Comparison of Neutronics Performance Characteristics of the Proposed NIST Reactor with Different LEU Fuels

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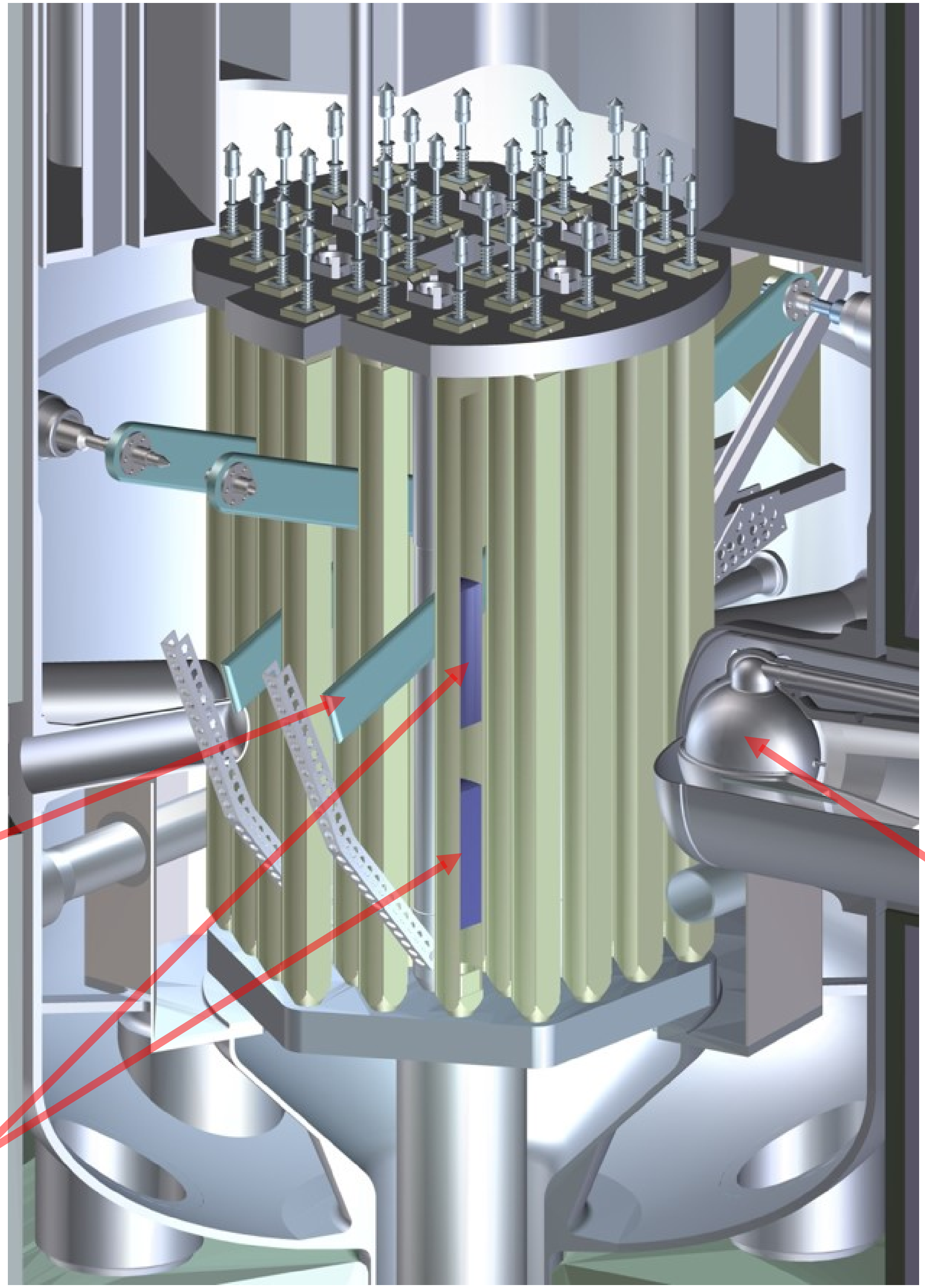
Outline

1. Background of the NIST reactor (NBSR)
2. Overview of a proposed design for next reactor (NBSR-2)
3. Comparison of NBSR-2 using LEU fuel options
4. Conclusions and future work

1. Background of the NIST reactor (NSBR)

National Bureau of Standards Reactor (NBSR)

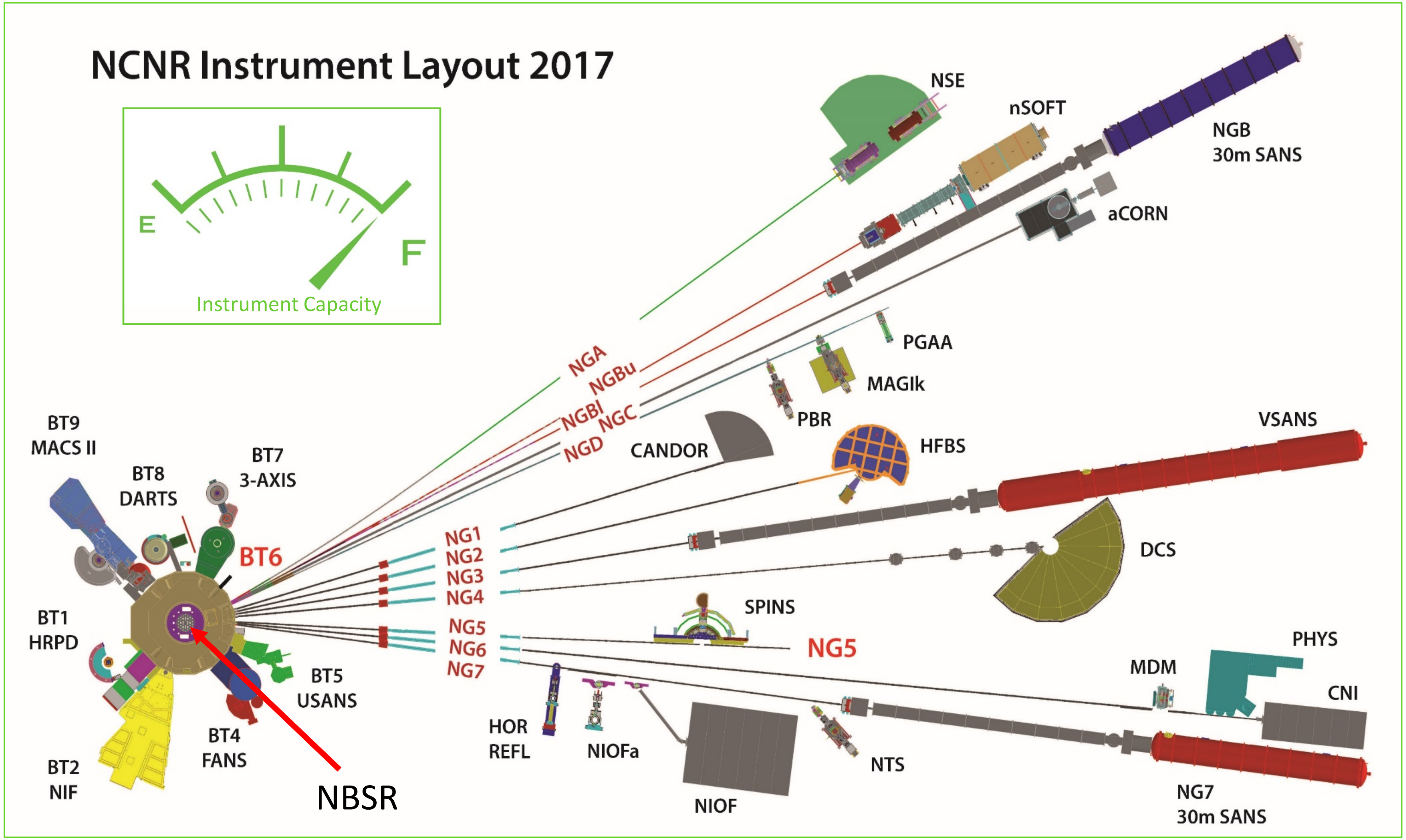
- D_2O cooled, moderated and reflected
- 20 MW thermal power
- HEU (U_3O_8/Al) fuel
- Unfueled gap for highly-thermalized neutron beams



Shim arms

Fuel meat

Cold neutron source



Most instruments utilize cold neutron beams

NBSR Future Options

1. Maintain NBSR
2. Refurbish NBSR in multi-year outage
3. Build replacement reactor

Future Options for the Neutron Source at the NIST Center for Neutron Research (2017)

Reactor Operations and Engineering Division, NIST Center for Neutron Research

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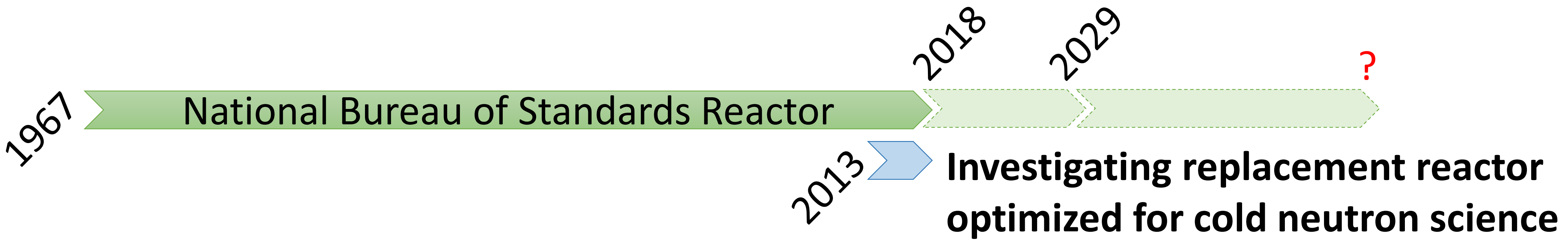
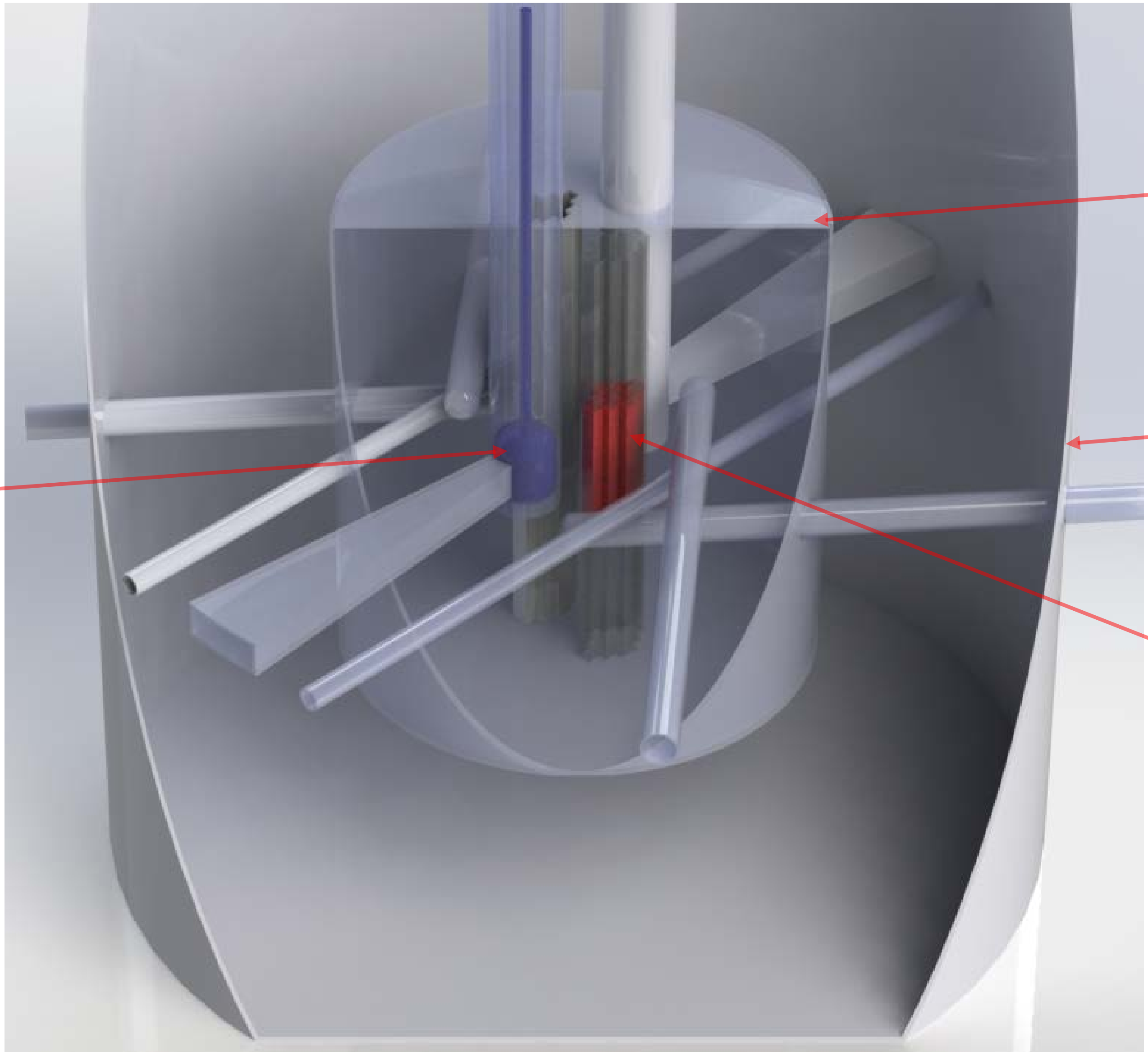


2. Overview of Split Core reactor design

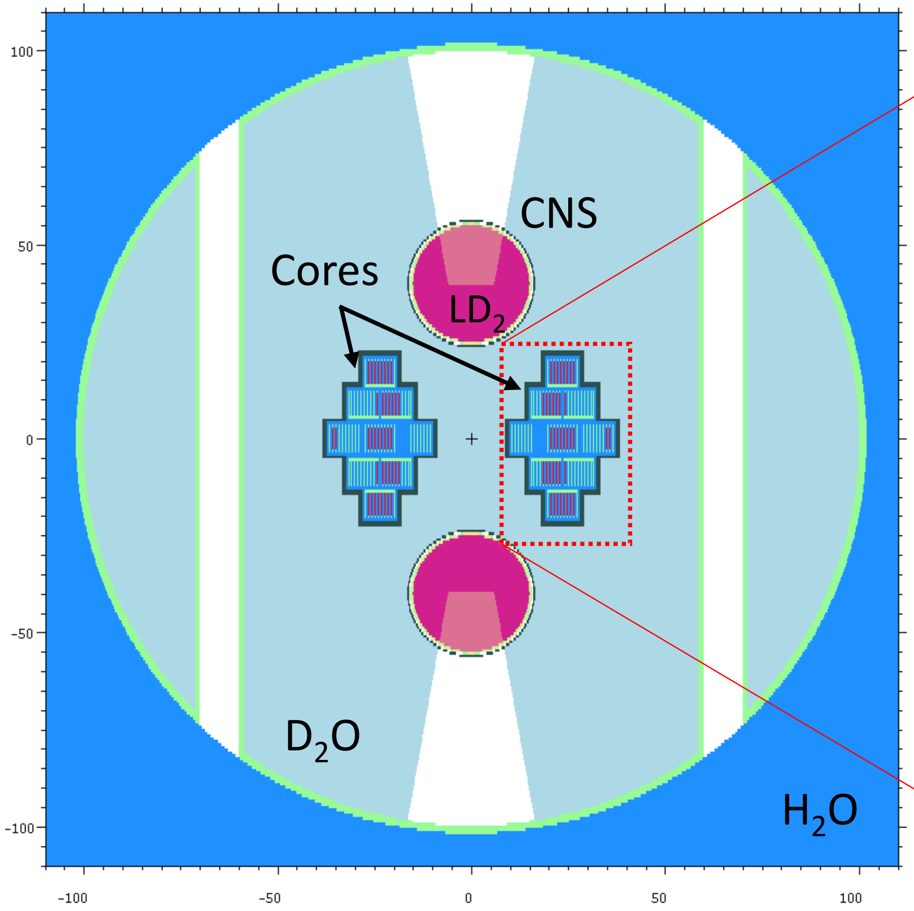
3-D model of the Split Core design



MCNP6 model

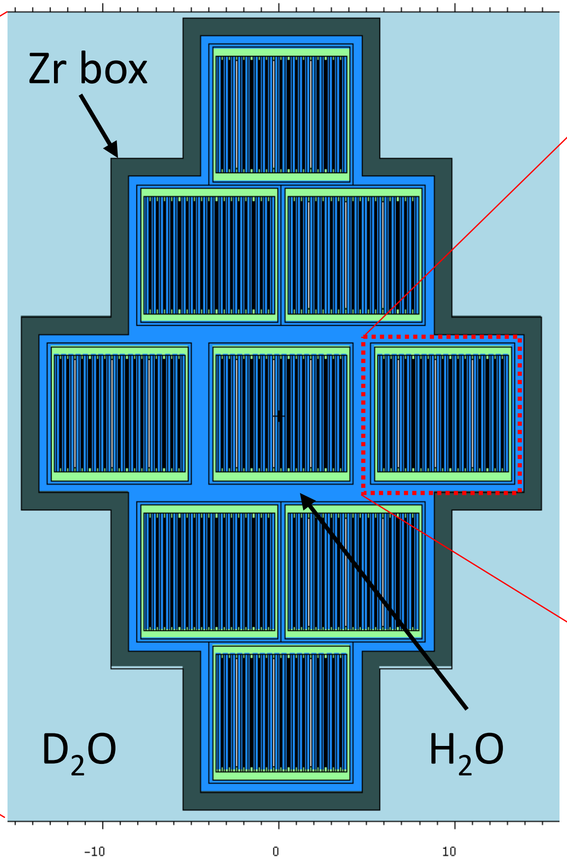
20 MW thermal power
30 day cycle

Plan view (xy) at mid-plane



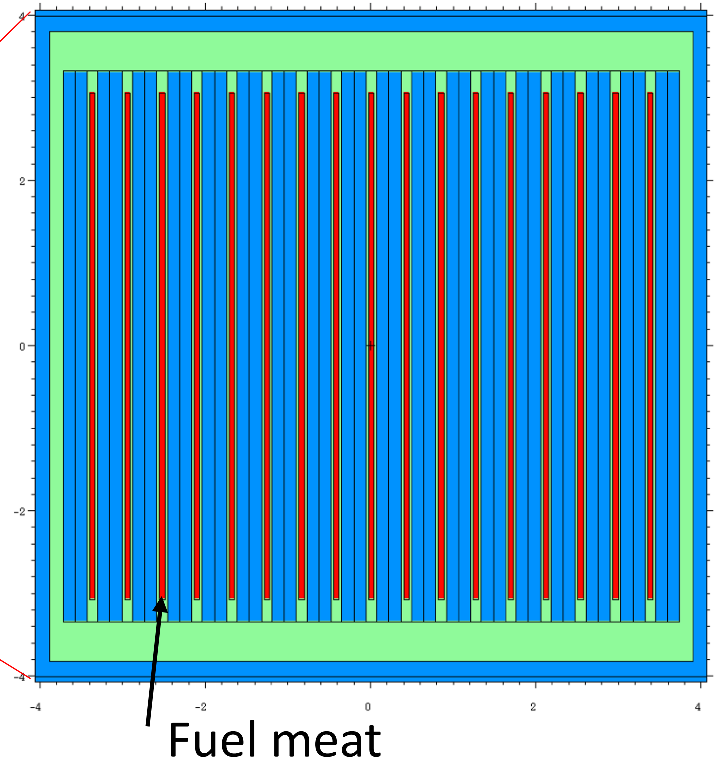
- Tank-in-pool design
- Two cores, two large-volume LD_2 CNSs

One core



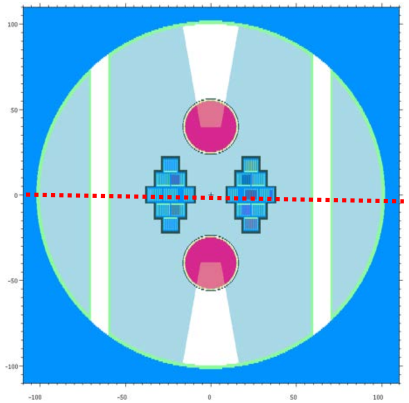
- Light water cooled
- Heavy water reflected

Fuel element

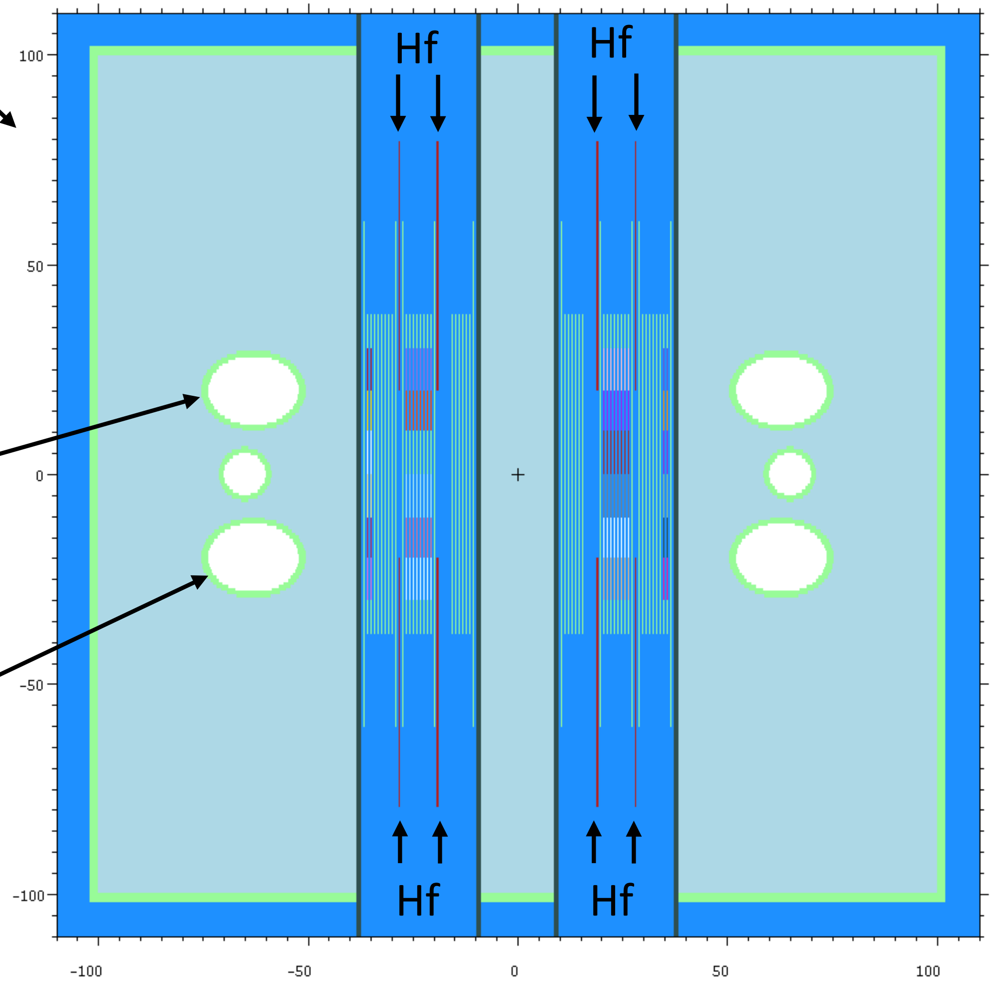


- 17 fuel plates, 50 mil thickness
- Fuel meat:
  6.134 cm width, 60 cm height

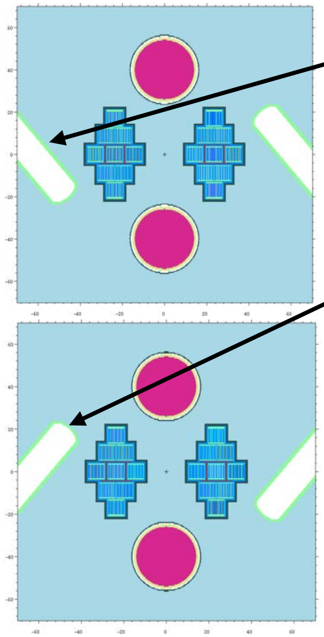
MCNP6 model



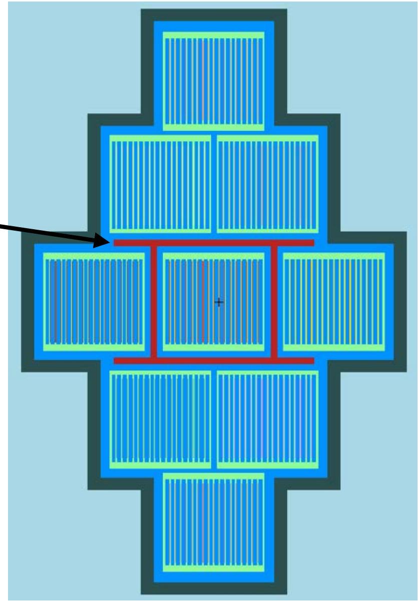
Elevation view (xz) at mid-plane



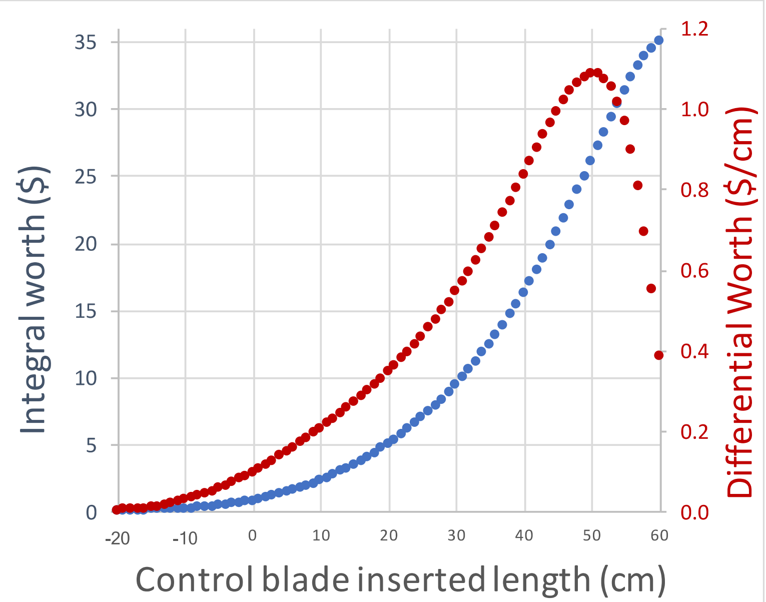
Thermal beam tubes



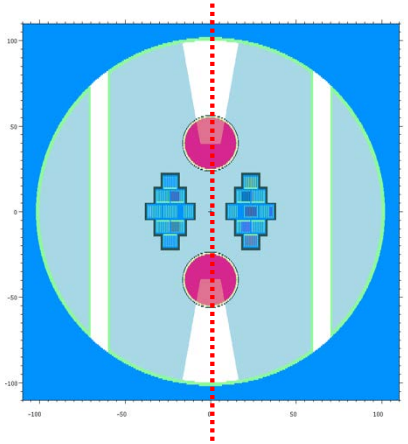
Hf control blade

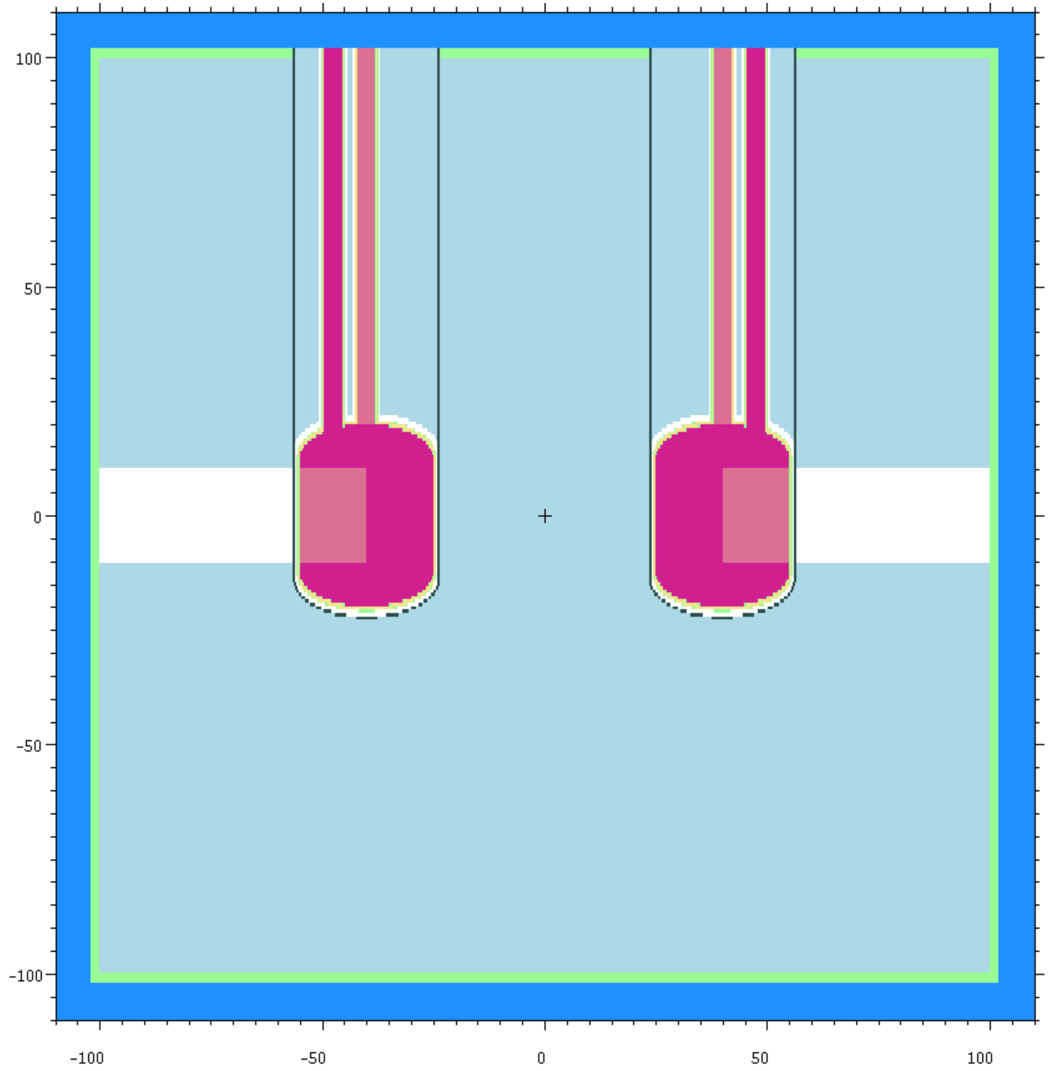


Reactivity worth of control blades



Vertical cold neutron sources





Elevation view (yz) at mid-plane

CNS design is not yet optimized

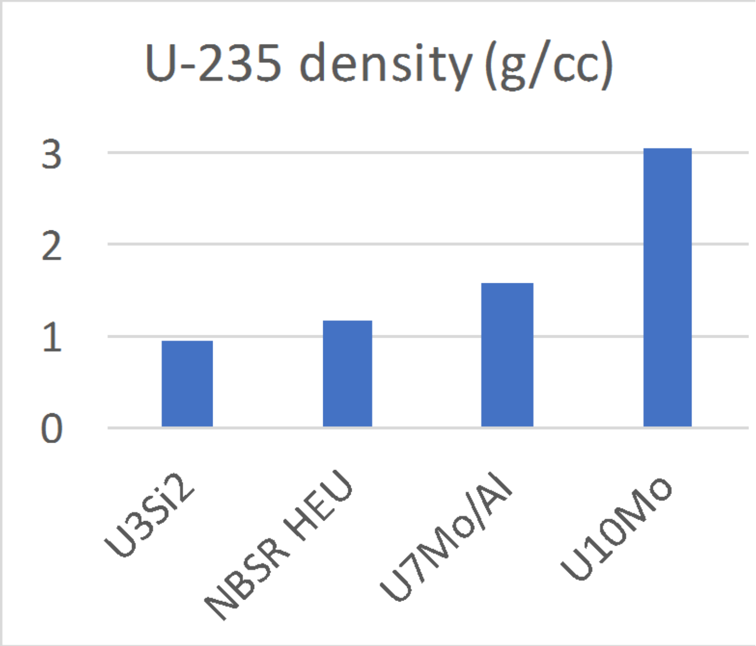
3. Comparison of NBSR-2 using LEU fuel options

LEU fuel options for NBSR-2

	U_3Si_2/Al*	U7Mo/Al	U10Mo
Form	Dispersion	Dispersion	Monolithic
Density (g/cm^3)	6.52	9.97	17.2
U density (g/cm^3)	4.80	7.98	15.5
^{235}U density (g/cm^3)	0.95	1.58	3.06

*Qualified to heat flux of 140 W/cm^2 (NBSR-2 average with 20 MW is 90 W/cm^2)

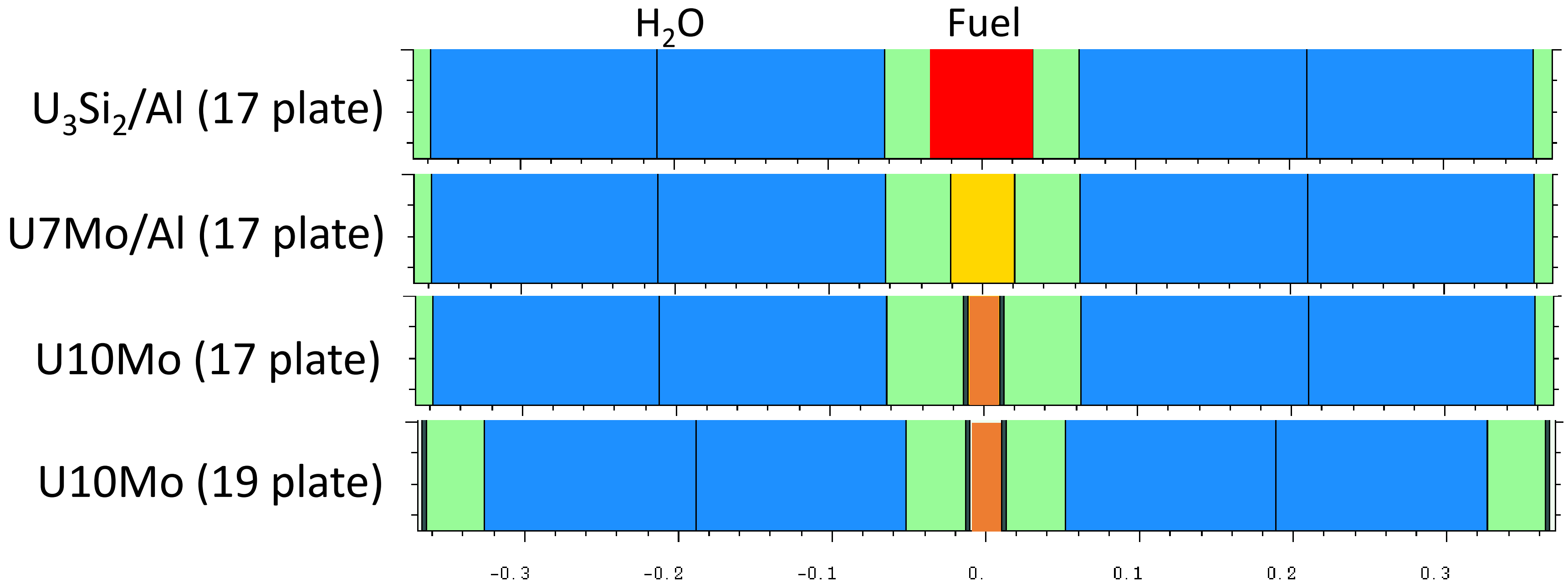
NBSR will be converted to UMo fuel when it's certified (10 years from now?)



UMo fuels have high ^{235}U densities

LEU fuel design for NBSR-2

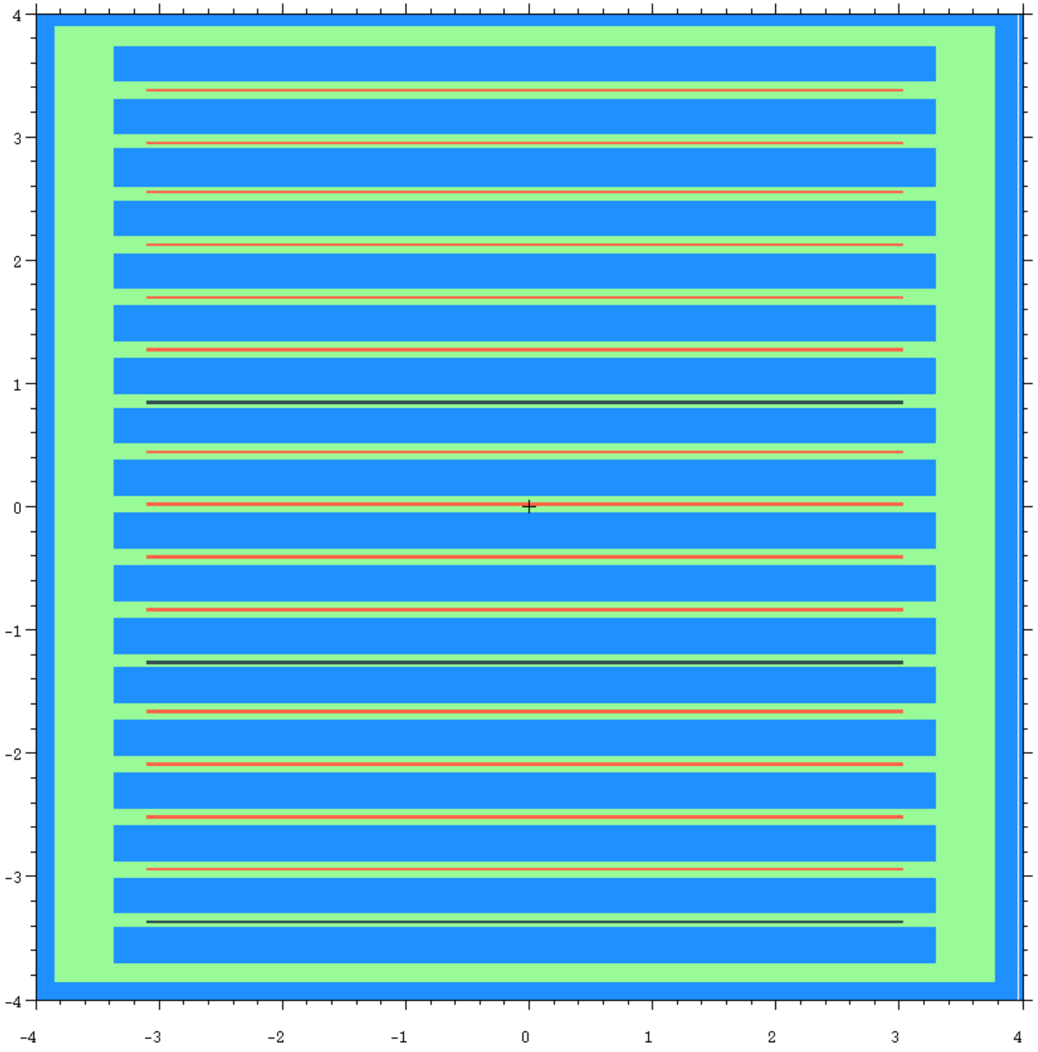
	U_3Si_2/Al	U7Mo/Al	U10Mo (17)	U10Mo (19)
Number of plates/FE	17	17	17	19
Fuel meat thickness (mil)	26.0	16.2	8.5	8.5
Fuel plate thickness (mil)	50	50	50	42.5
Cladding thickness (mil)	12	17	19.75	16
Total ^{235}U mass in FE (g)	392.5	406.7	413.6	462.2



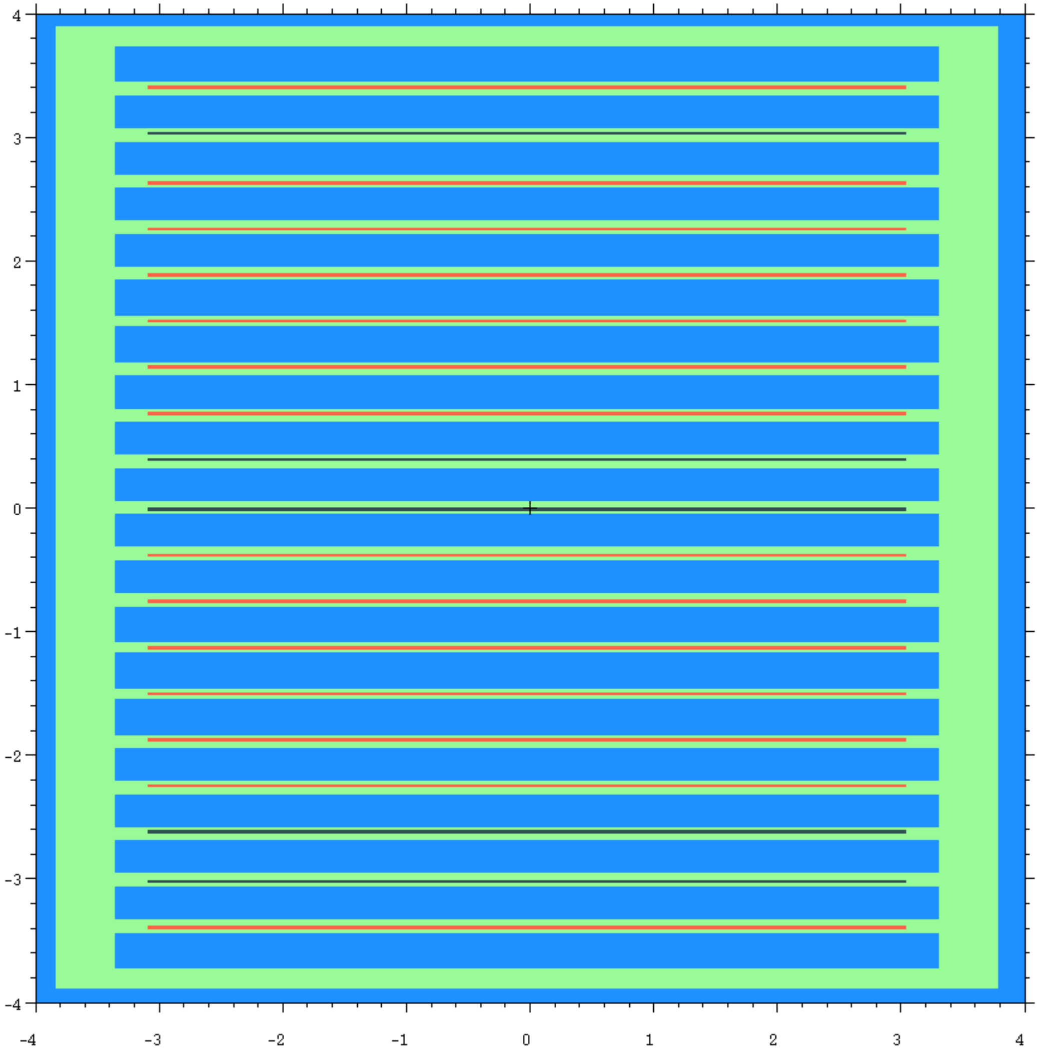
<u>19 plate U10Mo model:</u>

- Water channel width reduced by 6.8% from 2.95 mm to 2.75 mm
- Fuel mass and surface area increased by 11.8%

U10Mo fuel element cross-sectional view



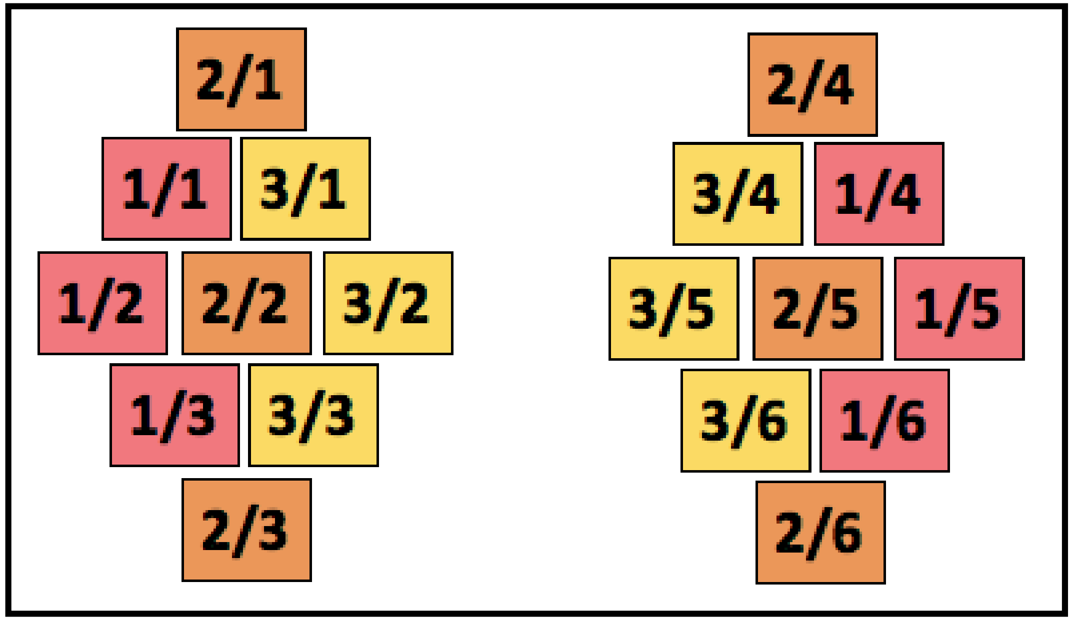
17 plate



19 plate

Fuel management schemes

Scheme A: Six fresh FEs/cycle

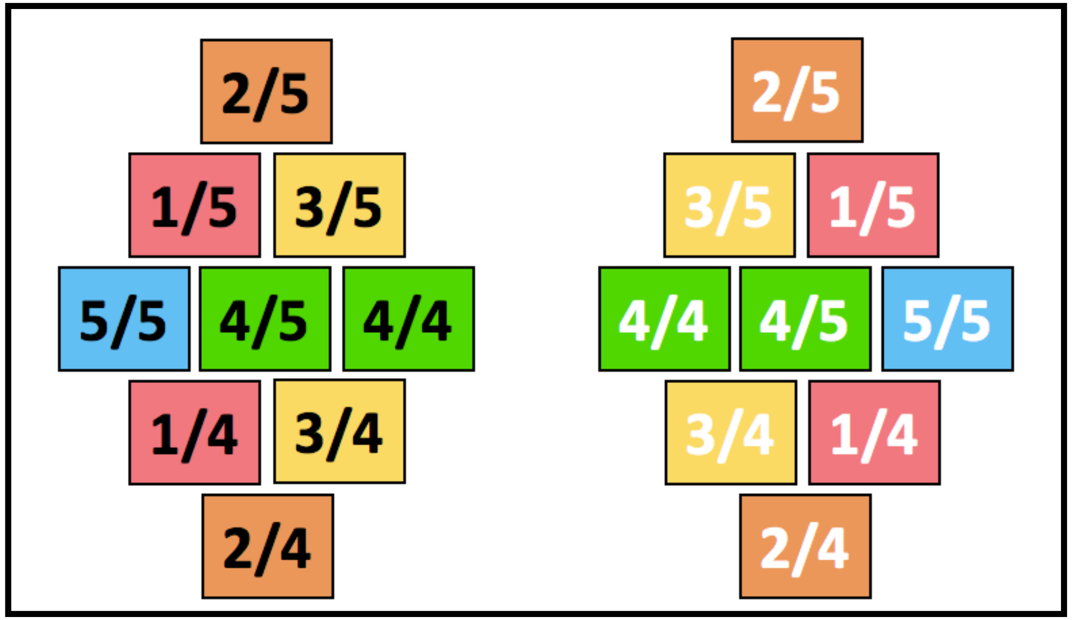


Legend:

1/# 2/# 3/#

Fuel element x/#
x ≡ cycle number
≡ unique identifier (1-6)

Scheme B: Four fresh FEs/cycle



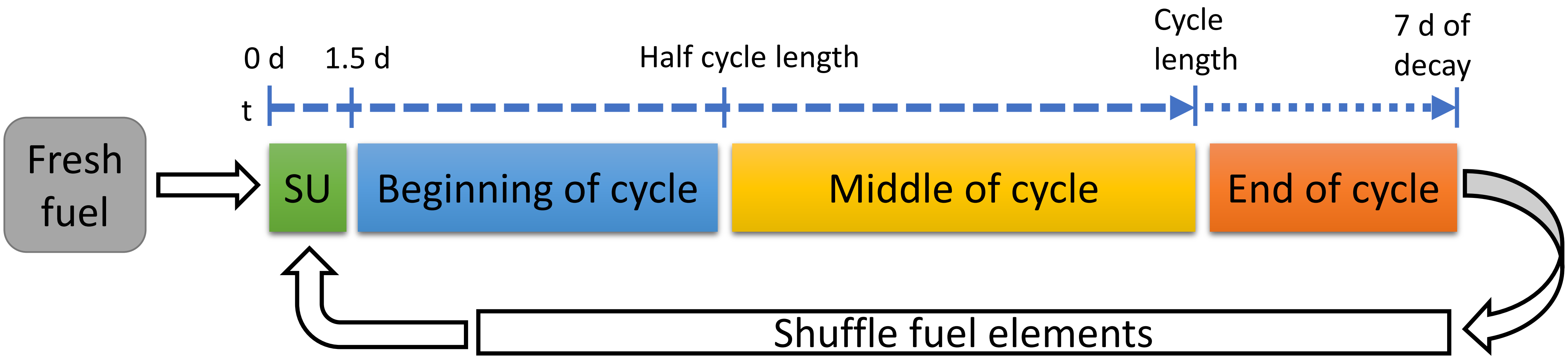
Legend:

1/# 2/# 3/# 4/# 5/#

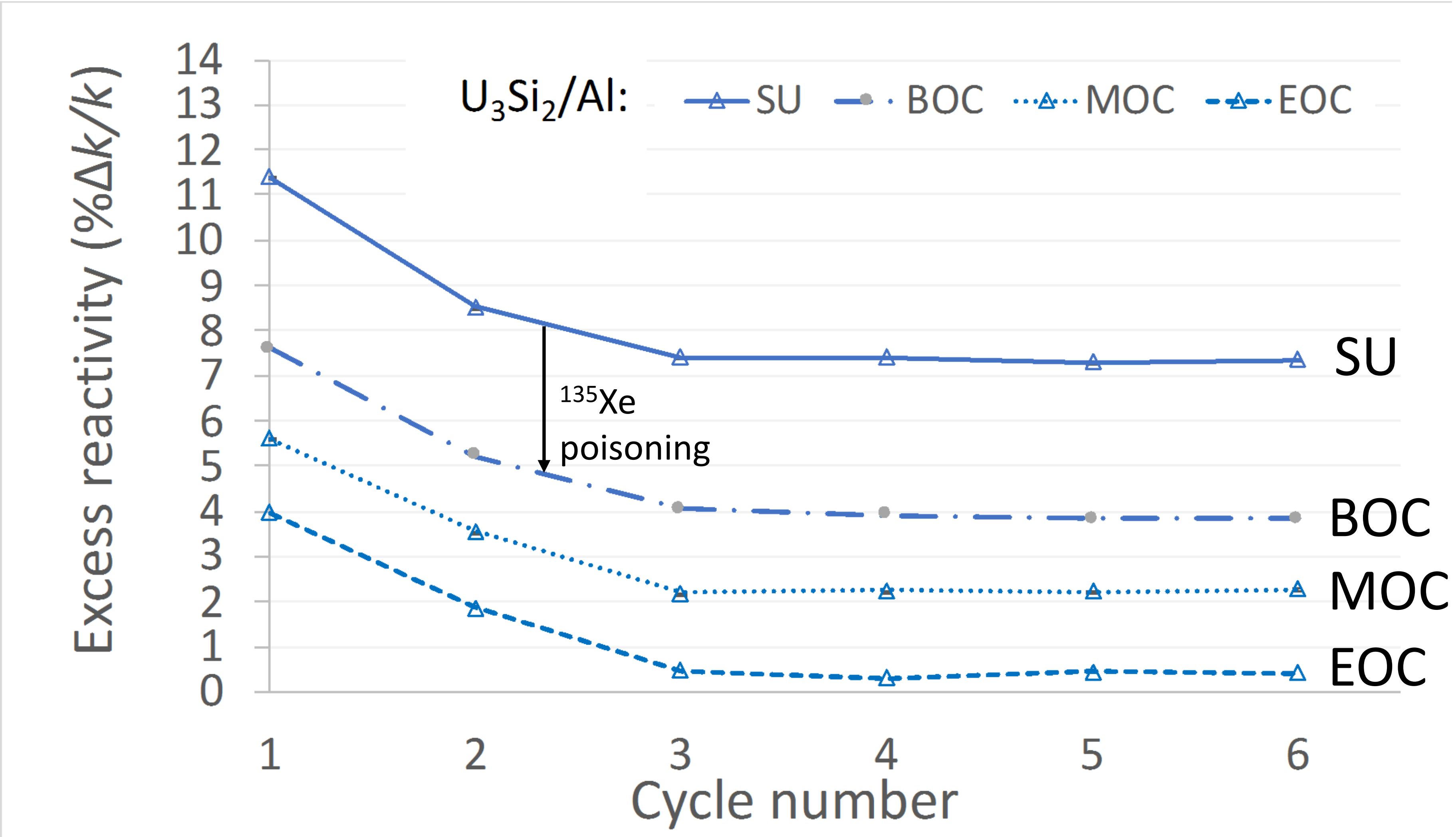
Fuel element x/#
x ≡ cycle number
≡ max. number of cycles

Equilibrium core search

- Evaluating performance of a reactor requires finding the equilibrium fuel inventories for states in reactor cycle
- The criticality (KCODE) and burnup/depletion (BURN) features of MCNP6 were used in an iterative process:



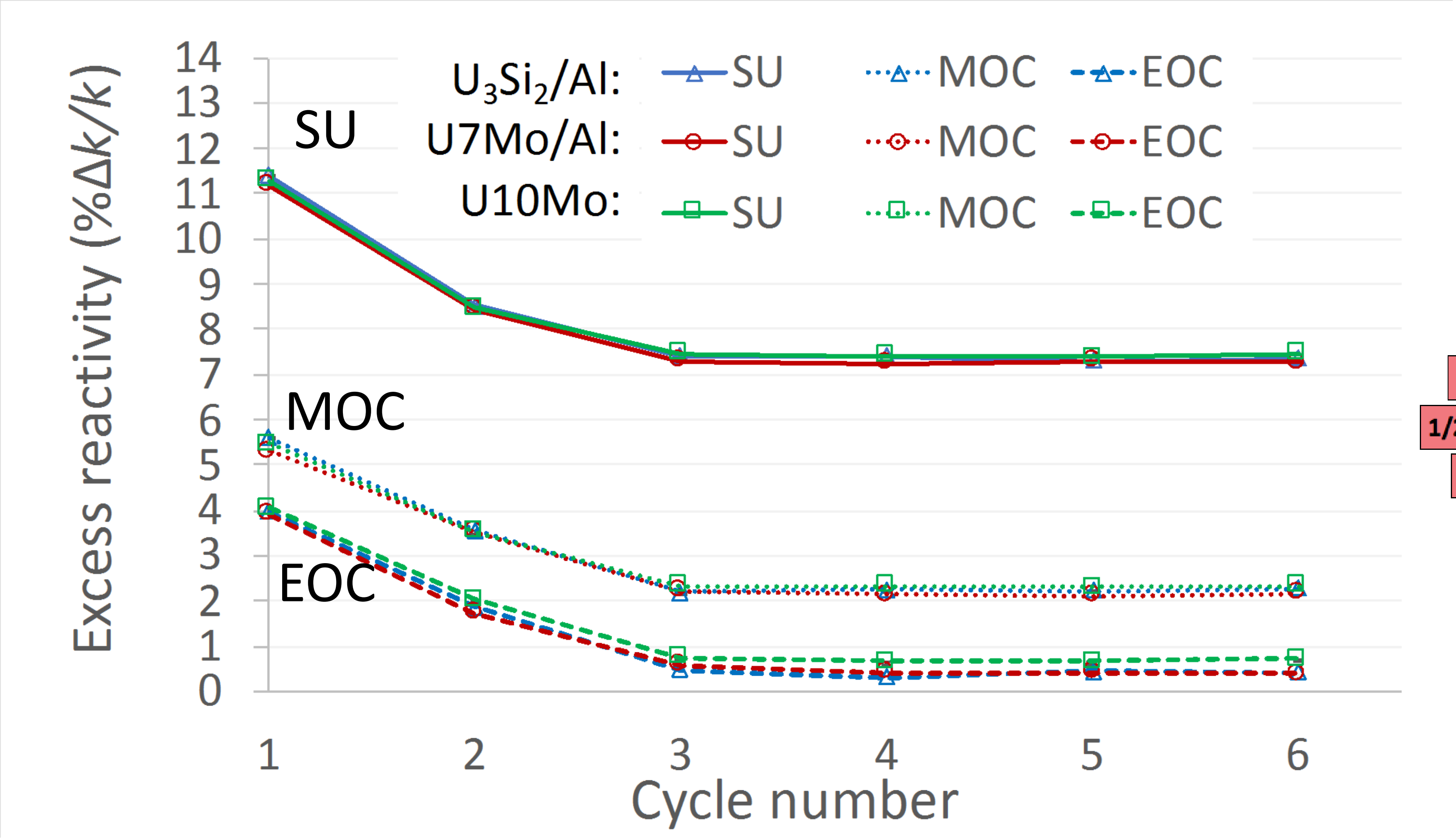
Equilibrium core search - continued



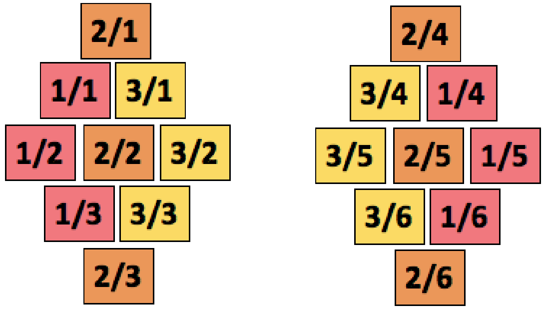
Cases investigated

Fuel	# of fuel plates	Fuel scheme	Power (MW)	Cycle length (days)	MWd
U_3Si_2/Al	17	A	20	30	600
U7Mo/Al	17	A	20	30	600
U10Mo	17	A	20	30	600
	19	A	30	30	900
	19	A	20	45	900
	19	B	20	30	600

Comparison of 17 plate model with LEU fuels

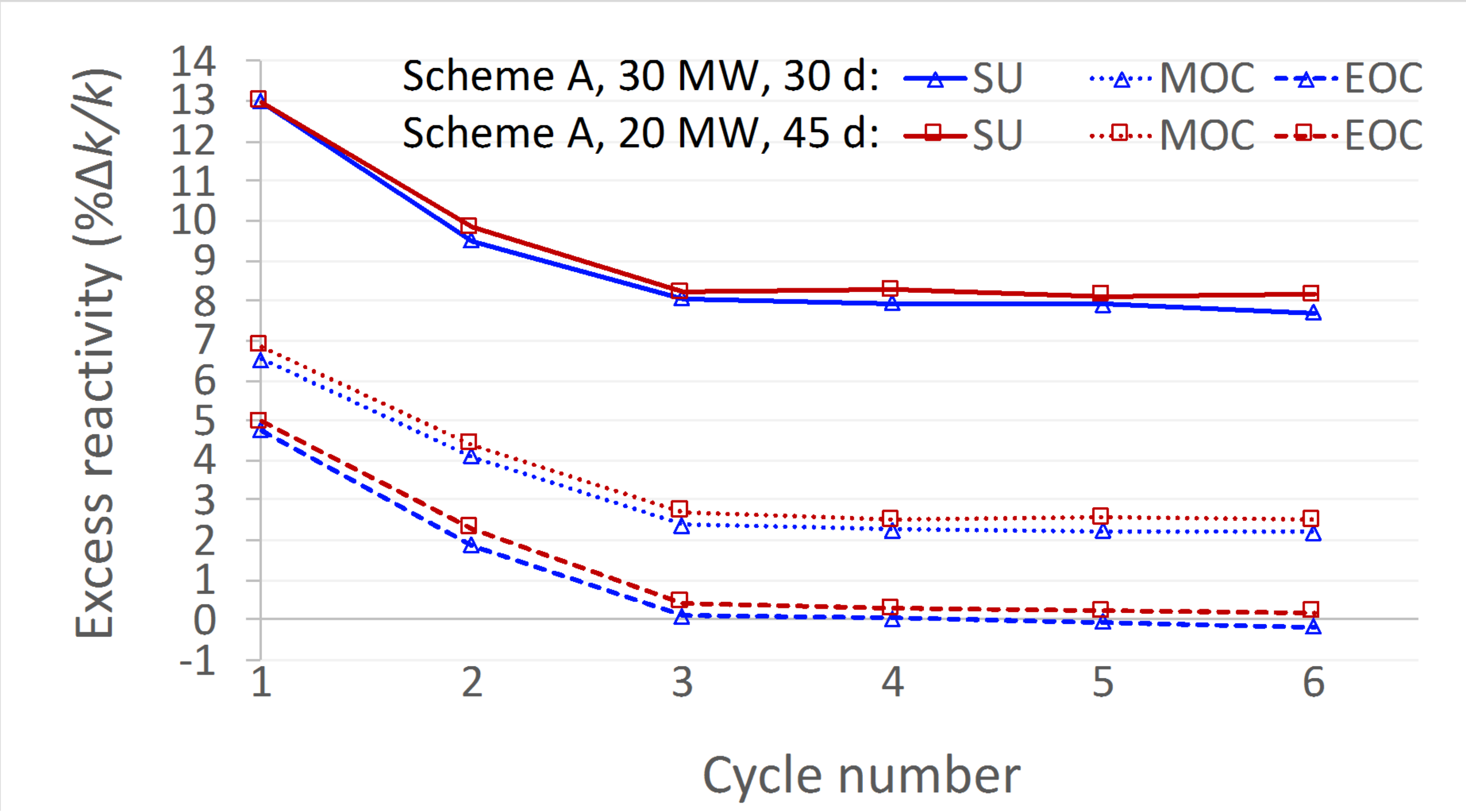


Scheme A

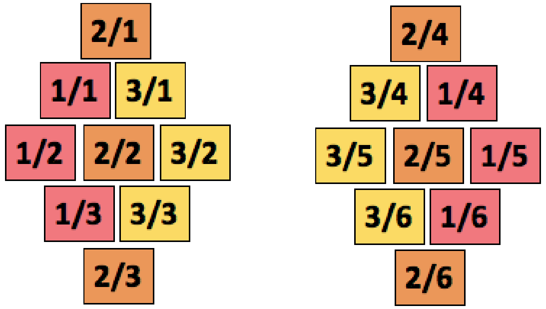


Each LEU fuel has enough reactivity for a 30 day cycle at 20 MW

19 plate fuel element with U10Mo

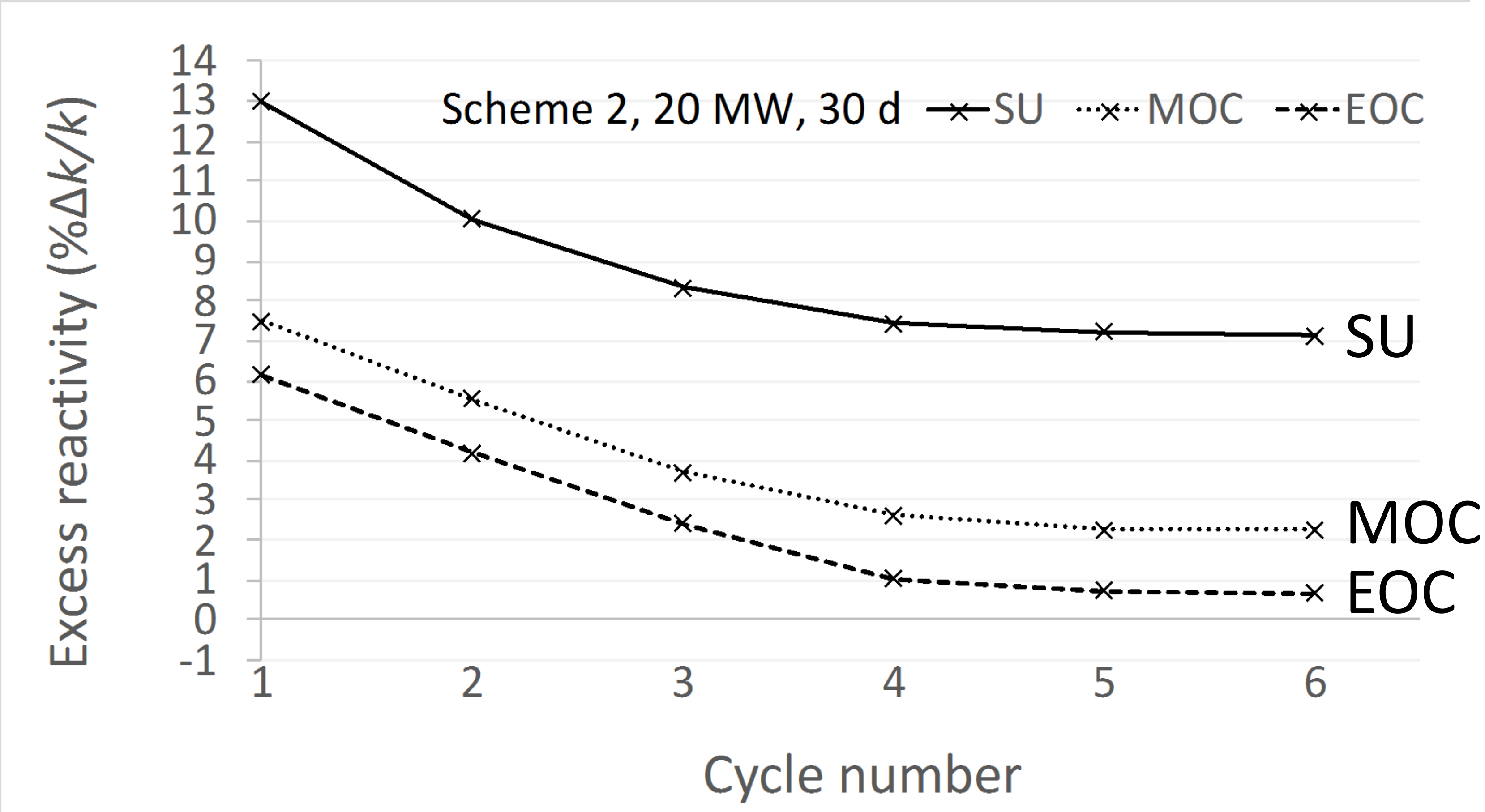


Scheme A

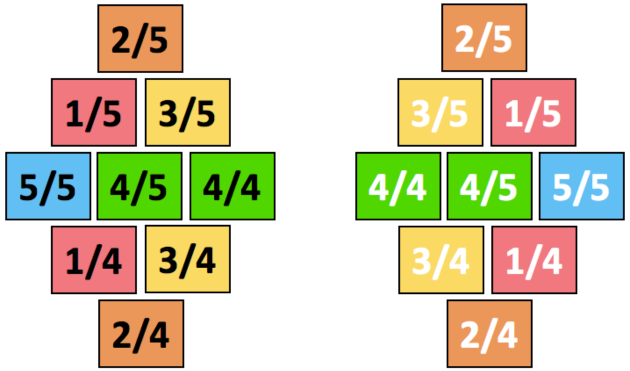


Potential to get 900 MWd cycle (20 MW×45 d or 30 MW×30 d)

19 plate fuel element with U10Mo



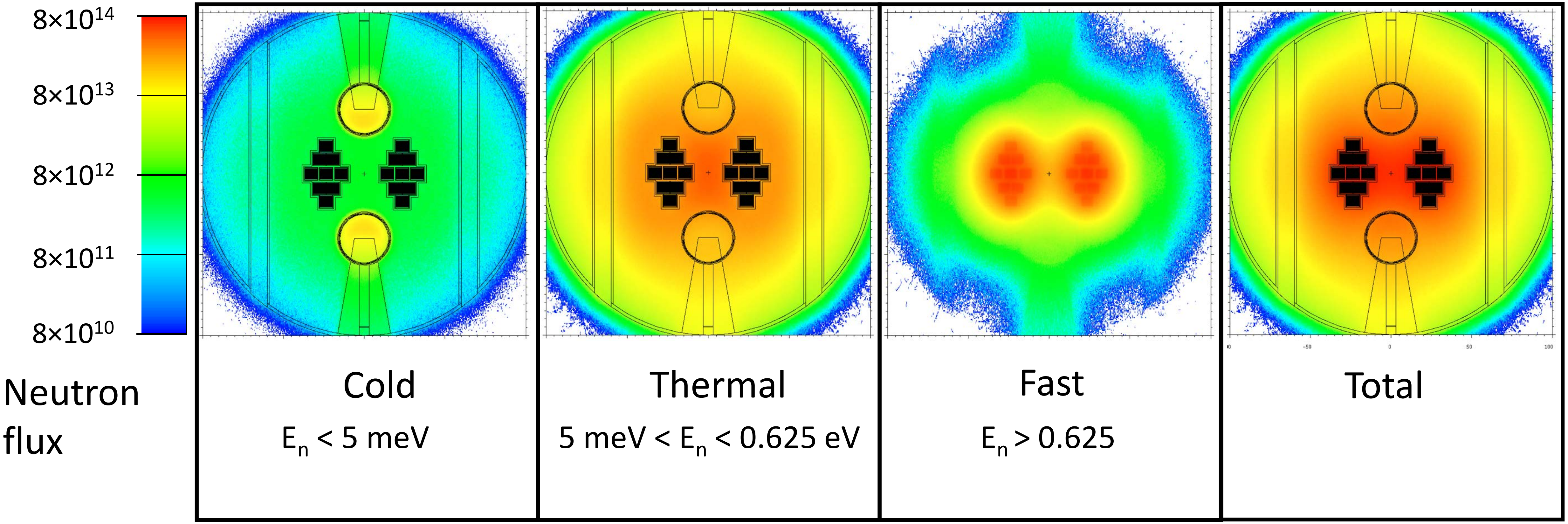
Scheme B



Potential to use four fresh elements per cycle instead of six

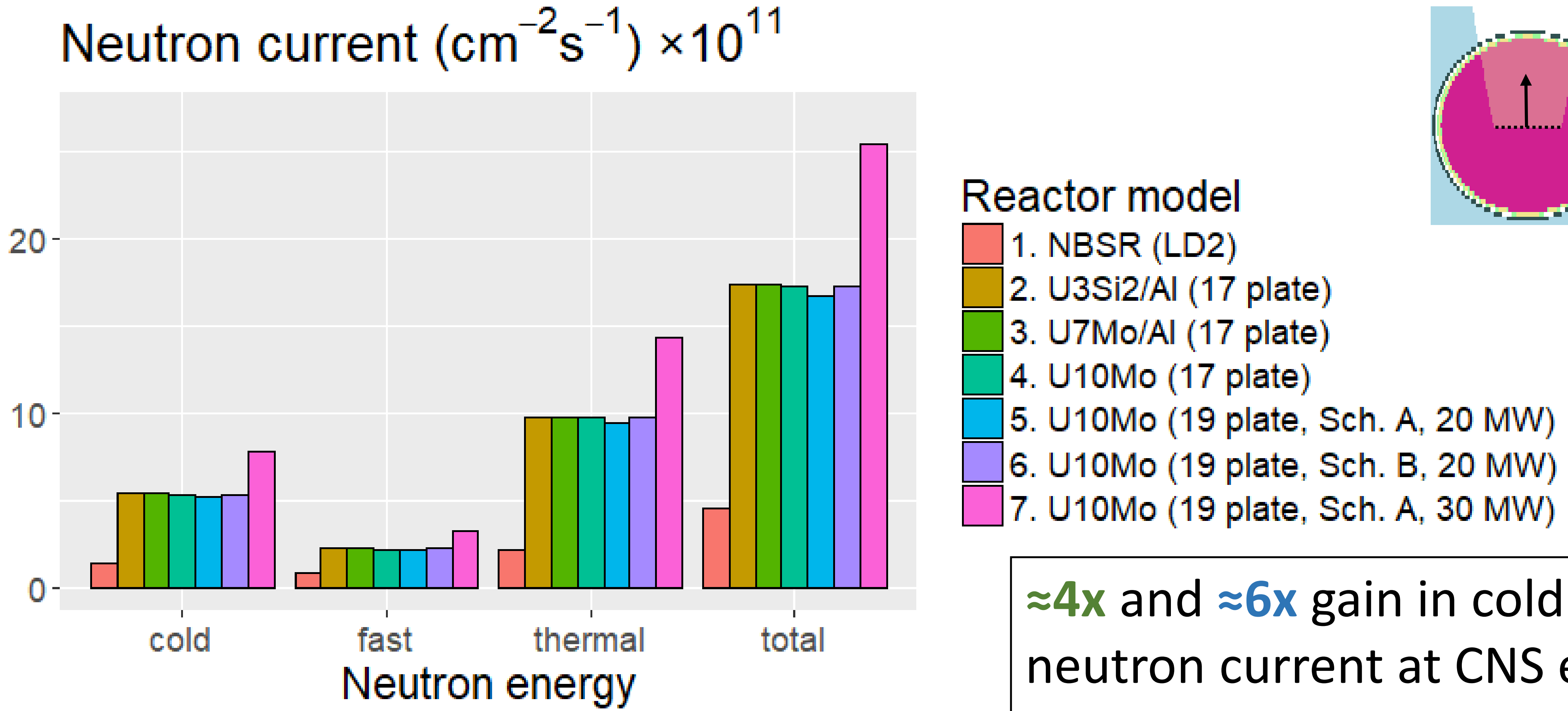
Neutron flux performance

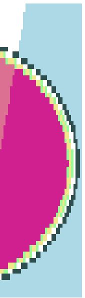
19 plate U10Mo model at BOC with 20 MW thermal power



Each compact core is an inverse flux trap, causing thermal flux to peak in the center

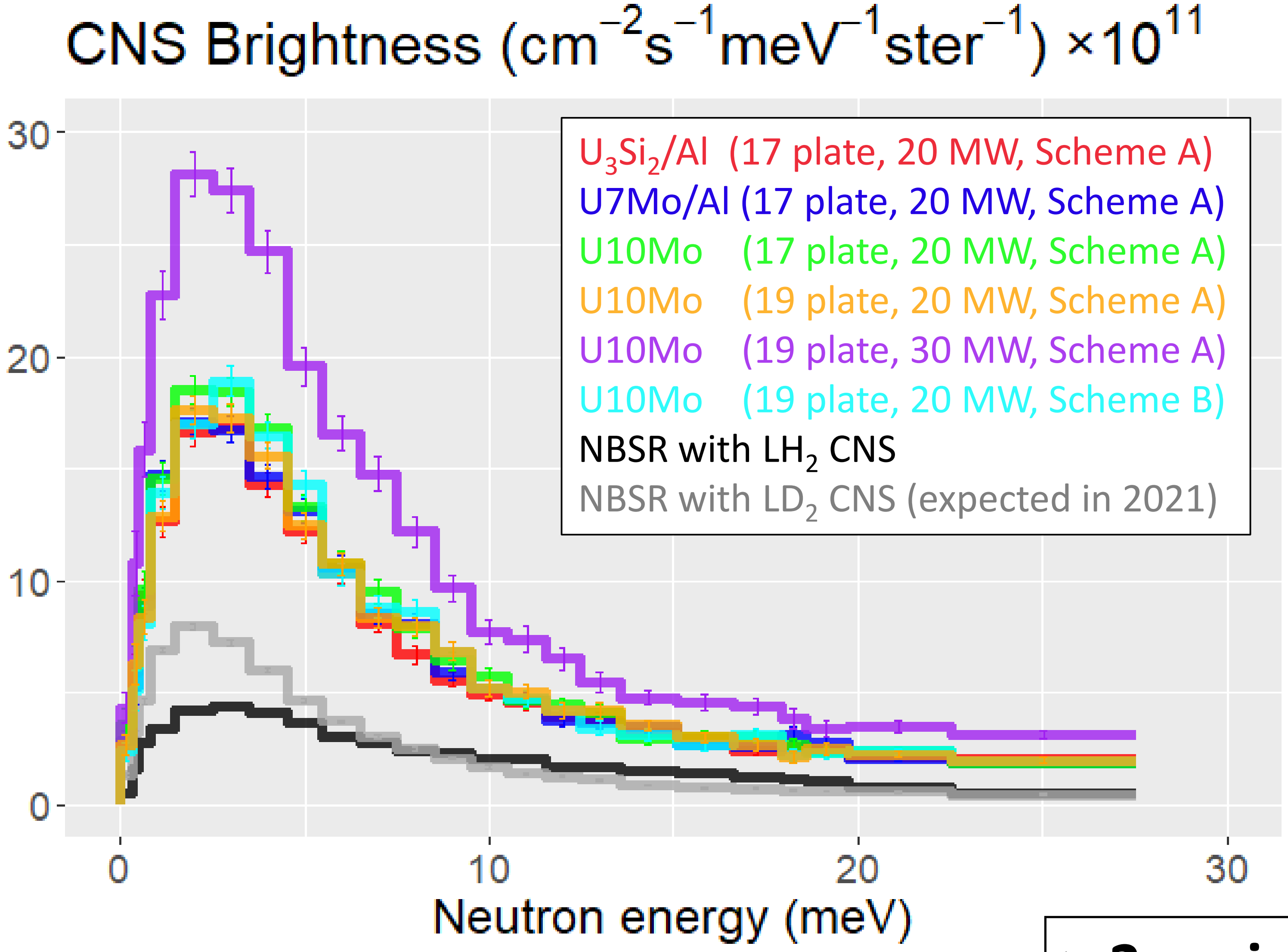
Cold neutron source performance

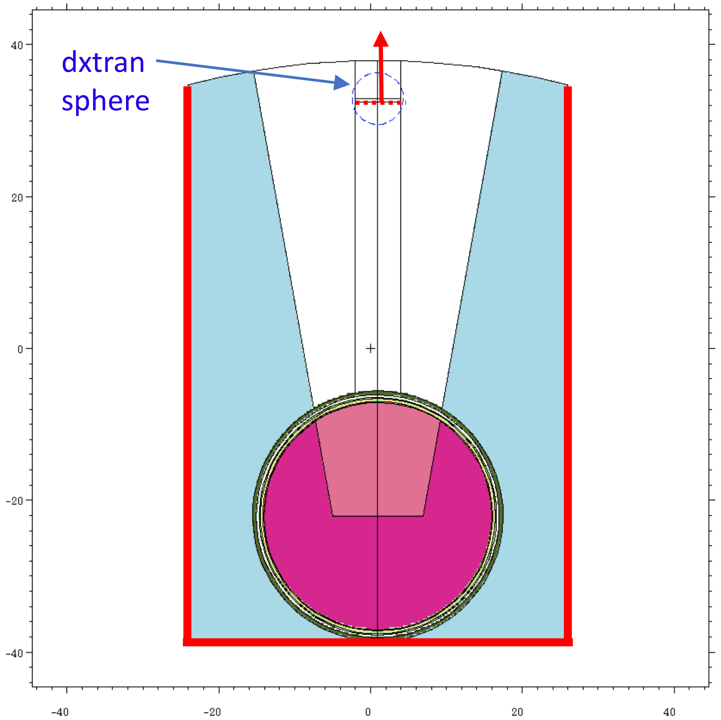




≈4x and **≈6x** gain in cold neutron current at CNS exit at **20 MW** and **30 MW** power

*Values for BOC with control blades each inserted 10 cm.
All tallies were performed with cos θ greater than 0.99, where θ is the angle between the neutron streaming direction and the normal direction of the exit surface



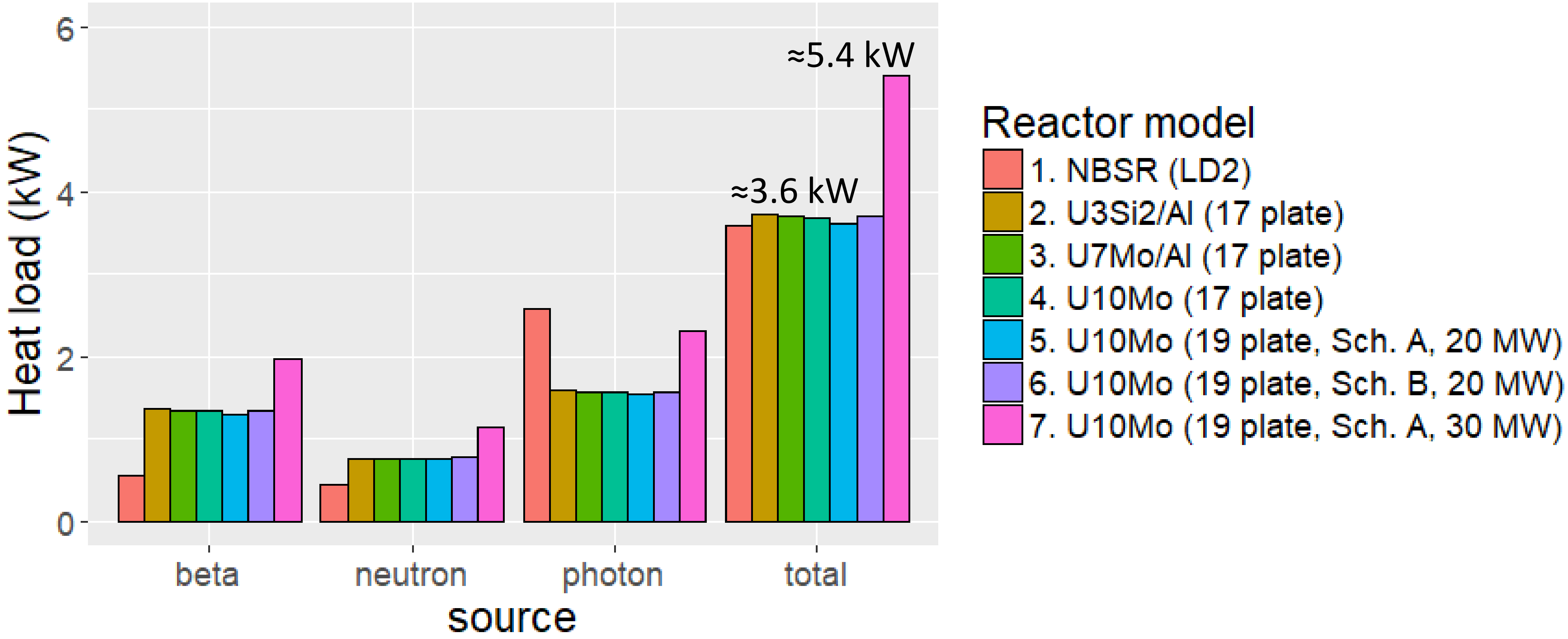


Surface source written in *kcode* problem with full reactor model

*Values for BOC with control blades each inserted 10 cm.
All tallies were performed with cos θ greater than 0.9998

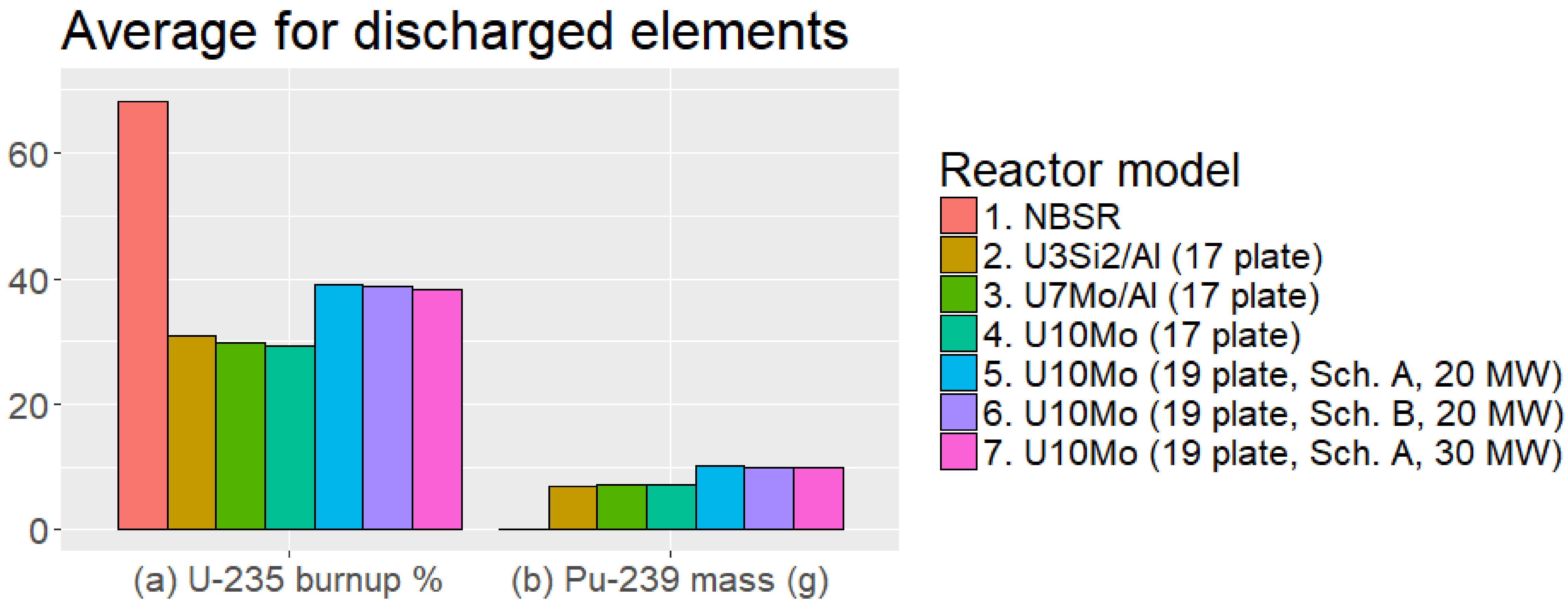
> 2x gain at 20 MW
> 3x gain at 30 MW

CNS heat load



Increasing to 30 MW power requires 50 % *more* cooling capacity for CNS

Comparison of fuel economy



Fuel utilization is improved with 19 plate U10Mo fuel elements

Conclusions

- The LEU fuels options produce similar results for CNS performance
- The very high U density of U10Mo enables more fuel per element in a 19 plate model, offering flexibility in cycle parameters

Future work

- Investigate reactivity control
- Perform safety analyses with RELAP5 for the Split Core reactor with 19-plate U10Mo fuel