance TRU or MA burning, especially Am which has a high decay heat and high radioactivity.

How can Am be transmuted by Am blanket effectively?

INRA's Strategy
Concepts of Early ARR and Future ARR



Early ARR

2025～

Matured technology

Future ARR

2050～

Innovative technology

Scope and Requirements of ARR core

	2025～	2050～
Core/ Policy	Early ARR core/ matured Technologies	Future ARR core/ Expecting Future Achievements, innovative technologies
Scope	1.Survey of Specification 2. Sustainability of Recycling 3. Accommodation to several kinds of TRU	1. Enhanced TRU burning core •High Am content and Moderator pins 2. Enhanced MA transmutation core •Am blanket
Conditions	TRU CR:~0.6 (Early ARR): ~ 40kgTRU/TWeh Void reactivity < $6 * Shutdown margin of primary and secondary CRs > $1, respectively* MLHR depended on TRU enrichments, 430 W/cm* at most Fast neutron Fluence (>0.1MeV) < 5.0E+23 n/cm2 Fresh Fuel Heat Generation < 6.0 kW/assy	

*The safety requirements are the same as JSFR.

Optimized Am blanket

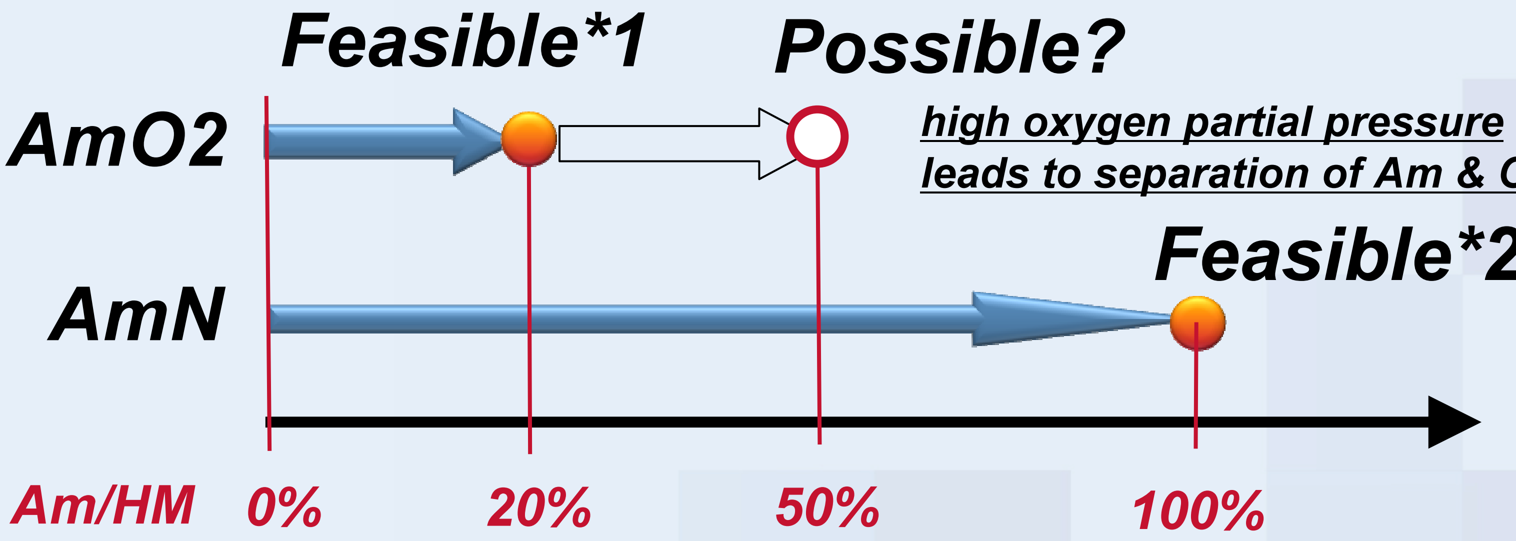
- Am blanket type ((Am, U)Ox, AmN)
- Other Parameters
- Performance in designed ARR

How to decide Am blanket type

	(Am, U)Ox	AmN
Technological Feasibility	Am/HM 20% Feasible*	Am/HM 100% Feasible*
Heat generation of fresh fuel (6kg of HM in subassembly)	Practicable (3kW/assy)	Challenging (6kW/assy)
Am transmutation capability	Good	Better
Power rise by Pu accumulation	Good	Better

***(20% Am, U) Ox and AmN is being developed in JAEA**

Why is AmN blanket promising?
Technological Feasibility



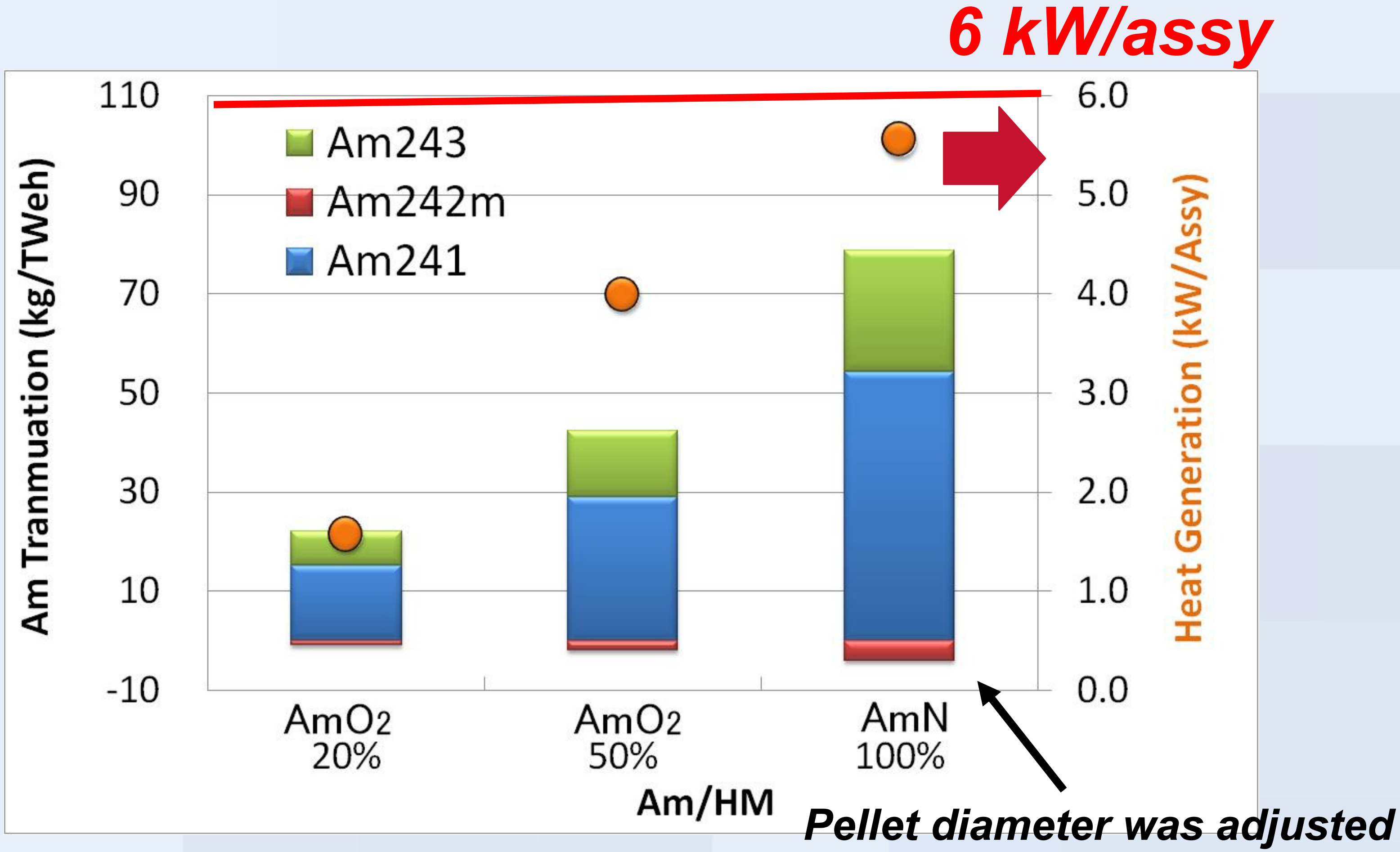
AmN can be Uranium-free blanket.

1, *2developed by JAEA through production & irradiation test

*1 K. Tanaka, Evaluation of MA recycling concept with high Am-containing MOX (Am-MOX) fuel and development of its related fuel fabrication process, Global 2009,

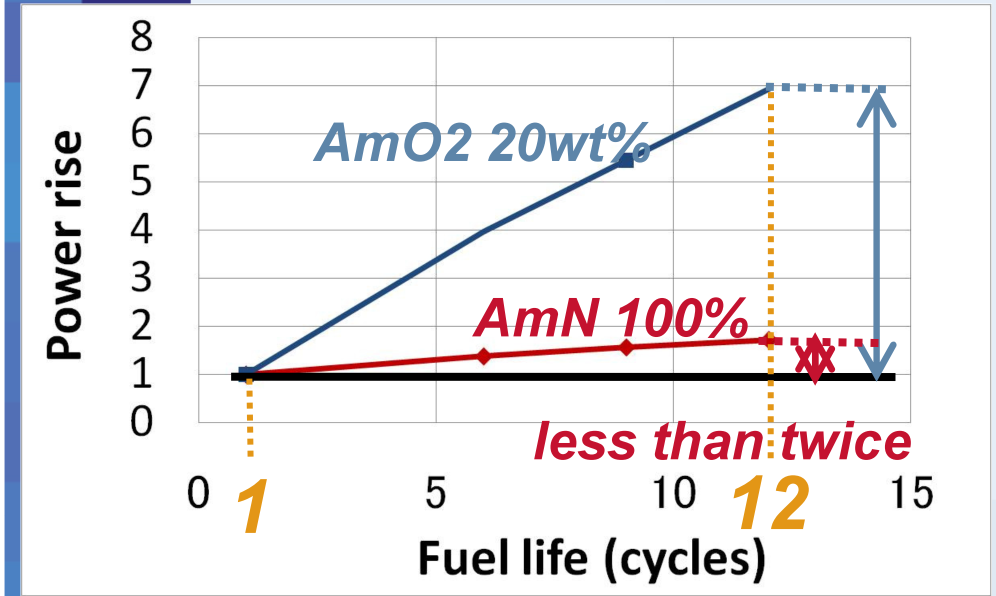
*2 Y. Arai, et al, Progress of Nitride Fuel Cycle Research for Transmutation of Minor Actinides, Global 2007,

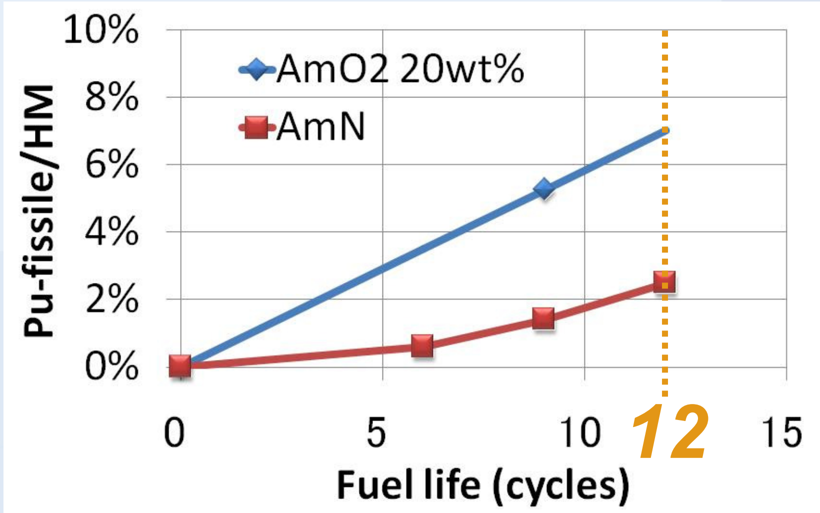
Why is AmN blanket promising?
Am transmutation & Heat generation of fresh fuel



AmN blanket : High Am transmutation & feasible in the heat generation issue

Why is AmN blanket promising?
Power rise by Pu accumulation





AmN does not cause high power rise during irradiation because of low Pu-239 production.

Optimization of Other Parameters

- *Am blanket life*
- *Length of upper/lower axial blanket*
- *Number of radial blanket*

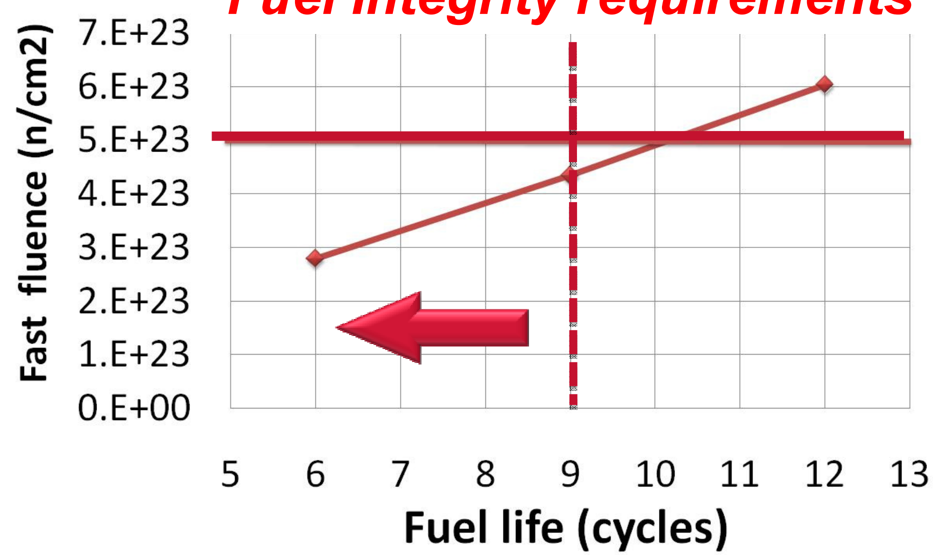
Fuel life of Am blanket

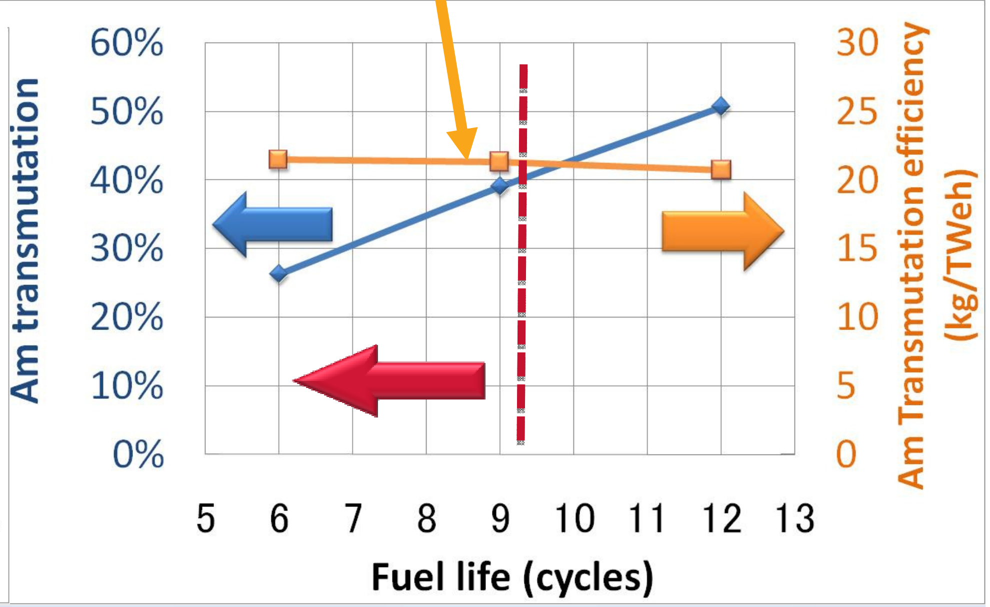
Limit from fuel Integrity

Am transmutation efficiency

Almost same Am transmutation capability

Fuel Integrity requirements





730 day/cycle

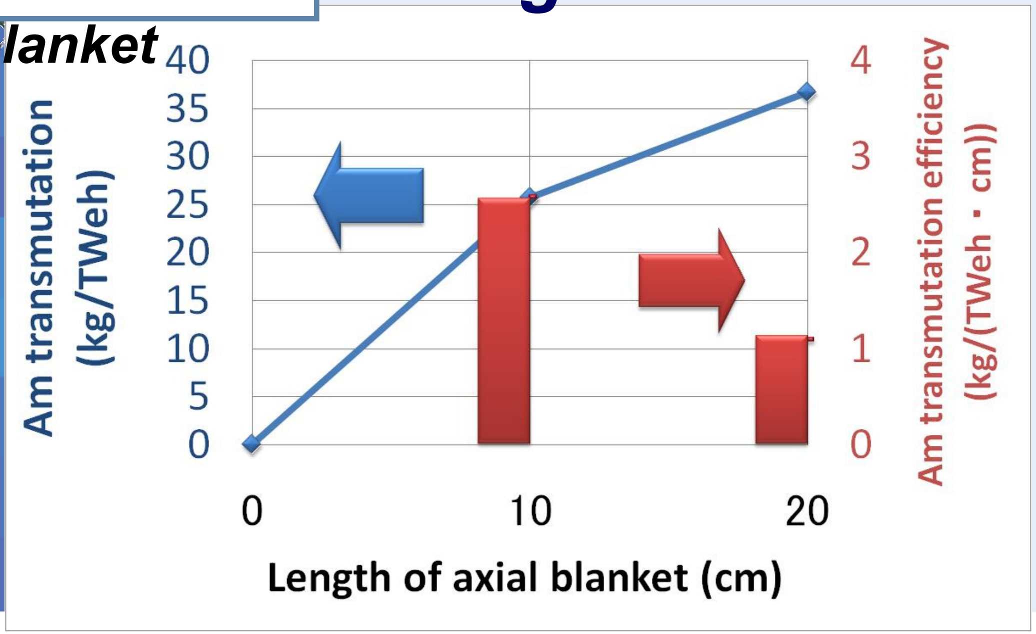
Fuel life (cycles)

Small Recycled Amount

Fuel Life of Am Blanket : 9 cycles

Length of ax. blanket & No. of rd. blanket

Axial blanket



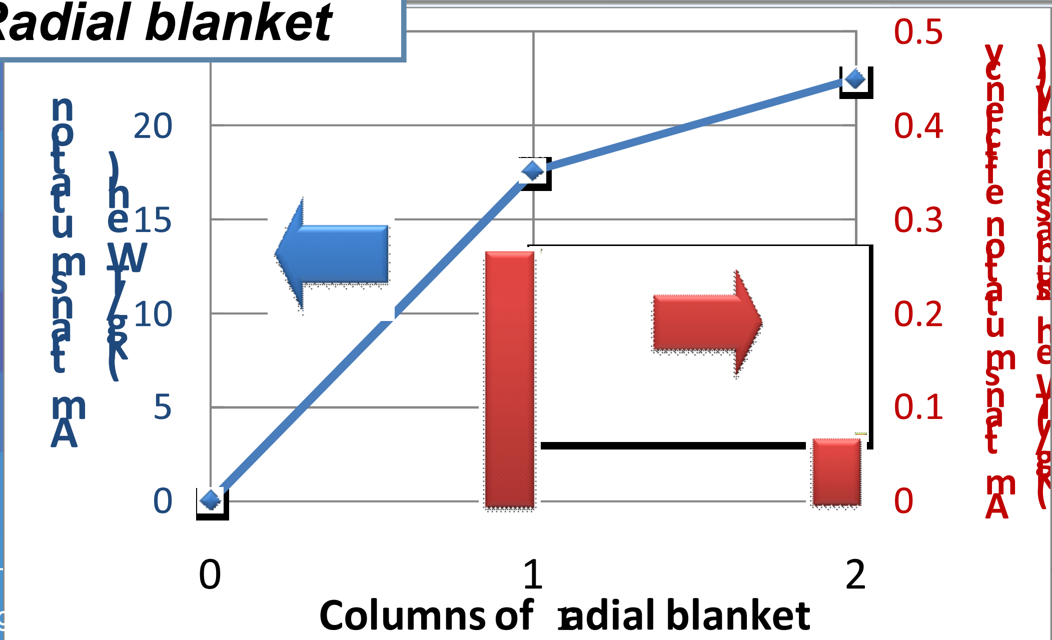
Trade-off of Am transmutation and recycled amount

Length of Ax. Blanket

→ **10 cm each**

→ **Large recycled amount**

Radial blanket

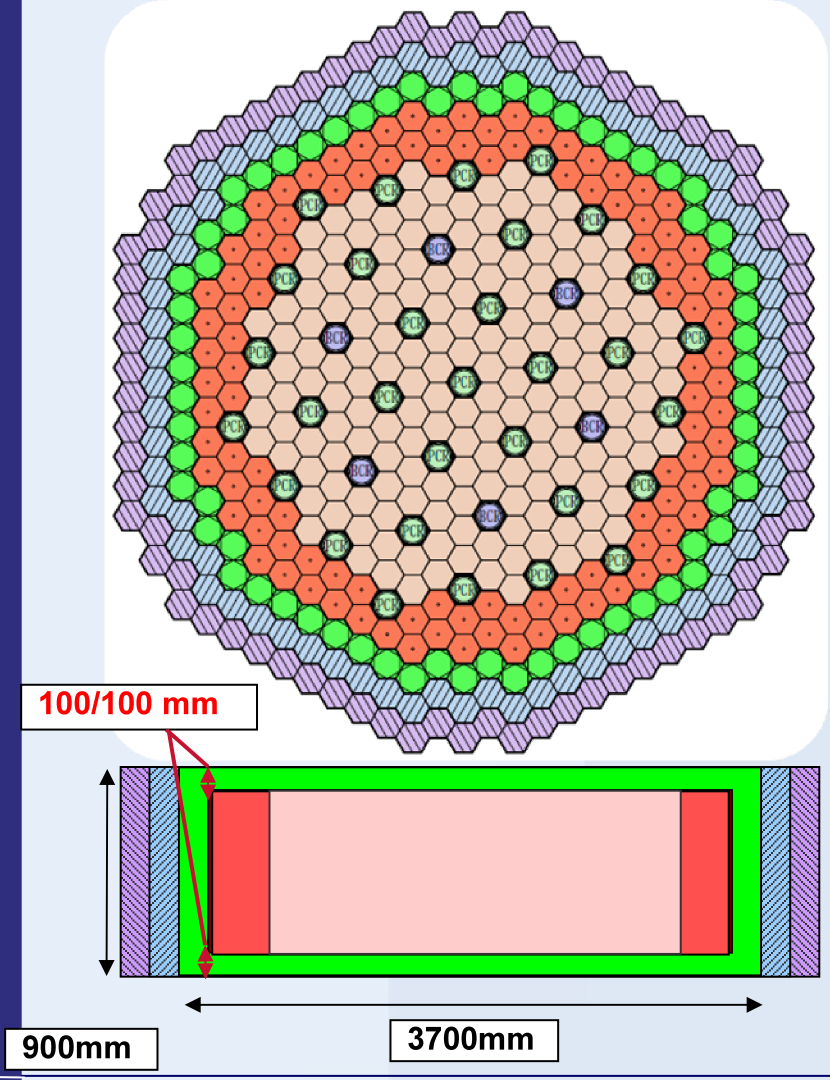


Number of Rd. Blanket

→ **66 /1 columns**

Core configuration of designed ARR

ARR with Blanket



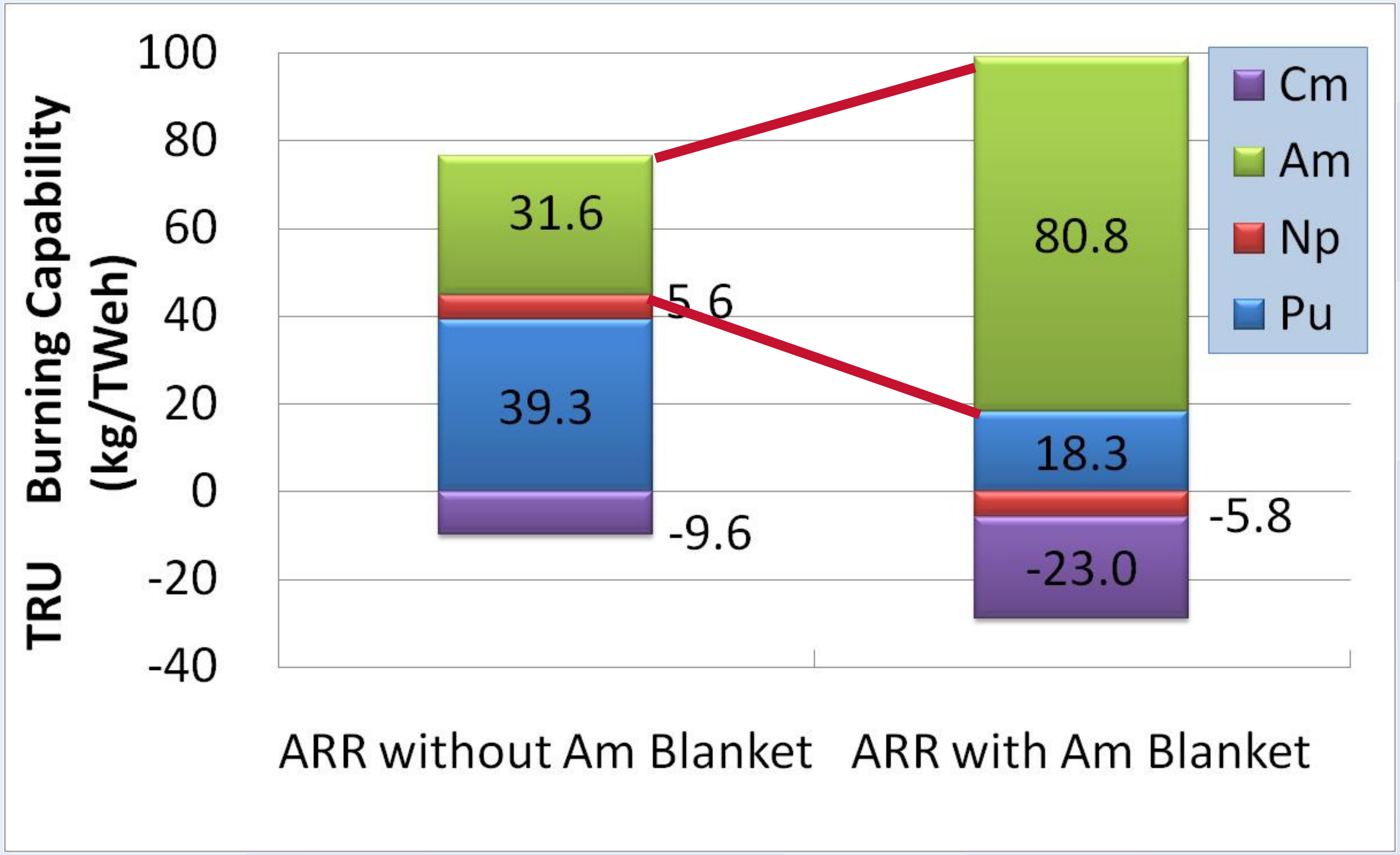
ARR Specifications	
Output	**1180MWt** **500 MWe**
Fuel	**Oxide**
Coolant	**Sodium**

	Inner Core	168
	Outer Core	108
	Control Rod(Primary)	31
	Control Rod(Back up)	6
	Radial Shield(SUS)	72
	Radial Shield(Zr-H)	78
	Am Blanket	66
	Total	529

Characteristics comparisons

	ARR core	
Blanket Type	Without blanket	AmN blanket
TRU/HM	50%	45%
Moderator pin ratio, $^{11}B_4C$	12%	15%
MLHR (core, blanket) (W/cm)	356, N/A	345, 368
Void reactivity ($)	5.7	5.3
TRU transmutation Am transmutation (kg/TWeh)	67 32	70 81

Performance of Am blanket
Am transmutation capability



By AmN blanket,

Am transmutation increases by 2.5 times.

Am Mass balance between ARR and LWR

Conditions of LWR used fuel

Ave. Discharged burnup	50 GWd/t
Storage time after discharging	6 years

Am transmutation

ARR with Am blanket

1GWe X 710 kg/GWey

=

Am production

LWR-UO2
56GWe X 13kg/GWey

LWR-MOX
31GWe X 23 kg/GWey

1GWe ARR with blanket can transmute Am from 56 plants of 1GWe LWR using UO2 fuel.

Conclusions

- In pursuit of Am transmutation in a closed fuel cycle, INRA team propose ARR core with AmN blanket (long duration time, high Am transmutation efficiency). It has Am transmutation capabilities of 81 kg/TWeh, 2.5 times higher than ARR without blanket, satisfying safety requirements.
- In other words, this 1GWe ARR can transmute Am from 56 plants of 1GWe LWR using UO2 fuel.

Thank you very much
for your kind attention.

Any comments or questions?

Feasibilities of core with Am blanket

- Several Technological difficulties

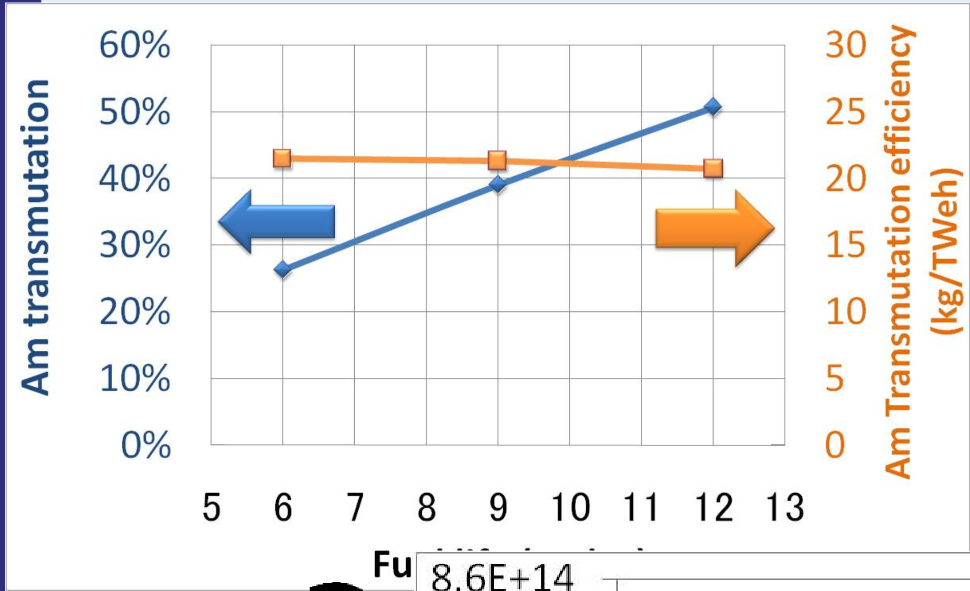
  Further R&D for

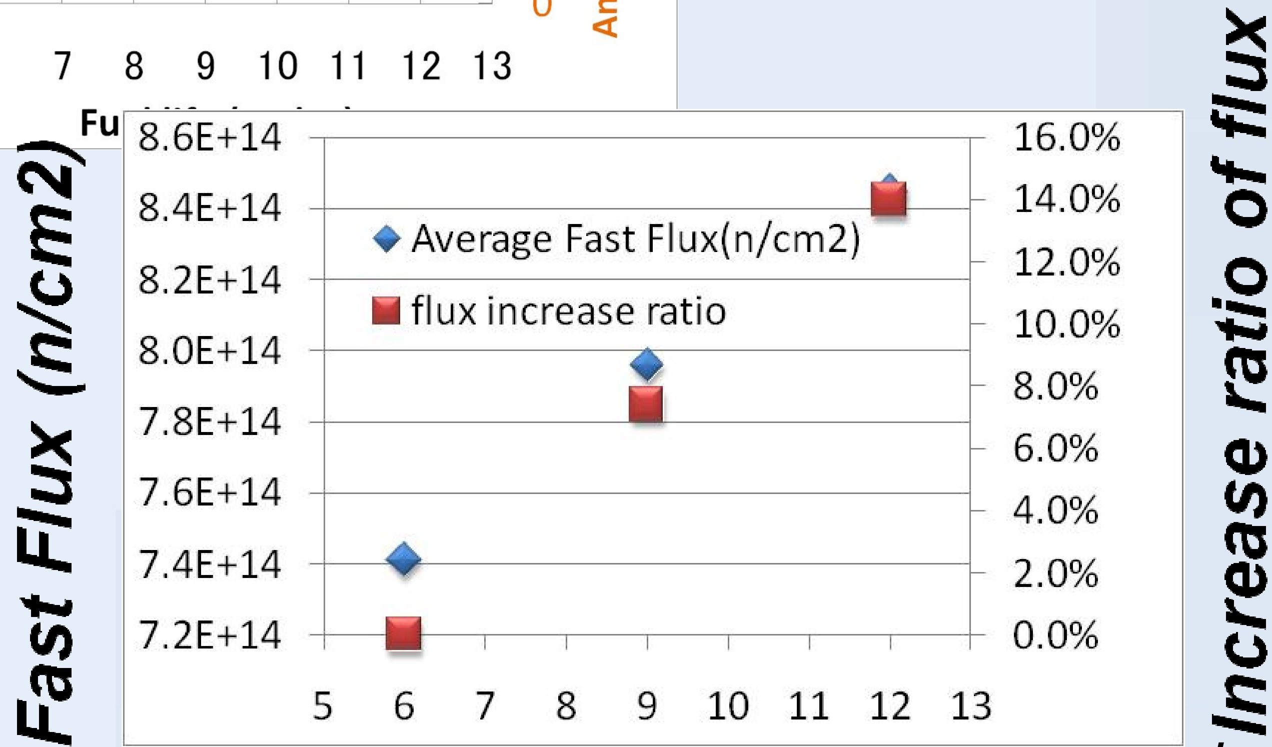
  - High MA containing fuel & nitride fuel
  - Manufacturing technology of MA bearing fuel
  - Irradiation tests of MA fuel
  - Assembling MA bearing fuel

    remote handling manufacture & forced cooling

    require 6 kW > current experience : 3 kW (MHI & JAEA)

Comparisons with each of equilibrium core



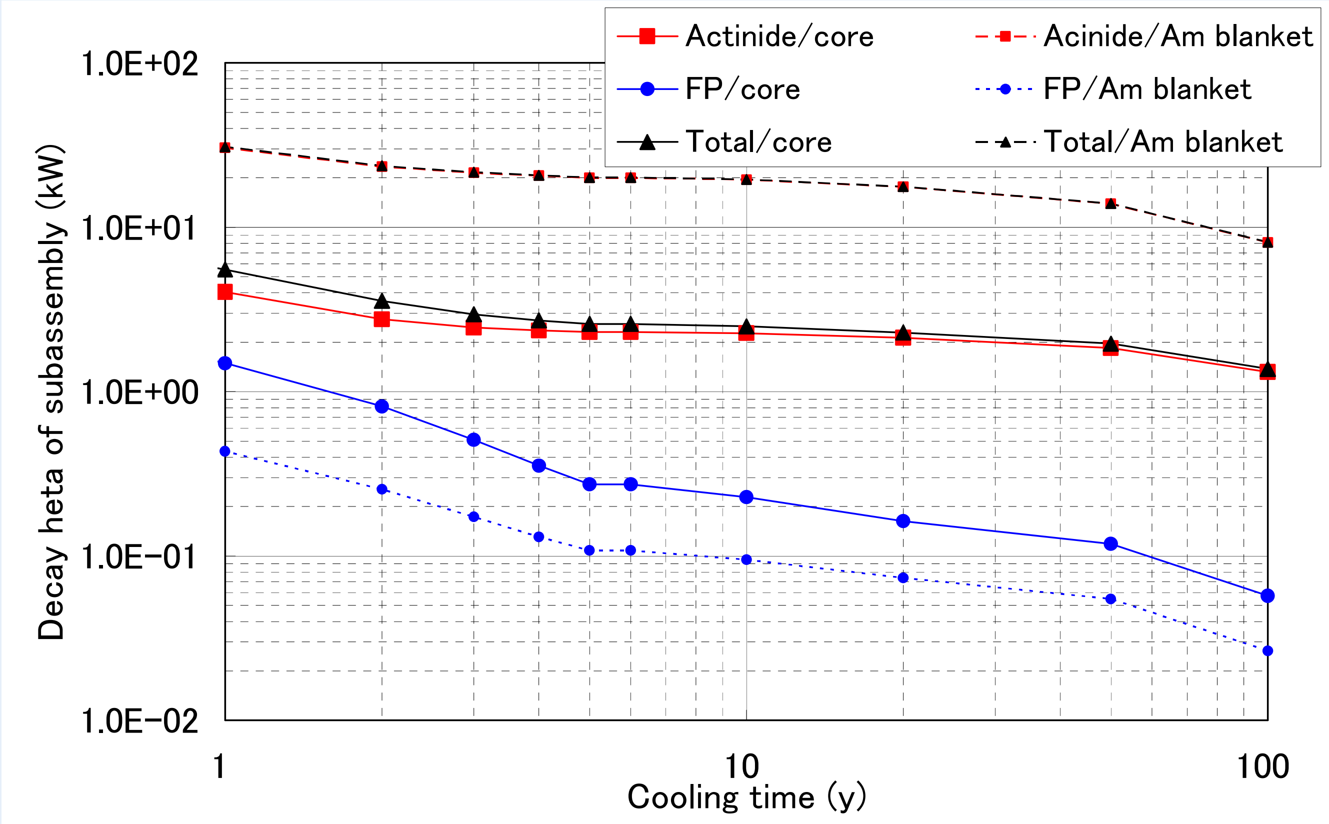


Power distribution of AmN blanket incrases

What is issues of Am blanket

- **Feasibilities** **Later**
- **High decay heat**

High Decay heat of 20 kW/assy until 20 years after discharging



High decay heat of the blanket by Cm-244 ***feasible***

Feasibilities concerning about decay heat

Decay heat level	Our prospectives
10kW	Feasible by forced air cooling
30kW	Feasible by Na. Some difficulty for transportation.

Early ARR and Future ARR

Parameter	Units	Early ARR	Future ARR	
		-	TRU burning core	MA tranmutation core
Thermal Power	MW	1180	1180	1180
Cycle length	EFPD	547/684	700	810
No. of Subassembly		276	276	276
Core Height	cm	70	70	70
Blanket		none	none	AmN
Moderator		none	$B^{11}4C$	$B^{11}4C$
Height of Axial Blanket (Lower/Upper)	mm	-	-	100/100
No. of Radial Blanket	mm	-	-	66
Cladding Thickness	mm	1	1	1
No. of Control Rod (Total/PCR/BCR)		37/31/6	37/31/6	37/31/6
No. of Pins		255	331	331
Fraction of moderator pins		0	12%	15%
No. of Exchange Fuel Batch		2/3	3	3
Volume Fraction of Fuel & Moderator		31.5%	30.7%	30.7%
Volume Fraction of Structure		31.6%	33.6%	33.6%
Volume Fraction of Void (fuel pins)		4.4%	4.6%	4.6%

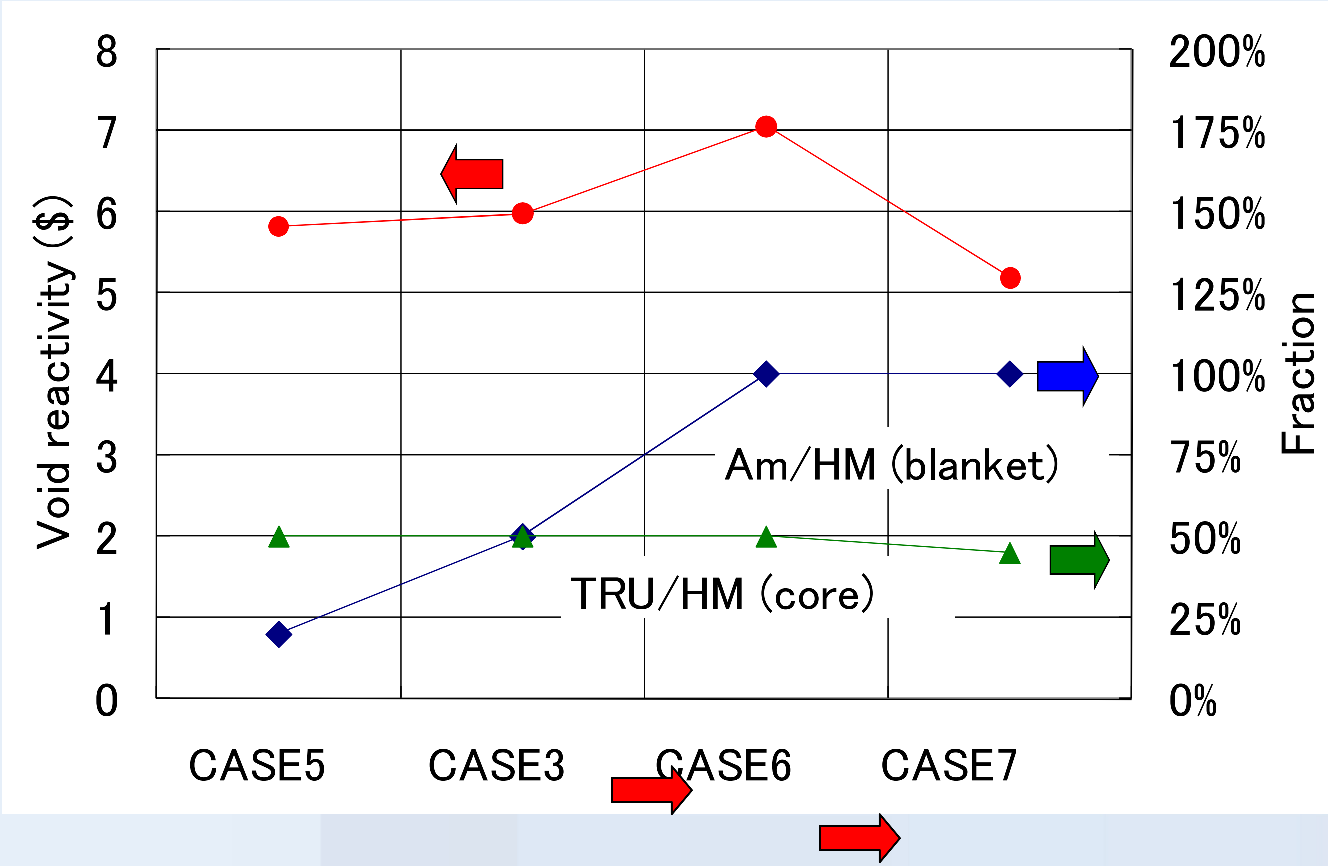
Detail of spcifications

Effective Full Power days	(days)	810
TRU Fraction (TRU/HM,wt%)	Core	45.0%
MA Fraction (Am/HM,wt%)	Inner Core	10.2%
	Outer Core	4.4%
	Am Target	
	Core	7.9%
	Total	45.4%
Assembly Pitch	(cm)	19.92
Number of Assembly	Inner Core	168
	Outer Core	108
	Am Target	0
	Radial Blanket	66
Moderator Fraction (vol%)		15.0%
Number of Fuel Pin	Core	281
	Radial Blanket	144
Number of Moderator Pin	Core	50
	Radial Blanket	25

Comparisons with AmN and AmO2

	Nitride	Oxide
Thermal conductivity	Several times higher	Almost same as UO2
Melting point		
MLHR	800～1000W/cm	～430W/cm
Problems	N-14 → C-14 radioactive (solution) Enrichment of N-15	Separation of Am and O2 (solution) Au linear plate in Russia

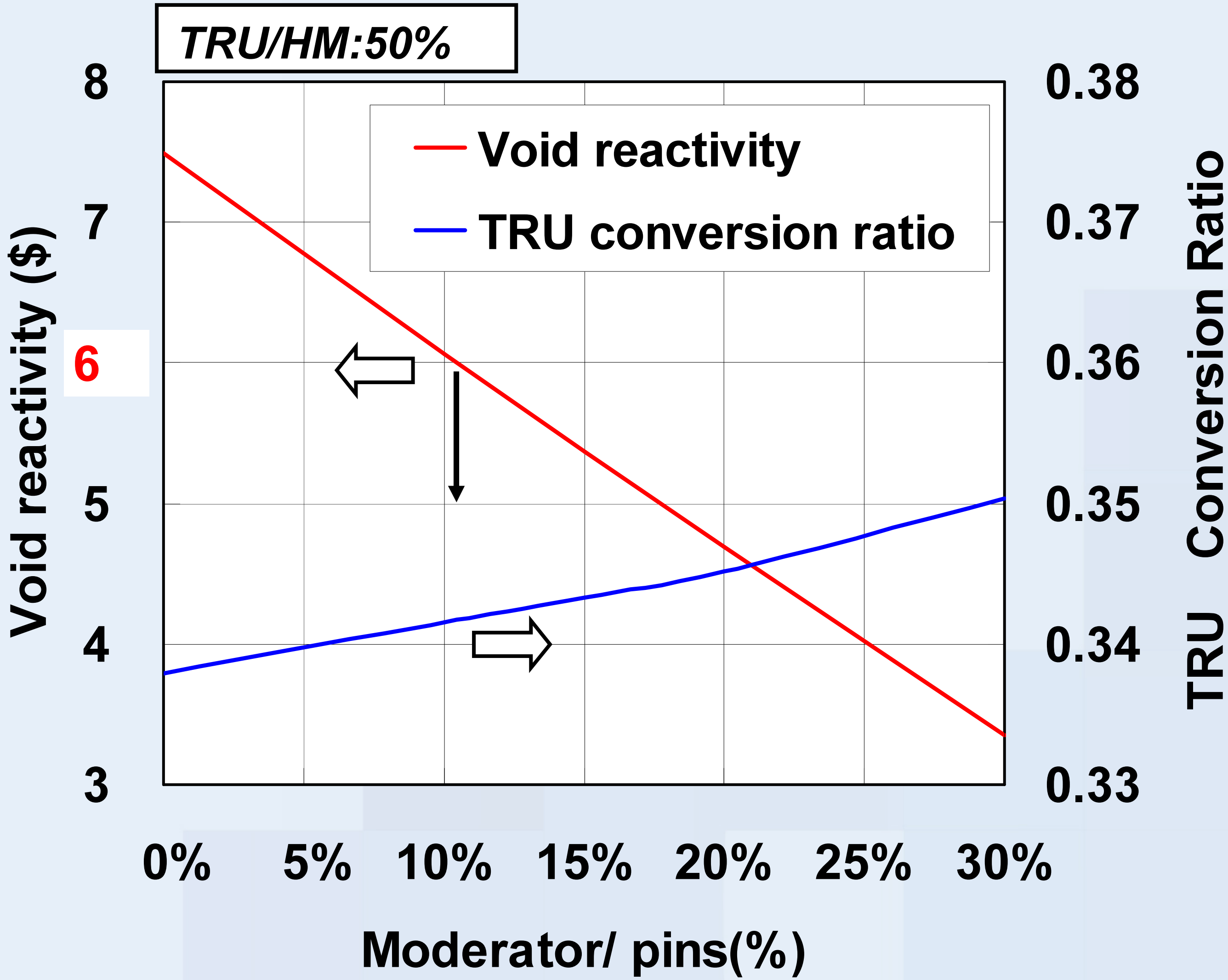
Some adjustments for Safety requirements



Moderator Pin : 15%

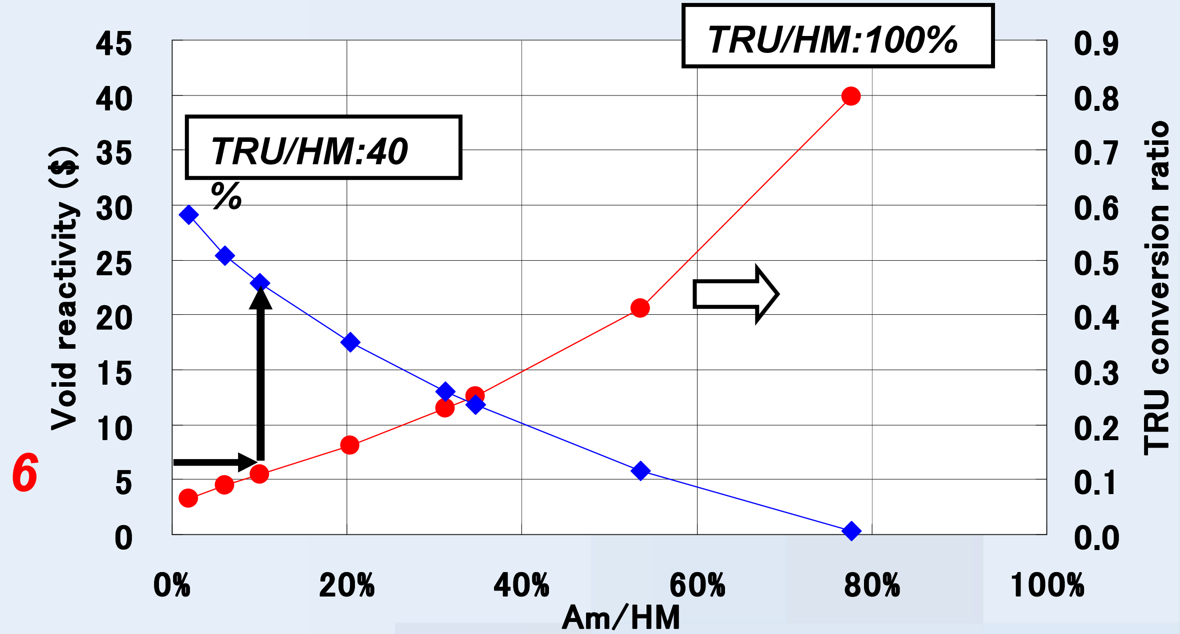
TRU/HM : 45%

Calculation Results
Moderator fraction (Step 5)



Moderator pins of 10% reduces the void reactivity to $6.

Calculation Results
Enrichment of Am contents (Step 4)



Am /HM:1.9%→10% Void reactivity:$3.3→$5.4,TRU CR:0.58→0.46

TRU conversion ratio = (RHM – RTRU)/RHM
RHM: mass consumption of HM between BOL and EOL
RTRU: mass consumption of TRU between BOL and EOL

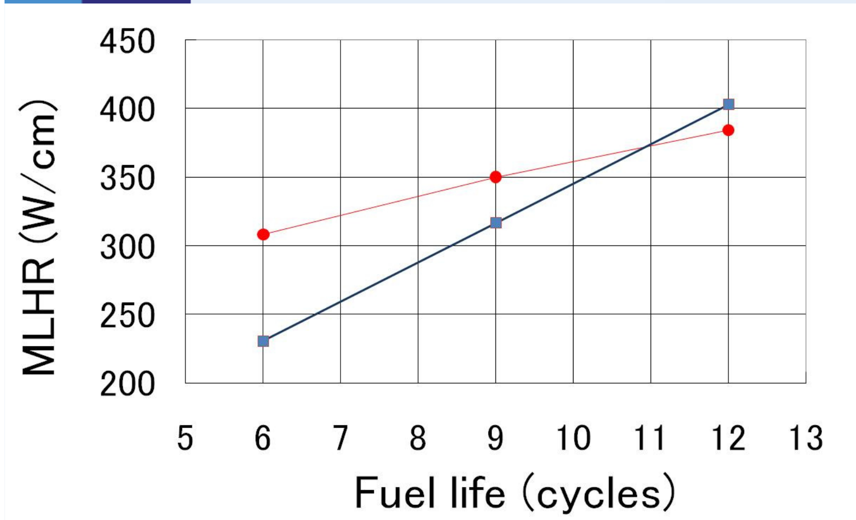
Void Reactivity

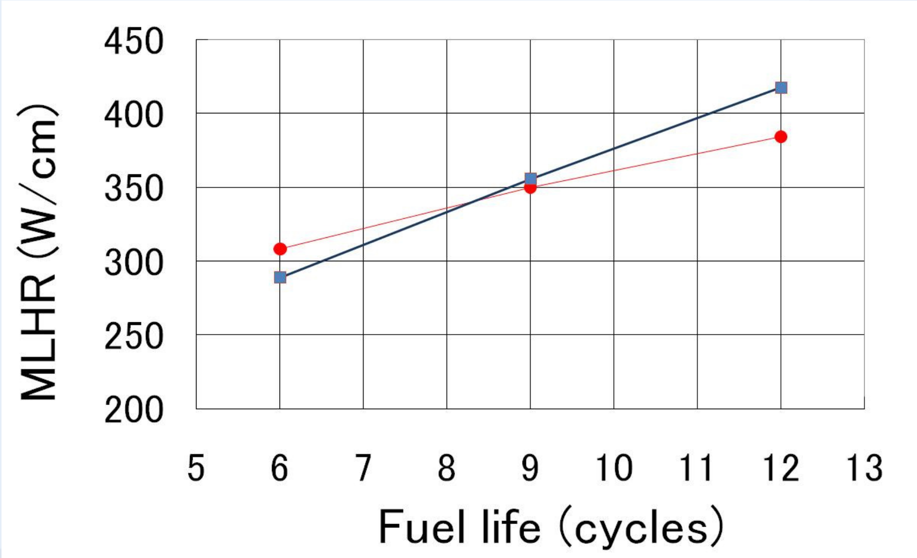
- **decrease of TRU/HM**
  - → **less TRU transmutation capability**
- **increase of Moderator Pin ratio**
  - → **increase maximum linear heat rate**

Trade off of these two parameters

Maximum Linear Heat Rate

AmN, AmO2 20wt% AmO2 50wt%

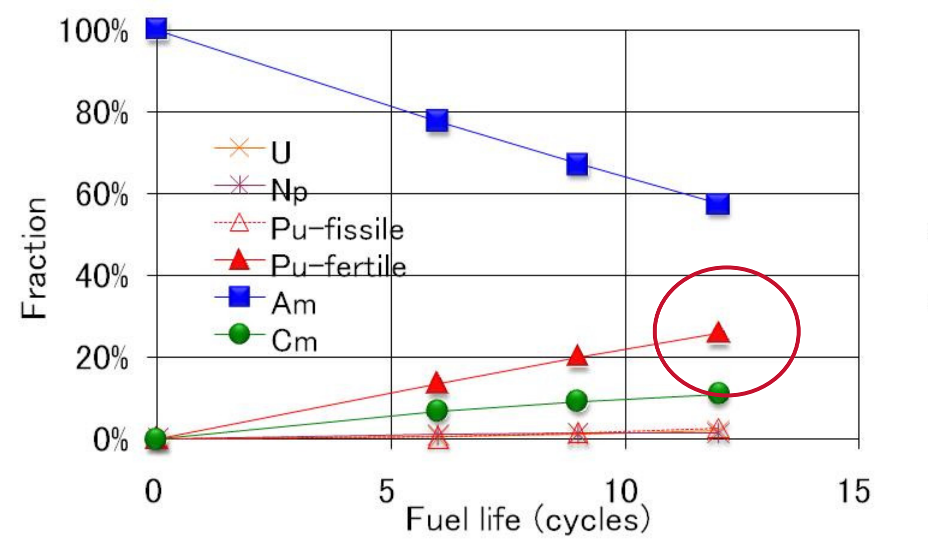




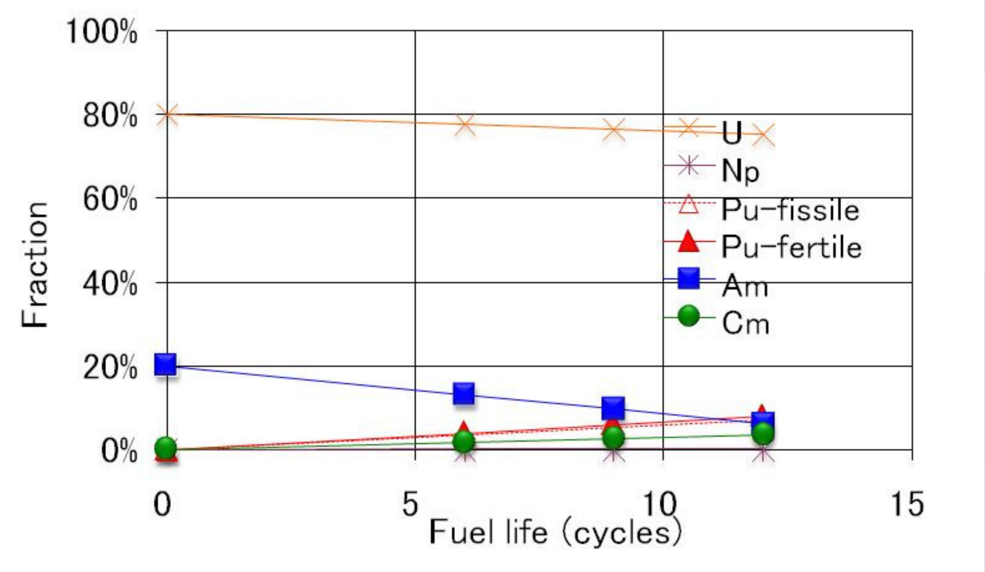
High Heat rise also leads to high sodium flow, and also leads to decrease of outlet temperature.

Am blanket components during irradiations

AmN



AmO2



How to calculate Void Reactivity

- Core region : Sodium → Void

- Only core region?   Yes.
  - This is because the limit of $6 restricts blow off of the core at ULOF accident.

  So, simultaneous, in other words, as the same time, is important, and our assumption is that the void of core and blanket will not occur at the same time.

  This needs more discussions.

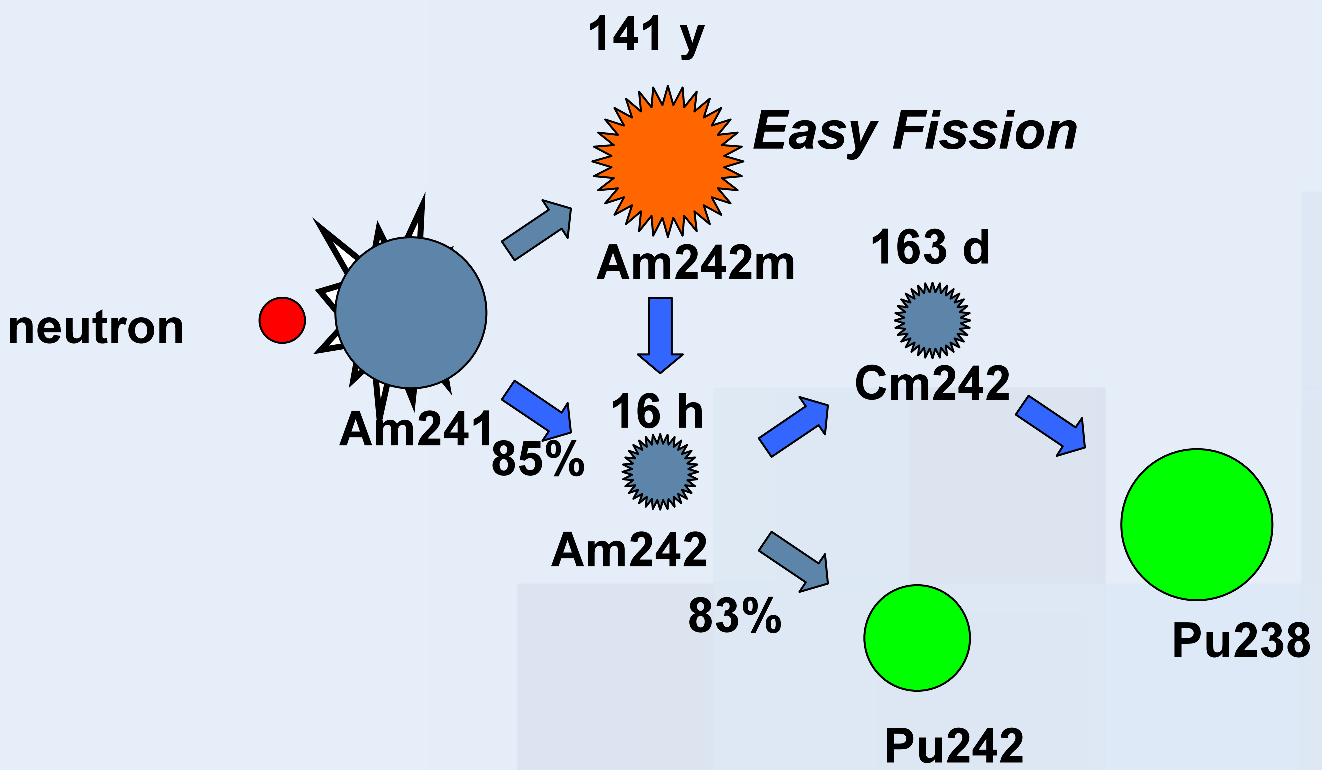
Calculation Conditions

- The composition of TRU content is the same as in used nuclear fuel (UNF) discharged from light water reactors with a burn-up of 50 GWd/t;

Np-237 5.3%
Pu-238 3.1%
Pu-239 45.7%
Pu-240 21.3%
Pu-241 7.2%
Pu-242 3.9%

Am-241 3.9%
Am-243 2.1%
Cm-244 0.8% (wt.).

Am Transmutation
Fission, Capture and Decay



Destructing Am by fission and changing to the small material number nuclide

Calculation Methodology

- The adopted nuclear methodology is basically the same as employed for the core design of JSFR. The calculations have been conducted using 70-group constants JFS3-J3.3 proposed from the nuclear data file JENDL-3.3 [15], a 3-D triangle mesh diffusion calculation code TRISTAN, and a perturbation code TRI-PERT. TRISTAN is of a corner mesh type having the calculation mesh points at the triangle corners, as compared with the type having the mesh points at the center of each triangle.

Performance of Am blanket
TRU Mass balance between ARR and LWR

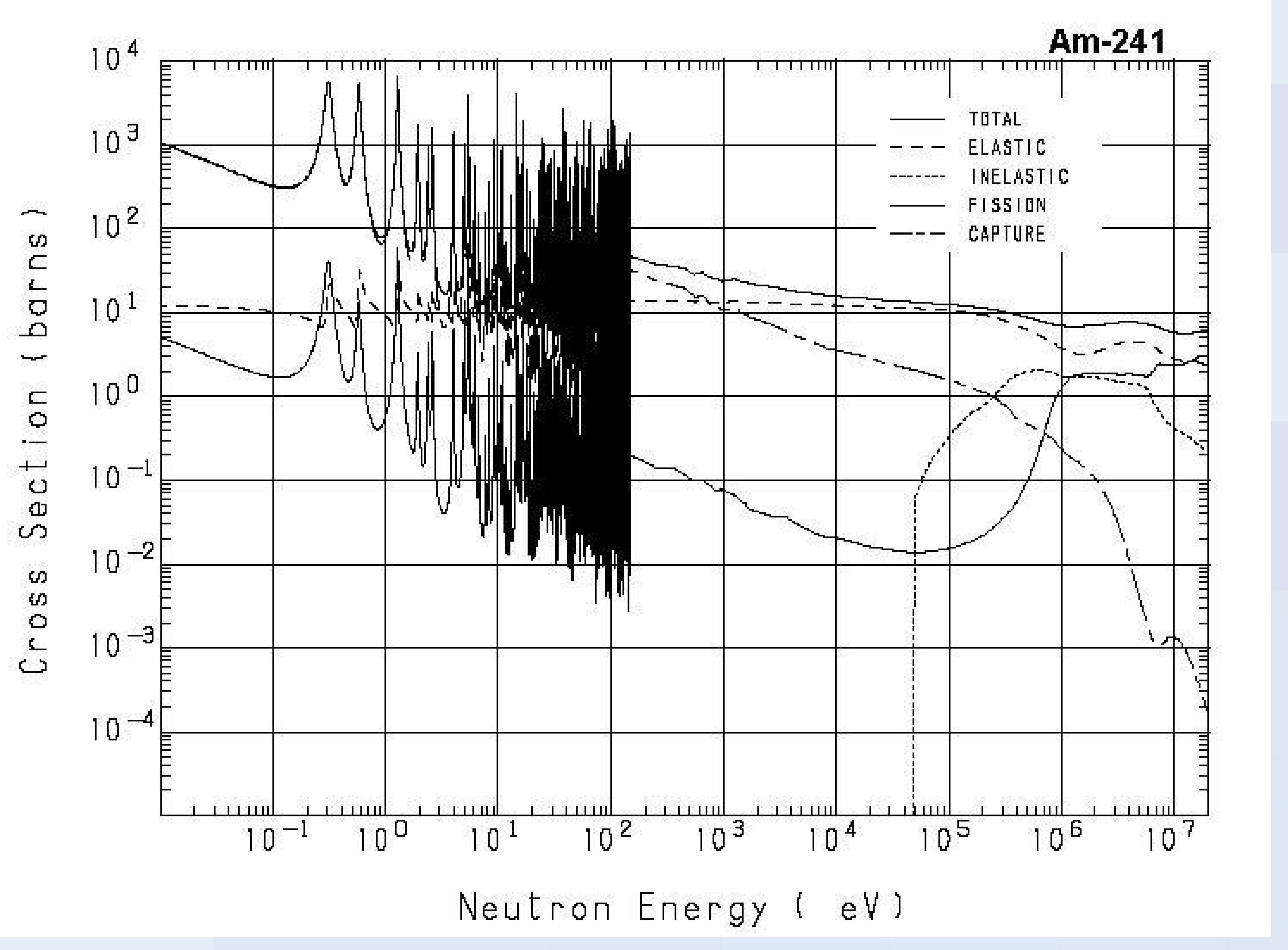
Conditions of LWR used fuel

Ave. Discharged burnup	50 GWd/t
Storage time after discharging	6 years

Kg/(y·1GWe LWR)

	UO2	1 MOX	2 MOX*
Am	12.7	22.7	30.9
Np	13.6	12.7	12.7
Pu	221.8	155.5	114.5
Cm	1.8	0.0	0.0

*** Twice recycled MOX fuel**


Am-241
TOTAL
ELASTIC
INELASTIC
FISSION
CAPTURE
Cross Section (barns)
Neutron Energy (eV)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7}