Multi-beam accelerator driven system
-- A new approach to nuclear waste transumutations

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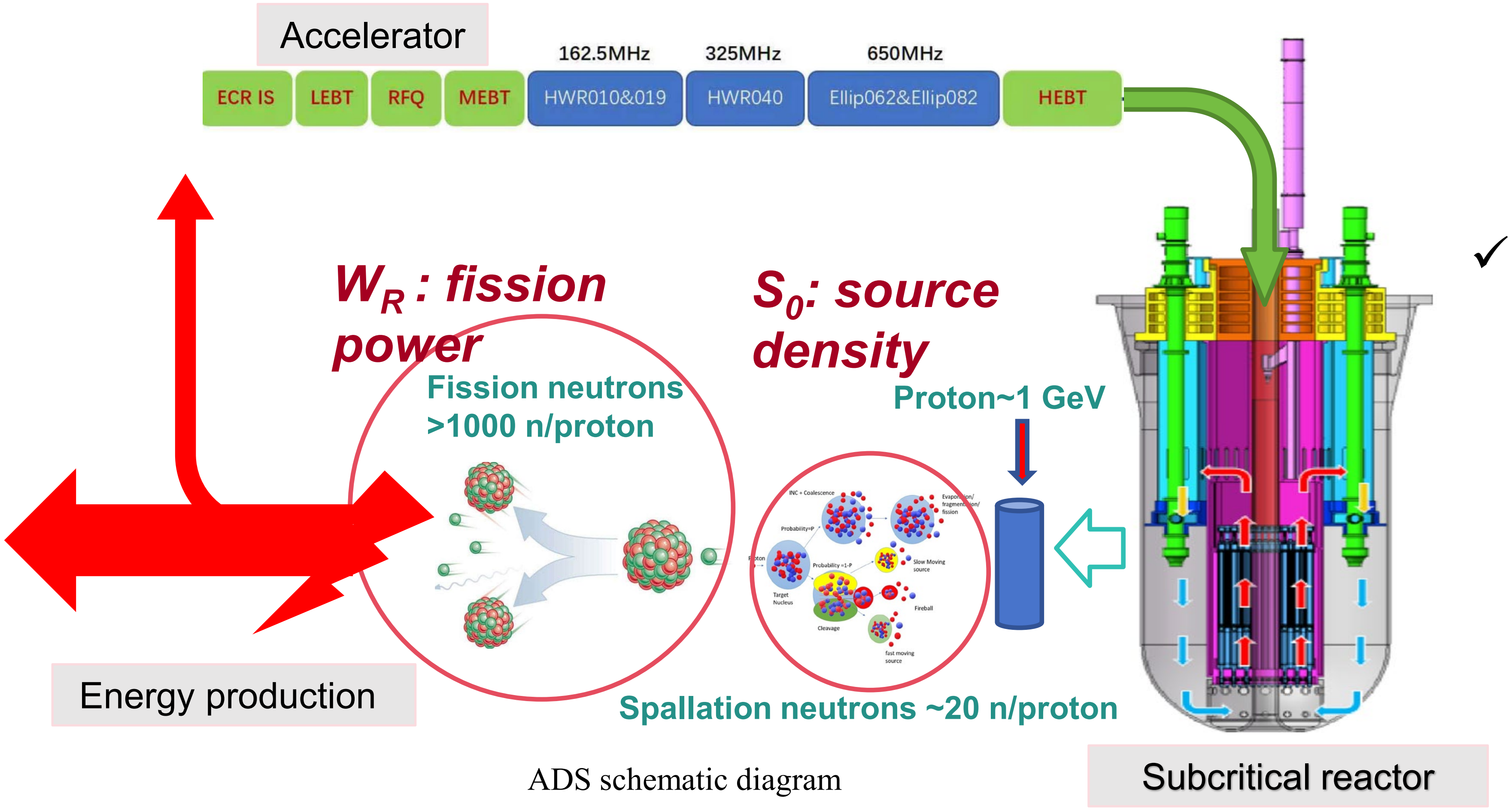
Principle of ADS:

ADS consists of accelerators, spallation targets, subcritical reactors. The subcritical reactor is driven by spallation neutrons generated by hitting the spallation target with accelerator beams.



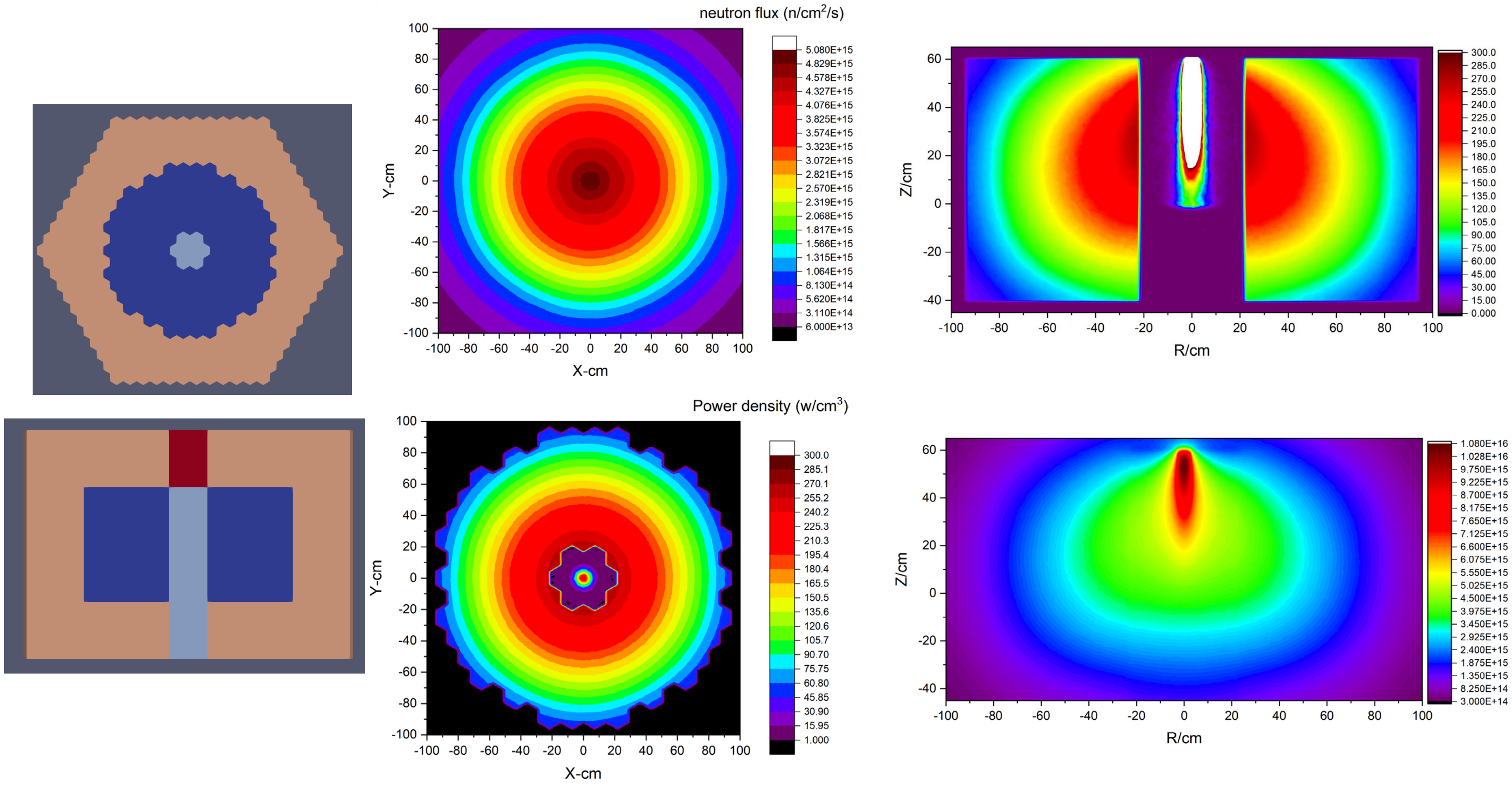
ADS schematic diagram

✓ Advantages：

- ➢ High flux.
- ➢ Hard energy spectrum.
- ➢ Subcritical mode
- ➢ Easily transmutable

Some limitations of ADS

Flux and power in Conventional ADS:

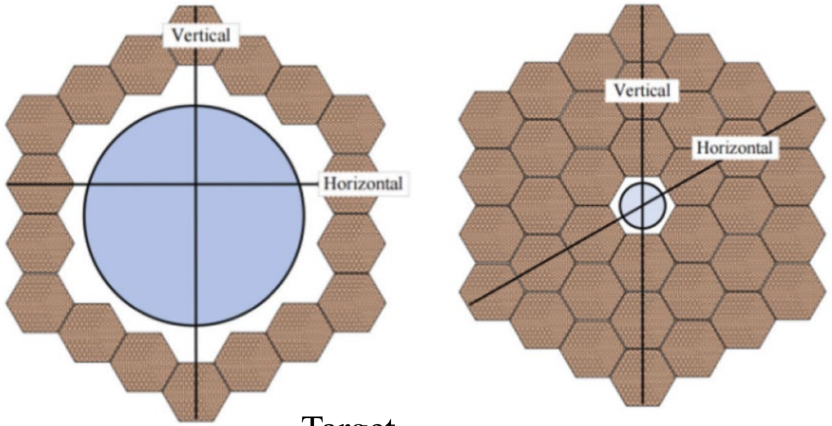


Flux and power distribution of ADS

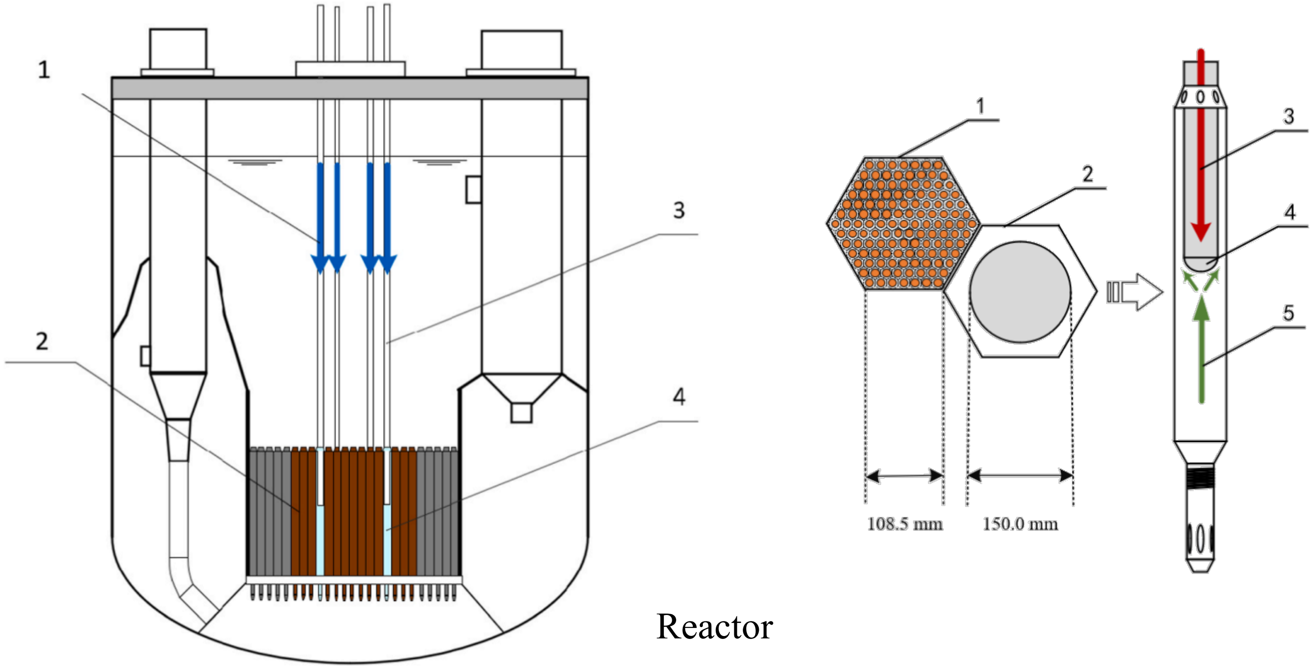
- Limitations：
  - Higher power peaking factor.
  - Low external neutron utilization.
  - High engineering complexity in target-reactor coupling

Our innovation - Multi-beam ADS

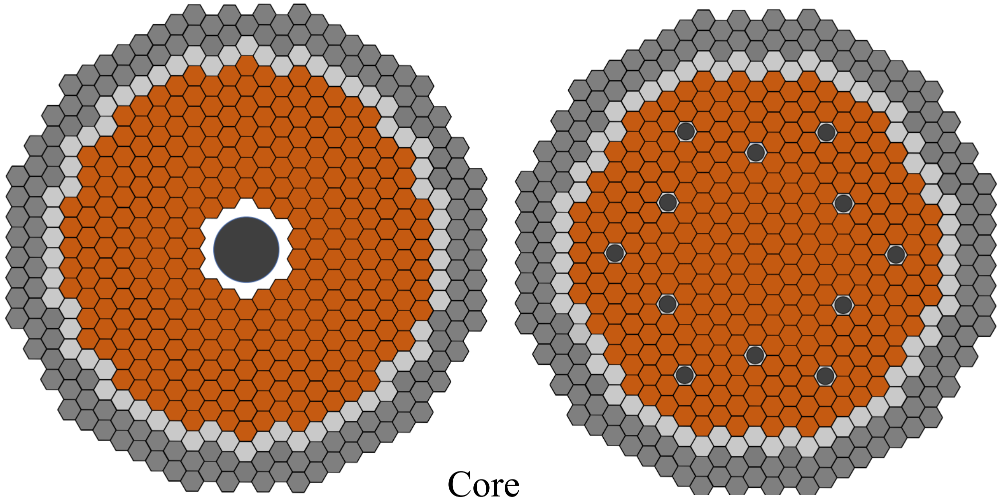
Multi-beam ADS design:



Target assembly



Reactor

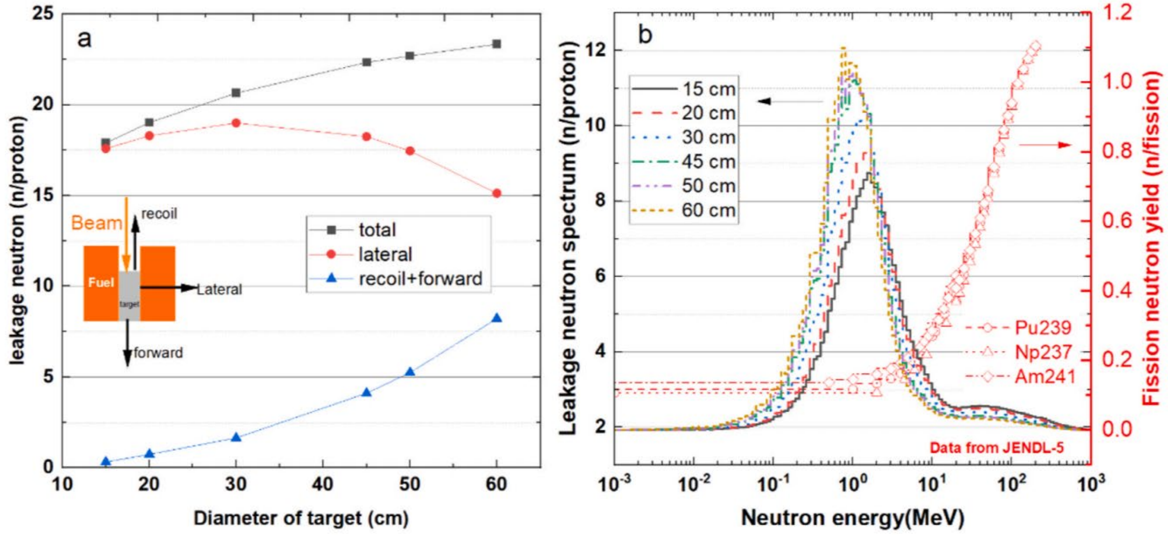


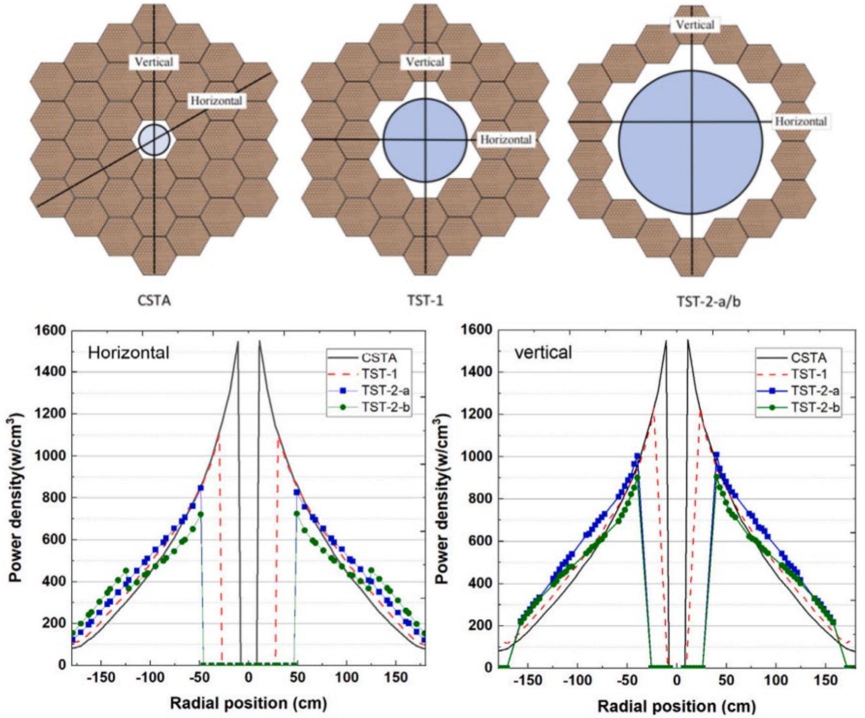
Core

- ✓ Innovation：
  - ➢ The spallation target is designed as a target assembly to the fuel assembly.
  - ➢ The high current proton beam is divided into multiple parts and injected into different targets scattered among the core

Neutronics optimization of Multi-beam ADS

The influence of the target diameter:





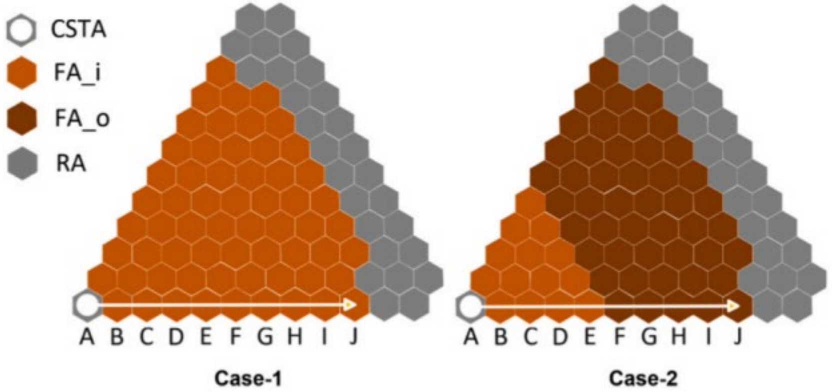
Target diameter (cm)	<S> (n/proton)	Average energy (MeV)	Energy group (MeV)				
			<0.1	0.1–5	5~20	20~200	>200
15	17.91	12.32	1.25%	80.19%	10.17%	7.17%	1.21%
20	19.03	9.97	1.47%	82.94%	8.69%	6.00%	0.91%
30	20.63	7.36	1.92%	86.34%	6.59%	4.56%	0.59%
45	22.35	5.28	2.72%	88.97%	4.69%	3.24%	0.38%
50	22.74	4.84	3.03%	89.42%	4.25%	2.96%	0.34%
60	23.97	4.20	3.69%	89.92%	3.58%	2.53%	0.28%

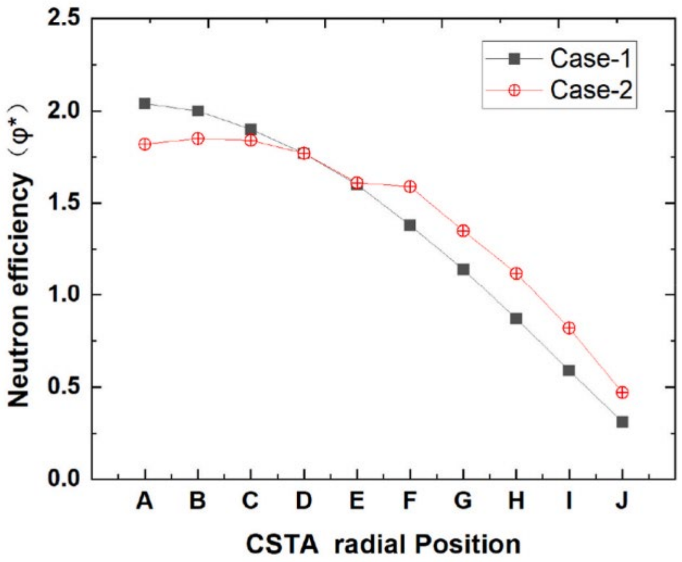
✓ Advantages of small diameter：

- ➢ Hard energy spectrum
- ➢ High neutron utilization efficiency

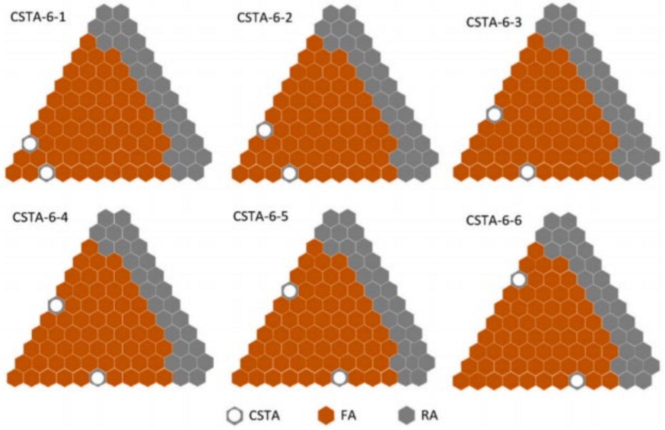
Neutronics optimization of Multi-beam ADS

The influence of the target position and fuel zoning:

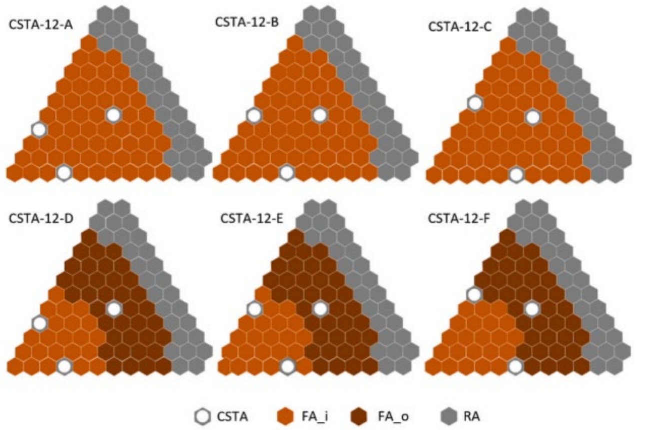




Variation of neutron efficiency with target position.



Case	k_{eff}	φ*	Beam density (μA/cm^2)	Beam current (mA)	Beam efficiency (EAF)
CSTA-6-1	0.97868	1.84	21.57	14.63	102.5
CSTA-6-2	0.97825	1.86	21.84	14.81	101.3
CSTA-6-3	0.97878	1.73	22.87	15.51	96.7
CSTA-6-4	0.97876	1.54	25.64	17.39	86.2
CSTA-6-5	0.97823	1.27	31.99	21.70	69.1
CSTA-6-6	0.97846	0.99	40.66	27.57	54.4



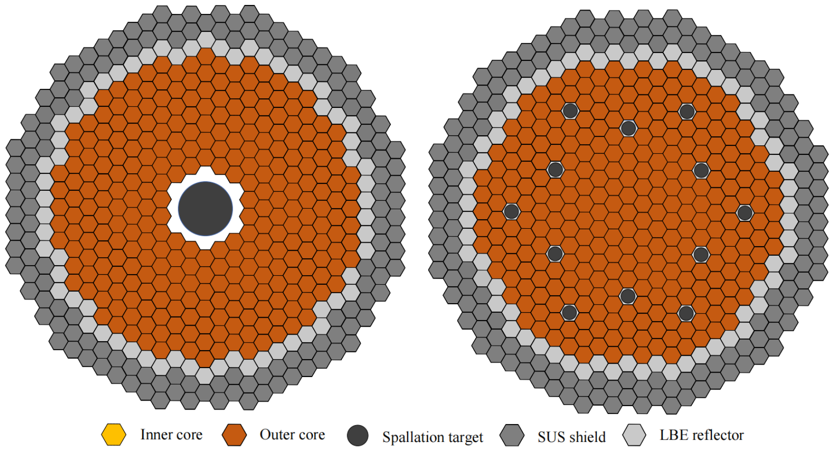
Position	k_{eff}	φ*	Beam density (μA/cm^2)	Beam current (mA)	Beam efficiency (EAF)
CSTA-12-A	0.97858	1.49	13.34	18.09	82.97
CSTA-12-B	0.97889	1.37	14.33	19.44	77.16
CSTA-12-C	0.97862	1.29	15.42	20.92	71.69
CSTA-12-D	0.97825	1.55	13.02	17.66	84.95
CSTA-12-E	0.97855	1.45	13.72	18.61	80.60
CSTA-12-F	0.97854	1.44	13.87	18.81	79.75

✓ Conclusion：

- ➢ Obtain the appropriate 12-beam strategy distribution.
- ➢ Fuel zoning strategy can reduce beam current.

Comparison of multi-beam and single-beam in single-fuel zone (Keff and I):

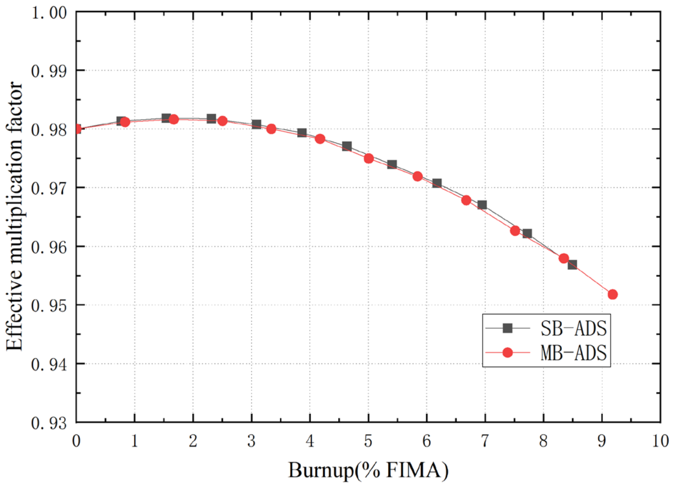
- Core design diagrams

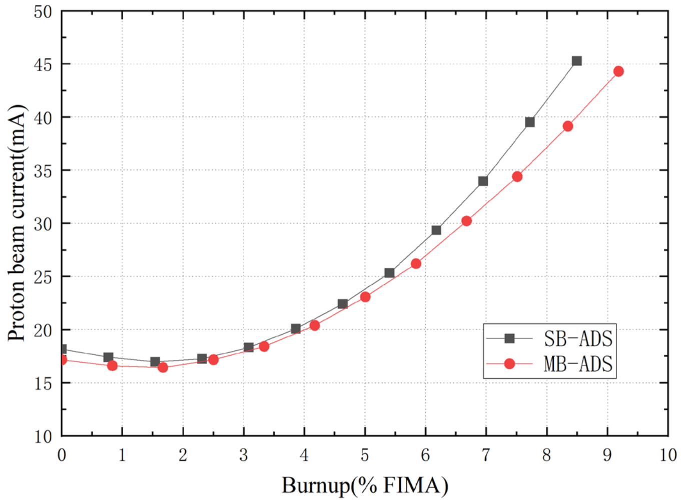


- Core design parameters

	SB-ADS	MB-ADS
Thermal power(MW)	1500	1500
Proton beam energy(GeV)	1	1
Initial of k_{eff}	0.98	0.98
Fuel Composition	(MA+Pu)N+ZrN	(MA+Pu)N+ZrN
Fuel loading weight(t)	10.95	10.59
Burnup days	1200	1200

- K_{eff} and proton beam current：





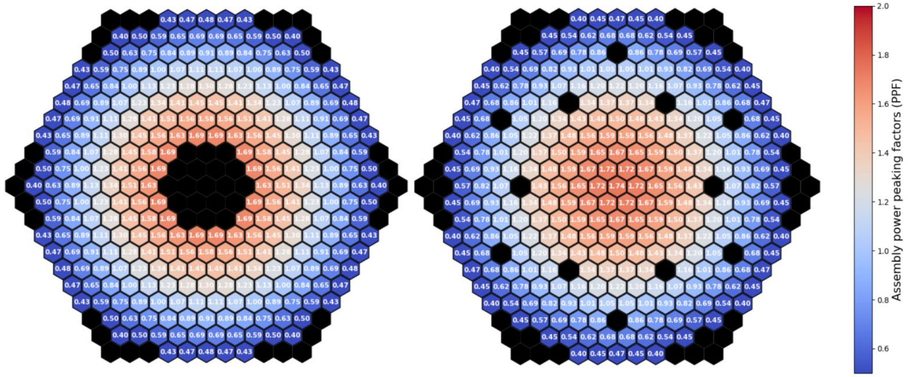
✓ Conclusion：

- MB-ADS load less fuel.
- MB-ADS and SB-ADS‘s reactivity performance is similar, but the MB-ADS’s fuel utilization rate is high.
- MB-ADS reduces beam current demand without other impact on system performance.

Burnup optimization of Multi-beam ADS

Comparison of multi-beam and single-beam in single-fuel zone (Power distribution):

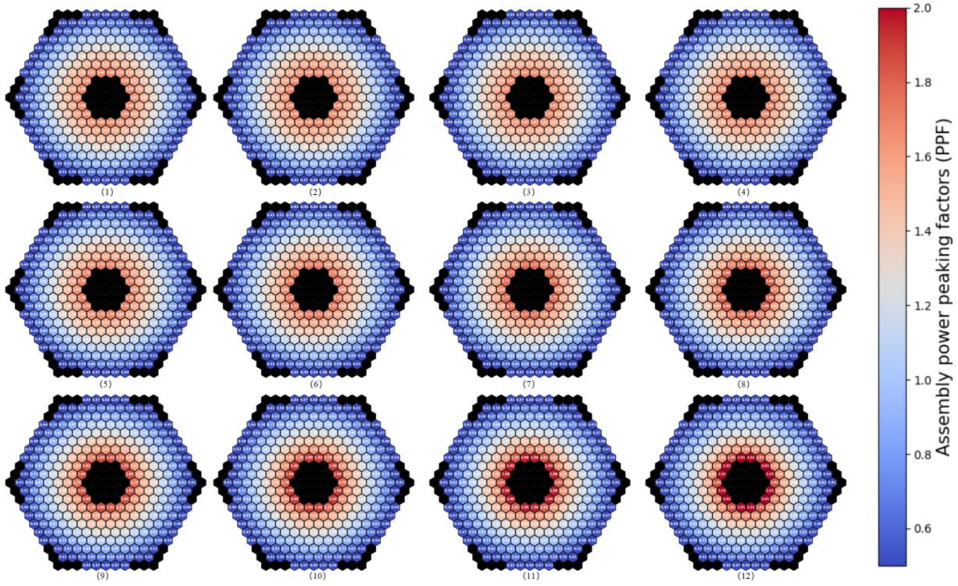
- First step of burnup

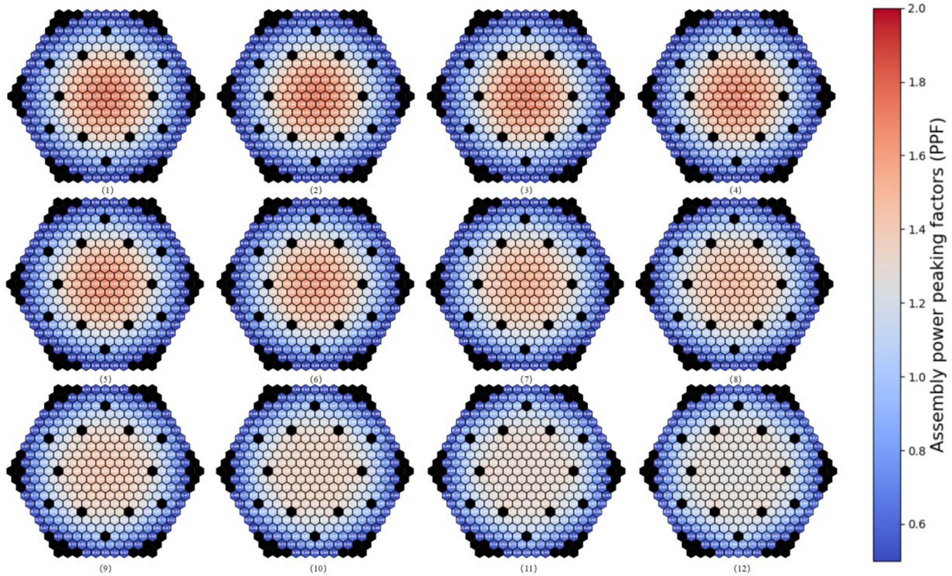


✓ Discoveries：

- ➢ In first step, the peak factors of assemblies are all in the centermost.
- ➢ Howerver:
  - SB-ADS core exhibits a continuously increasing power peak
  - MB-ADS displays a flatter power distribution with its peak gradually shifting toward peripheral target assemblies.

- Evolution for whole burnup

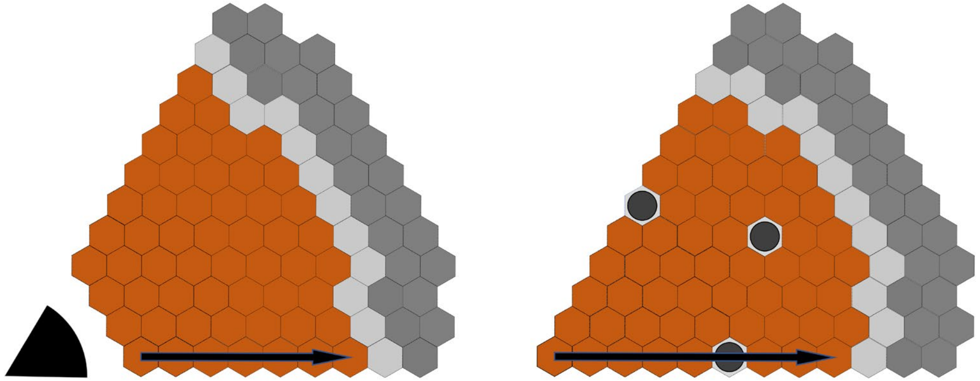




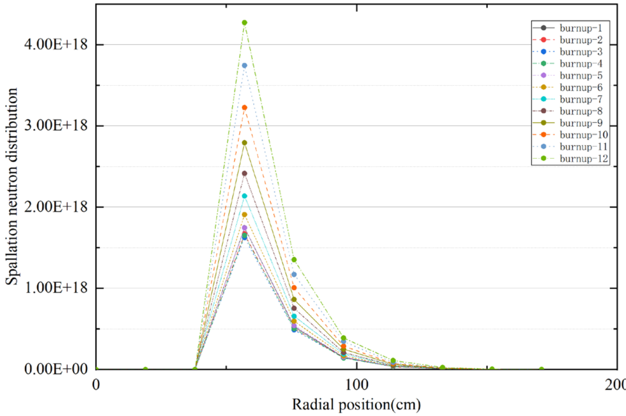
Burnup optimization of Multi-beam ADS

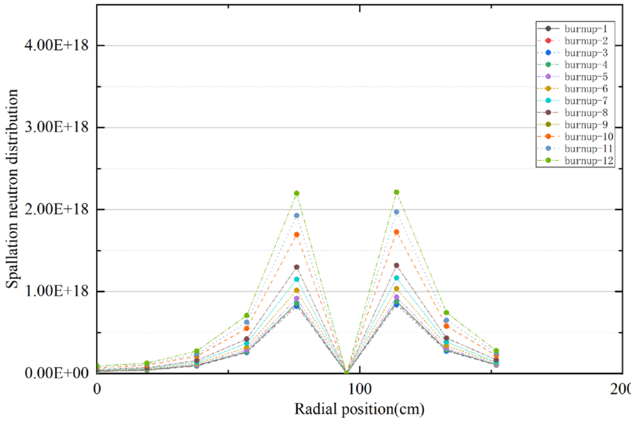
Reasons for the flatter power distribution of MB-ADS:

- Analysis in the X direction

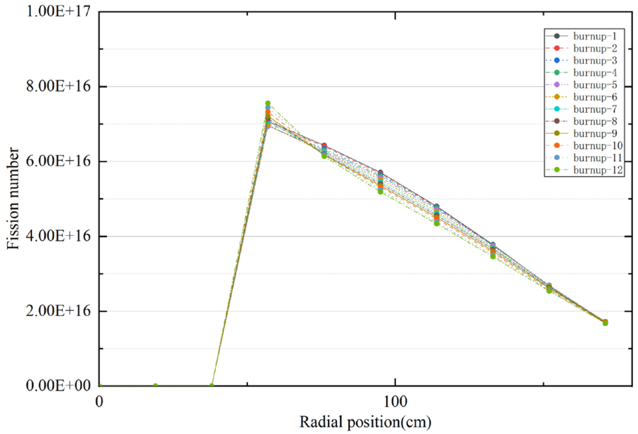


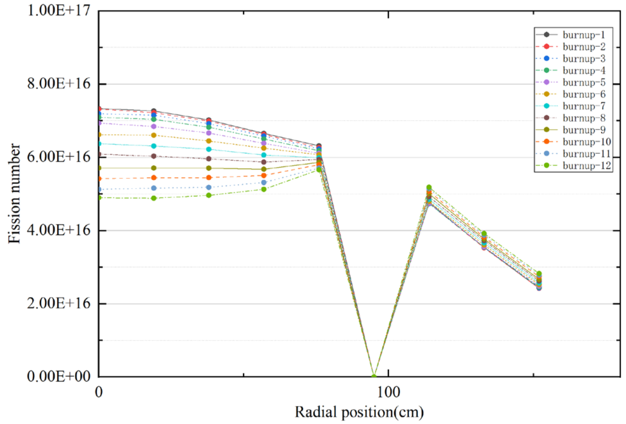
- Spallation neutron distribution





- Number of fissions



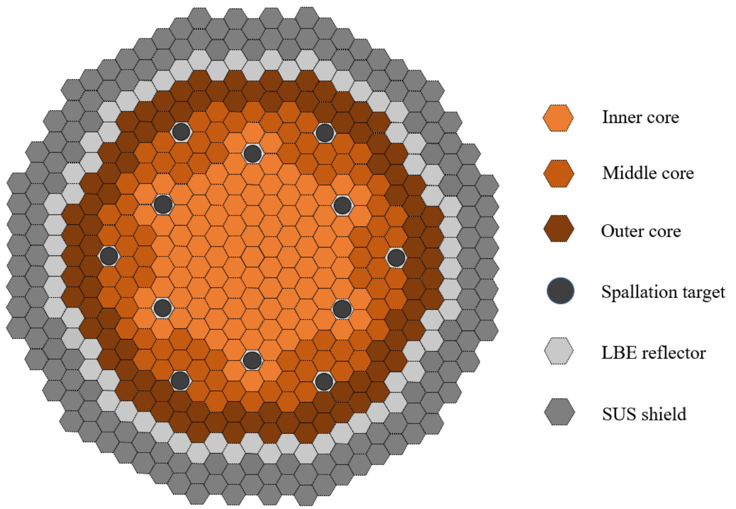


✓ Conclusion：

- During the burnup, reactivity decreases while the beam current increases.
- The spallation neutron effects of SB-ADS are more concentrated in the reactor core.
- MB-ADS reduces the concentration of spallation neutrons and balances the fission power.

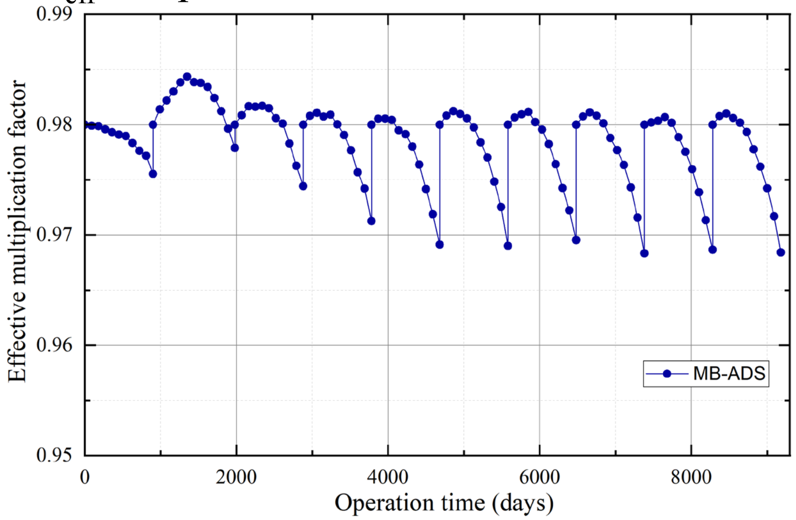
The complete transmutation fuel cycle for MB-ADS:

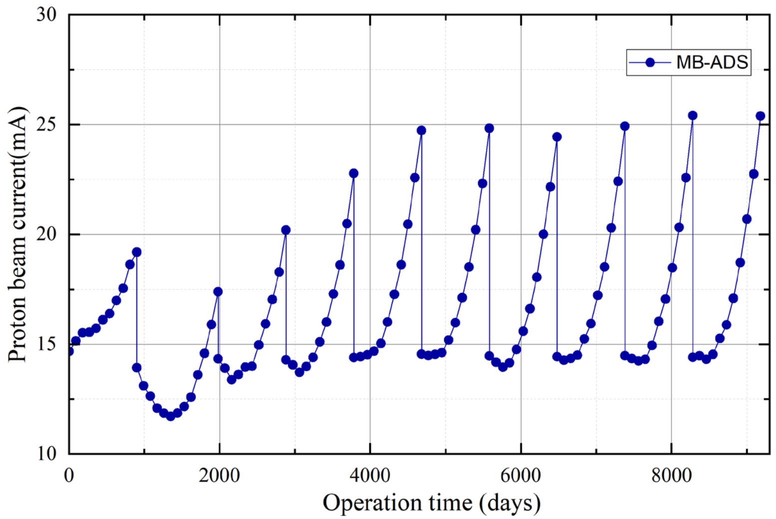
- Fuel zoning strategy and parameters



	MB-ADS
Thermal power(MWt)	1500
Proton beam energy(GeV)	1
Proton beam power/current(MW/mA)	30/30
Fuel Composition	(MA+Pu)N+ZrN
Coolant/Structural material	LBE/T91
Initial of k_{eff}	0.98
Number of fuel assembly(IC/MC/OC)	103/84/96
Pu ratio (1st) [wt%]	30.0
ZrN ratio (1st) [wt%]	33.0
Factor to ZrN ratio at IC/MC/OC	1.20/1.00/0.80
Number of fuel pins per FA	121
Fuel pin diameter/element pitch (cm)	1.04/1.56

- K_{eff} and proton beam current for whole burnup：



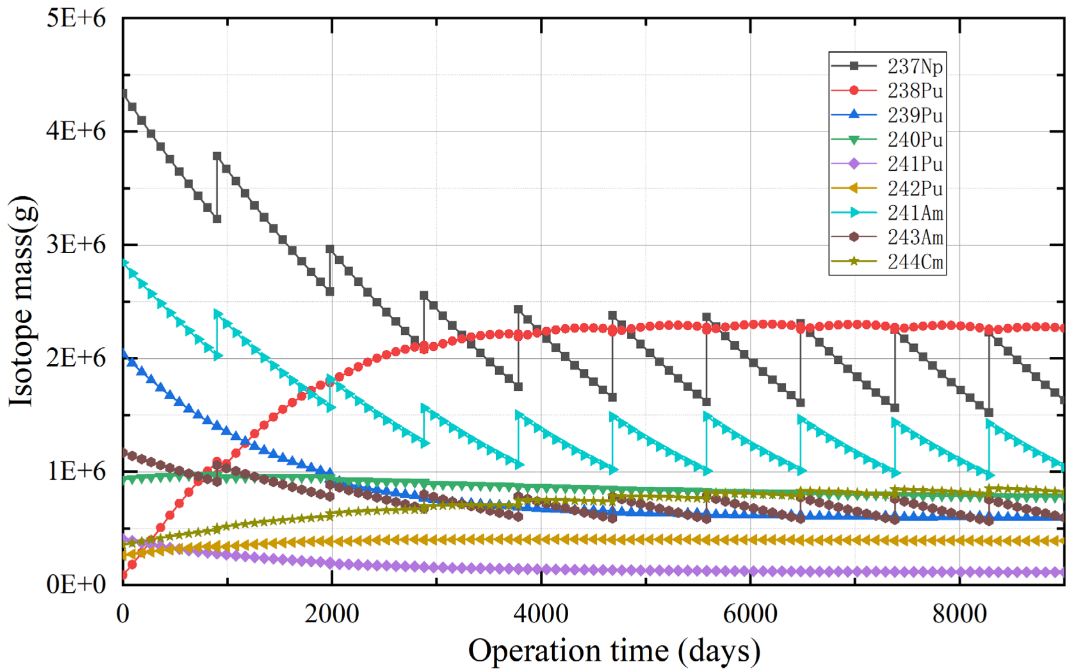


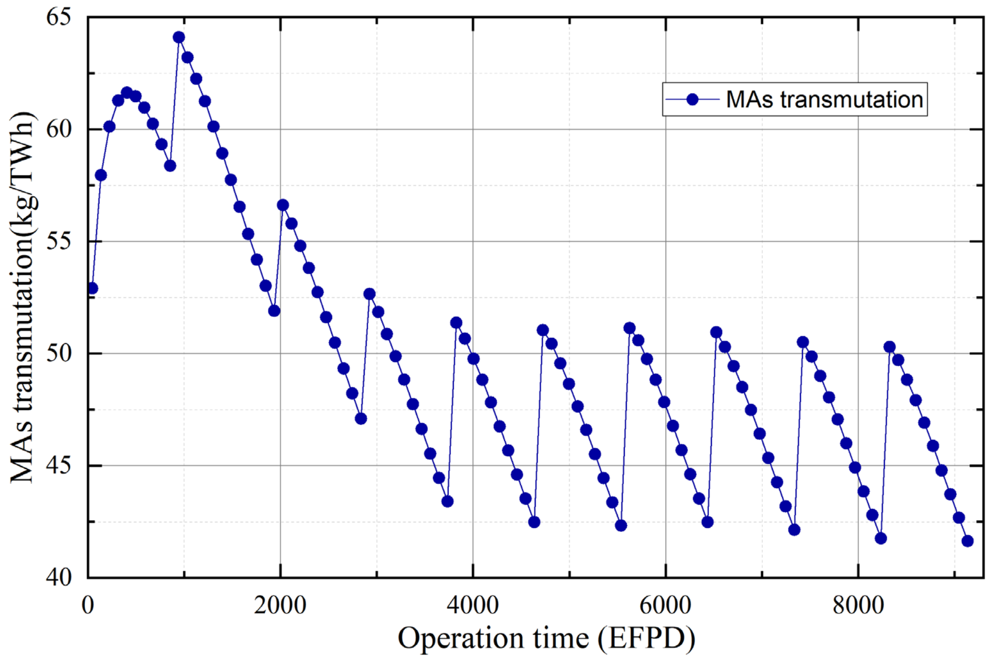
✓ Conclusion：

- Stable fuel burnup cycles (k_{eff}: 0.965~0.98; I: 10~25mA)
- Reach to equilibrium cycle.

Burnup optimization of Multi-beam ADS

Mass variations of major isotopes and MAs transmutation:



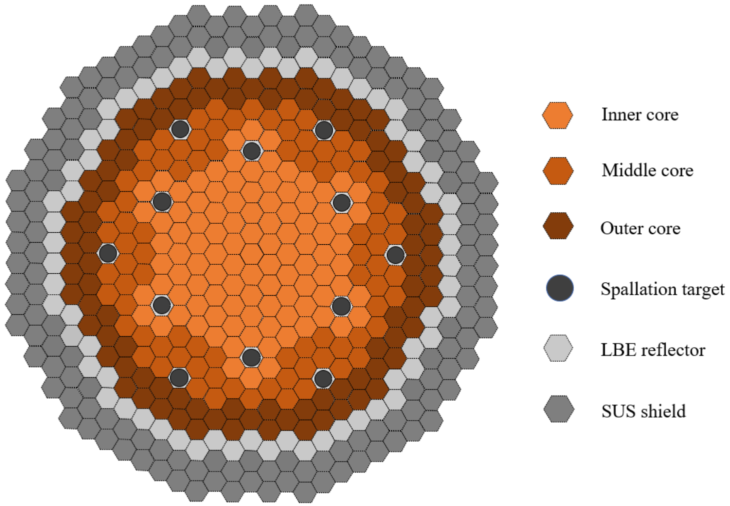


✓ Conclusion:

- As burnup progresses, ^{238}Pu (red line) which produced by (n,γ) reaction of ^{237}Np and ^{241}Am in MAs gradually provides reactivity
- Equilibrium cycle MAs transmutation rate to 47kg/TWh (International high efficiency 39kg/TWh, JAEA model)

Conclusion

- **Initial multi-beam core design achieved through divided beam quantity and position optimization**
- **Multi-beam advantages over single-beam:**
  1. Beam requirement reduced by >20%
  2. Power peaking factor decreased by 30%
  3. Beam density on target window lowered by 25%
  4. Enhanced MAs transmutation to 47kg/TWh.



Comparison parameters		MBADS	SBADS
Main Parameters	Beam Particle	Proton	←
	Reactor Thermal Power (MW)	1500	←
	Beam Power (MW)	18	24.3
	Beam Energy (GeV)	1	←
	Number of Beam Lines	12	1
	Power of Each Target (MW)	1.5	24.3
	Energy Amplification Factor	83	62
	Coolant of Reactor and Target	LBE	←
	Electric power (MWe)	510	479
Beam Splitting and Transport	Beam Tube Diameter (mm)	150	400
	Maximum Beam Current Density ($\mu A/cm^2$)	18.5	24.9
	Beam Traverse Period (ns)	73.8	-
Reactor	Peak Power Density of Fuel Pin (W/cm^3)	594.2	901.5

THANKS