

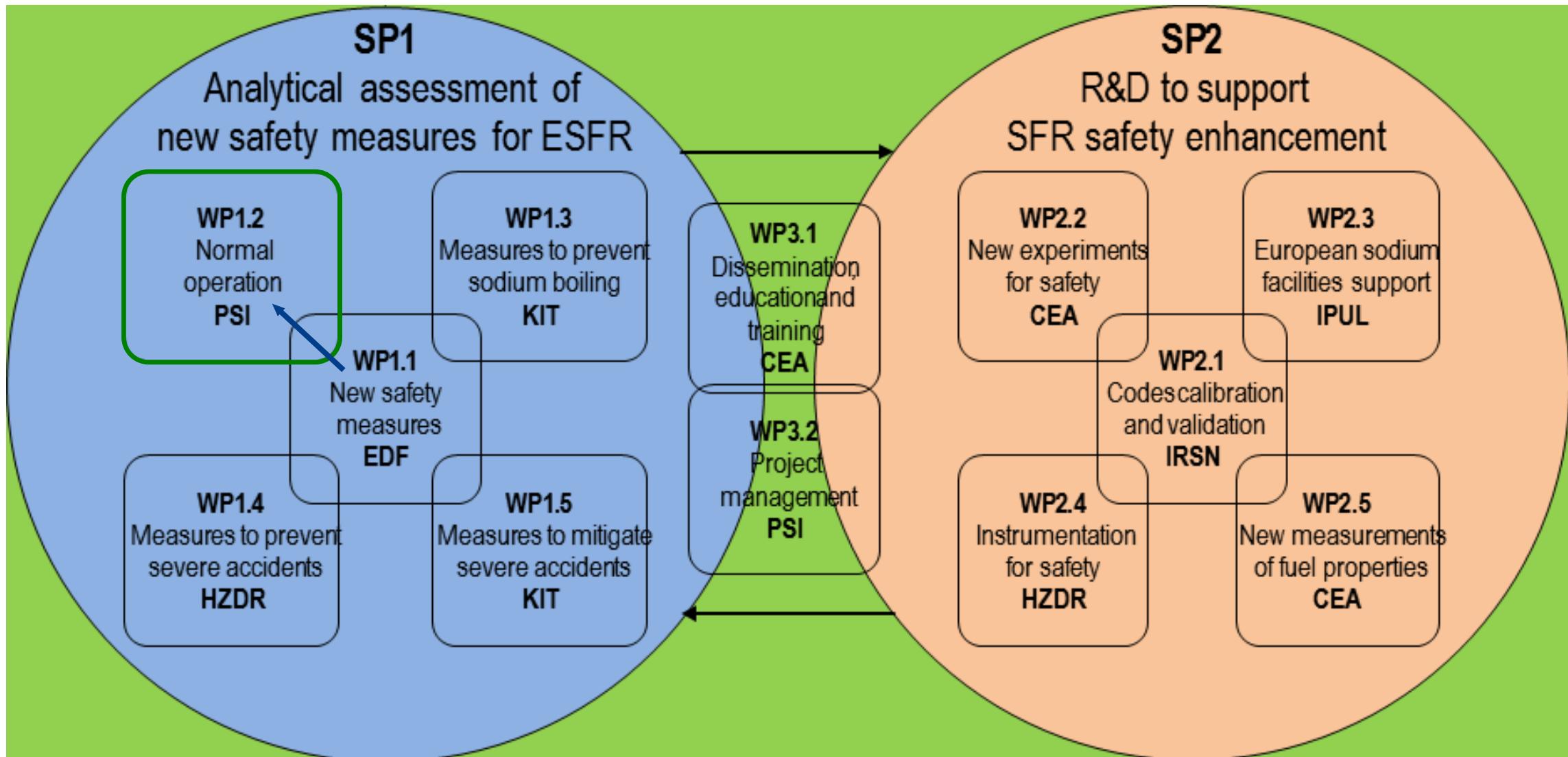
Initial ESFR-SMART core performance & burnup calculations

Emil Fridman

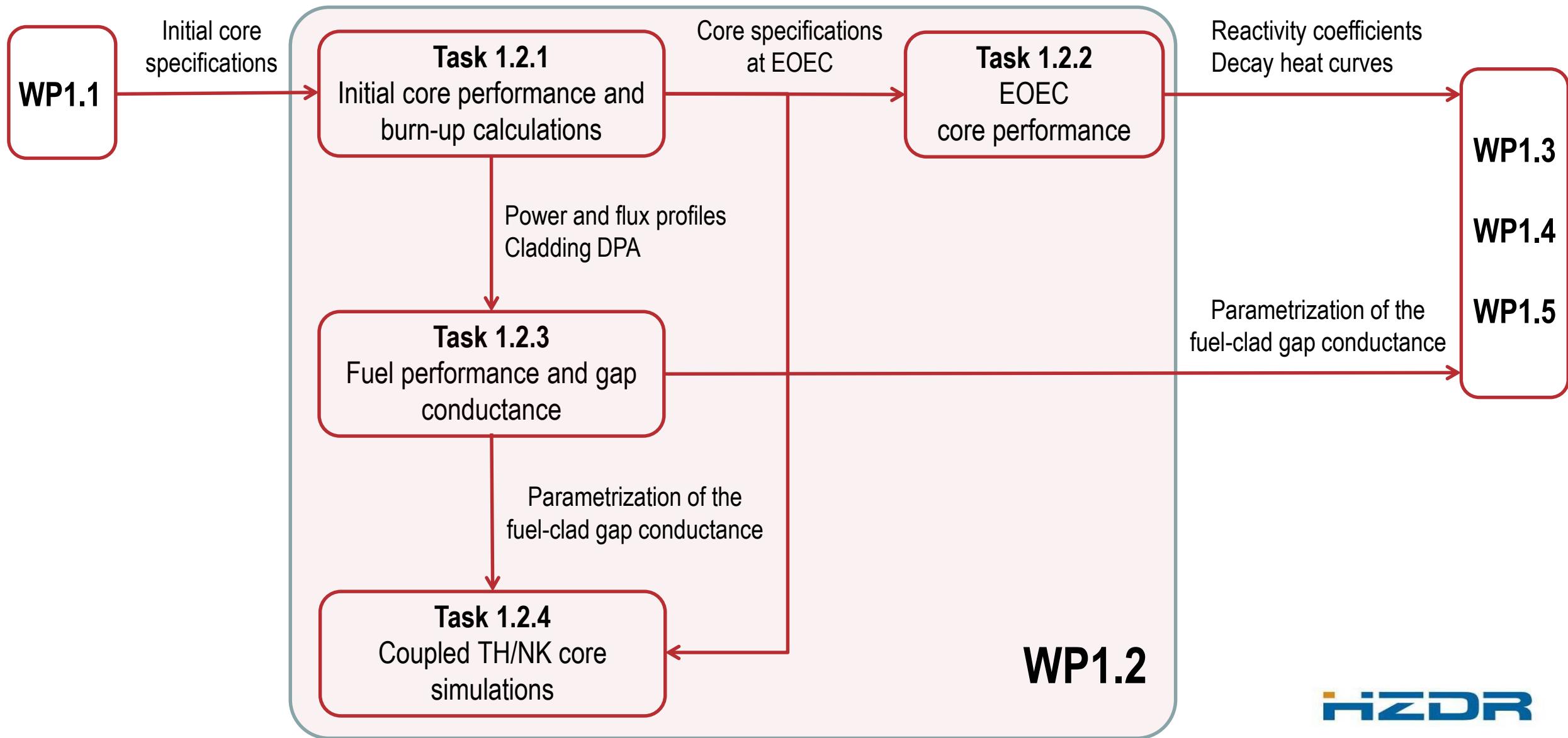
HZDR

 HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

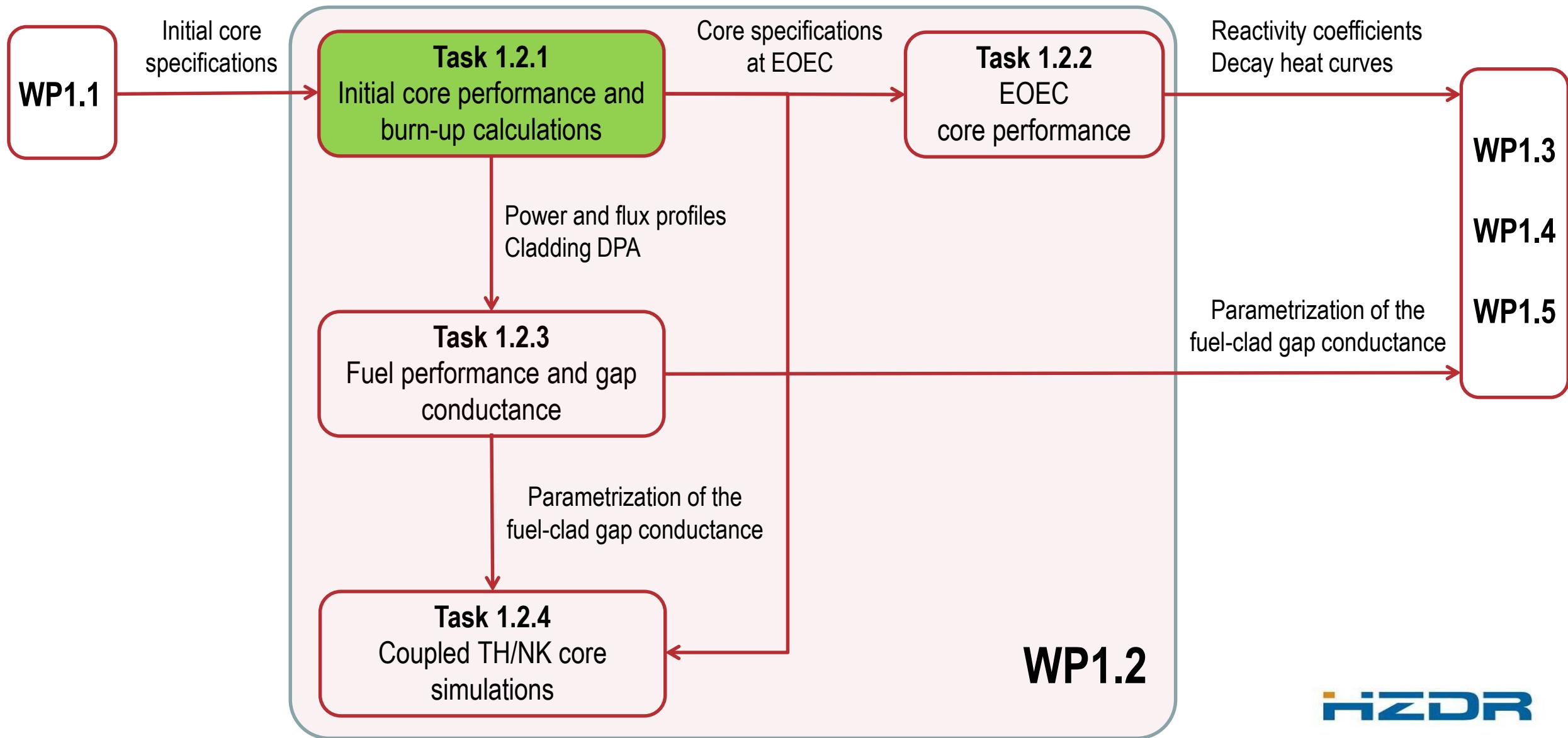
ESFR-SMART project structure



Structure of WP1.2 – “Normal operation”



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Overview of the ESFR-SMART core design

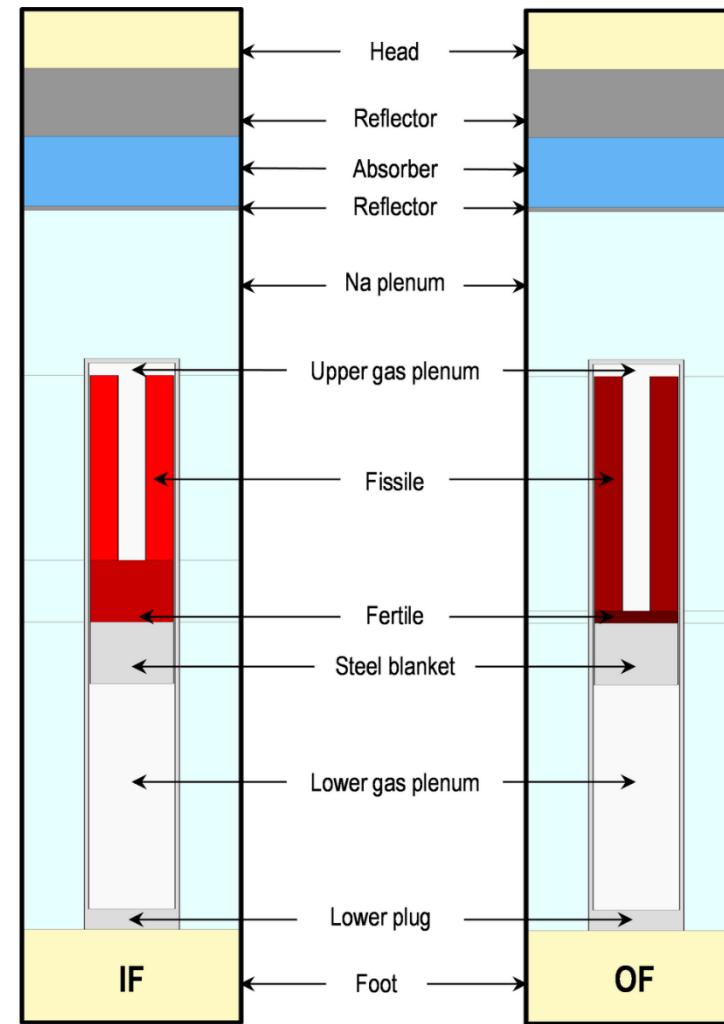
Overview of the ESFR-SMART core design

- ESFR-SMART core is evolutionary design based on CP-ESFR and ESNII+ experience
- Nominal operating parameters are similar to CP-ESFR core

Reactor power (MWth)	3600
Core inlet temperature (°C)	395
Core outlet temperature (°C)	545
Average sodium temperature (°C)	470
Average core structure temperature (°C)	470
Average fuel temperature (°C)	1227
Average fertile materials temperature (°C)	627

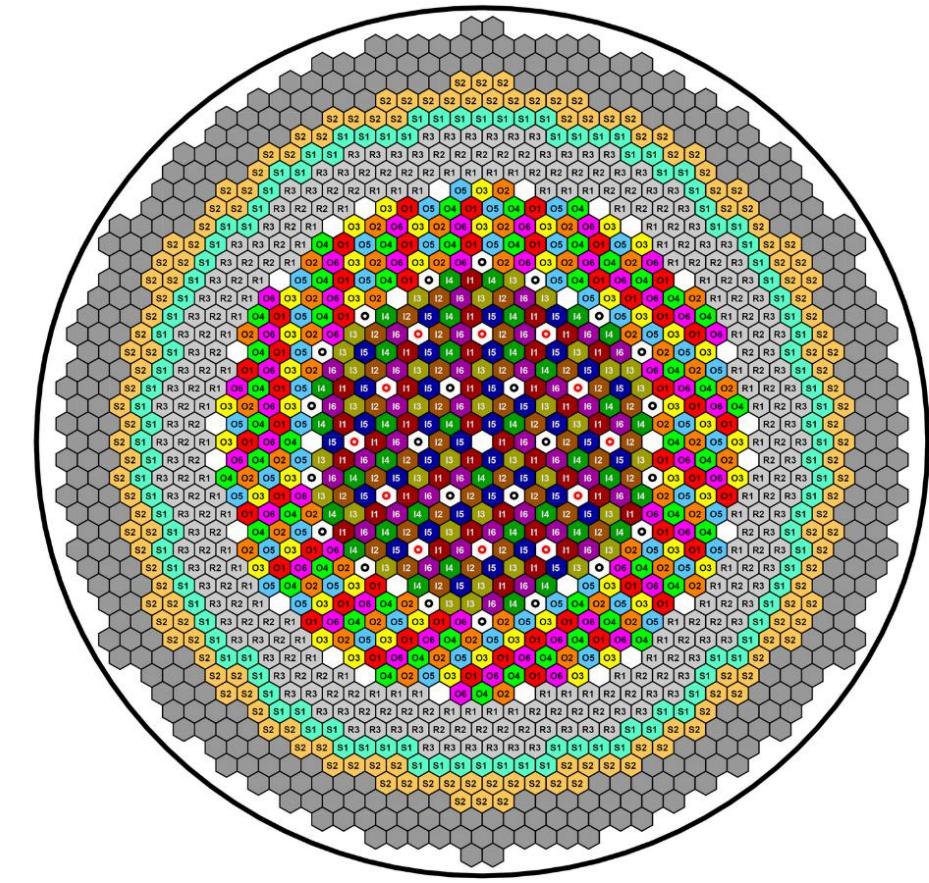
Axial design of IF and OF sub-assemblies

- Core is split into inner (IF) and outer (OF) fuel regions
- Large Na plenum as in CP-ESFR
 - For coping with Sodium Void Reactivity Effect (SVRE)
- Variable fissile and blanket heights
 - IF: 75 cm fissile / 25 cm blanket
 - OF: 95 cm fissile / 5 cm blanket
 - CP-ESFR: 100 cm fissile /30 cm blanket
- Aligned top boundaries of IF and OF
 - In contrast to ASTRID
- No intermediate axial blanket
 - In contrast to ASTRID



Radial design of ESFR-SMART core

- 6-batch core loading
- 51 more fuel S/A compared to CP-ESFR
 - Compensation for shorter fissile
- Identical Pu enrichment in IF and OF
 - Simplified fuel fabrication
 - Variable in CP-ESFR
- 31 CDT connected to corium catcher
- 12 Diverse Shutdown Devises (DSD)
 - 9 in CP-ESFR
- Somewhat different design of CSD and DSD
 - Axial profiling of B10 enrichment



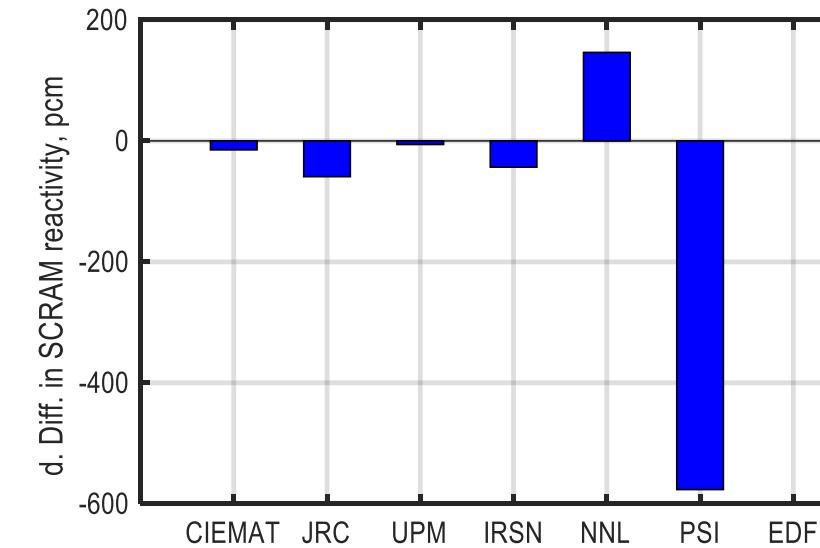
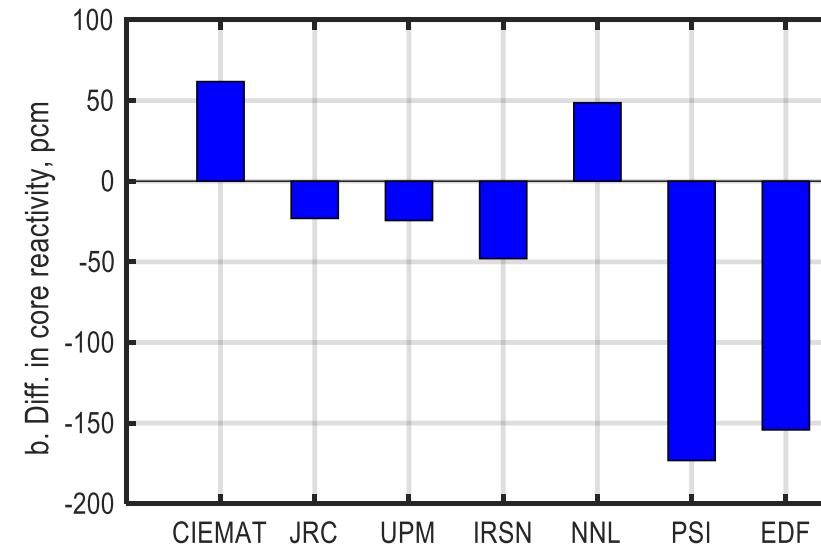
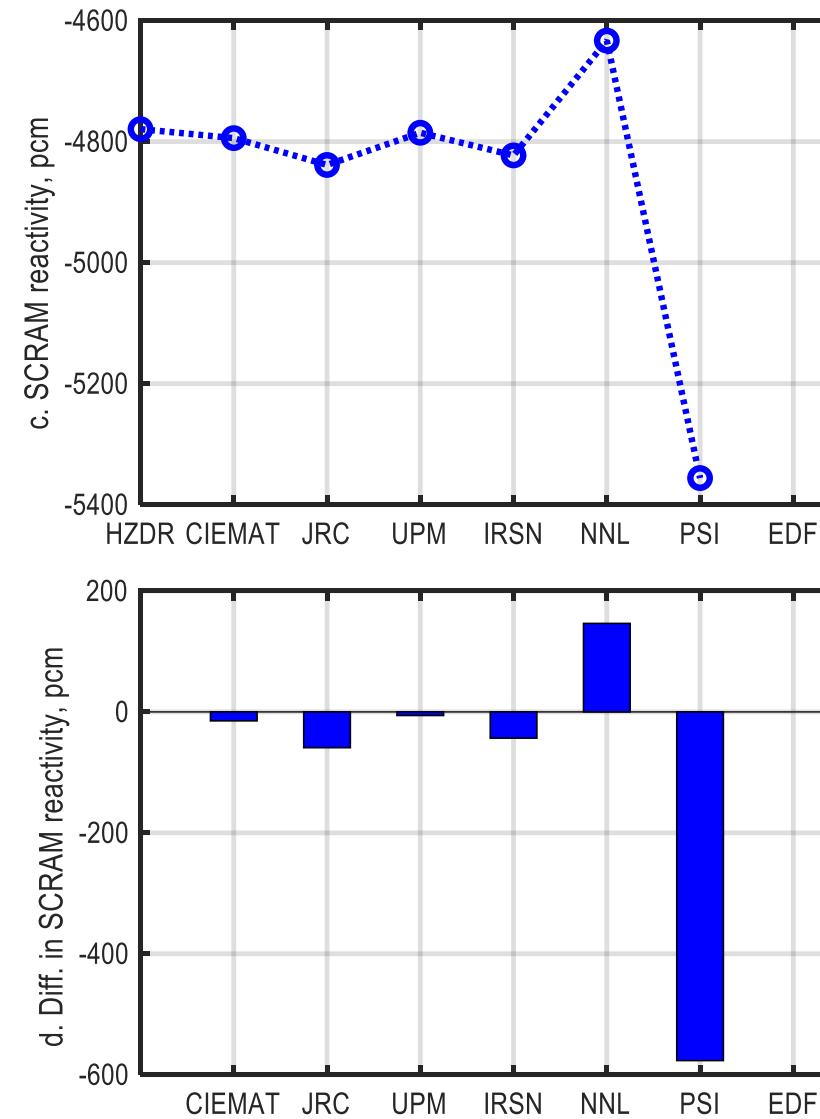
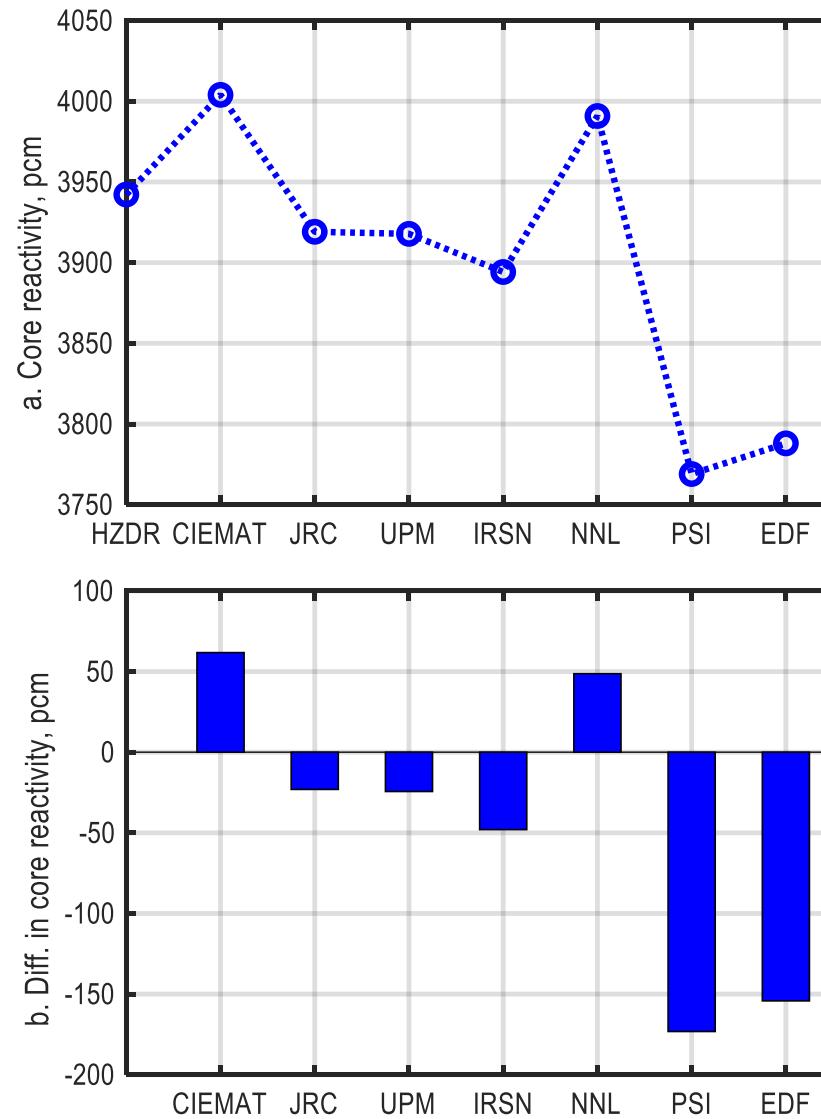
	Inner fuel	6 batches×36 = 216
	Outer fuel	6 batches×48 = 288
	CSD / DSD	24 / 12
	1 st / 2 nd / 3 rd reflector ring	66 / 96 / 102
	Spent Inner / Outer fuel storage	3 batches×36 = 108
	Spent Inner / Outer fuel storage	3 batches×48 = 144
	Corium discharge tubes	31

Neutronic analysis of the initial core

- Evaluation of safety-related neutronic parameters for the initial core
 - Core reactivity
 - SCRAM reactivity
 - Sodium void reactivity
 - Doppler constant
- Calibration and verification of the neutronics codes:

Organization	Code	Solver	Nuclear data library
HZDR	Serpent 2.1.29 (Reference)	CE-MC	JEFF-3.1
CIEMAT	MCNP6.1.1b	CE-MC	JEFF-3.1
JRC	MCNP6.1.0	CE-MC	JEFF-3.1
IRSN	MORET 5.C.1	CE-MC	JEFF-3.1
UPM	KENO-VI	CE-MC*	JEFF-3.1
NNL/Cambridge	WIMS11	Deterministic	JEFF 3.1.2
PSI	ERANOS/VARIANT	Deterministic	JEFF-3.1
EDF	ERANOS/VARIANT	Deterministic	JEFF-3.1

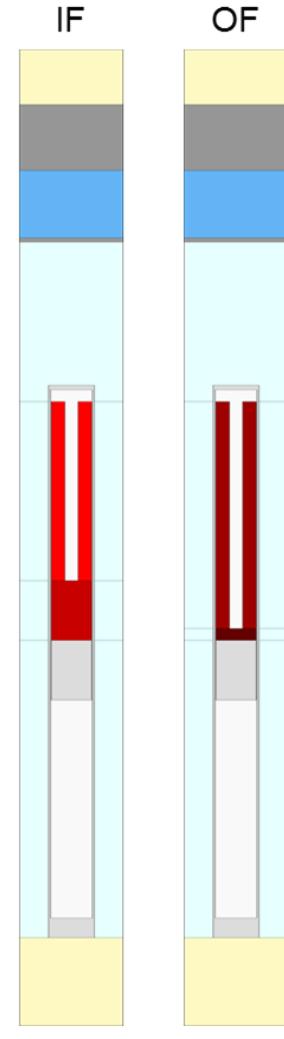
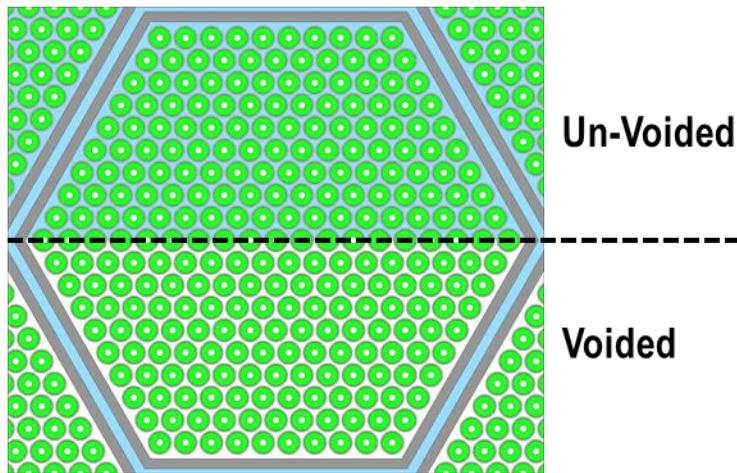
Core and SCRAM reactivity



Sodium void reactivity

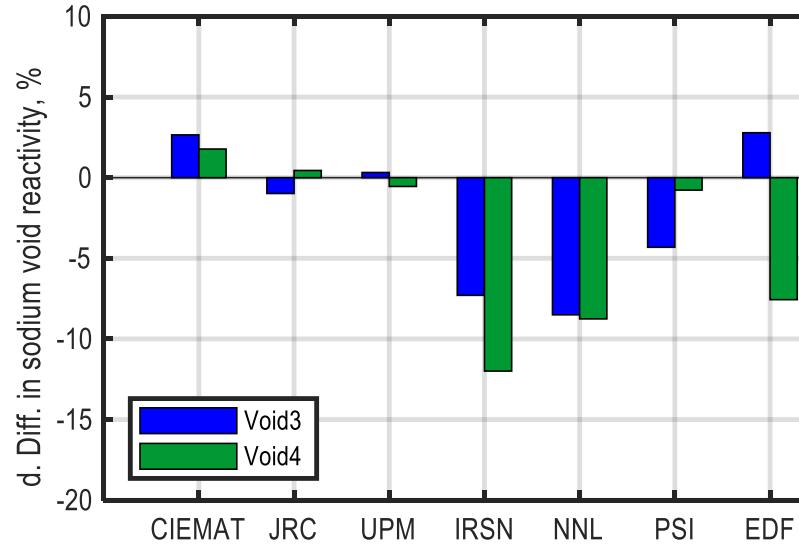
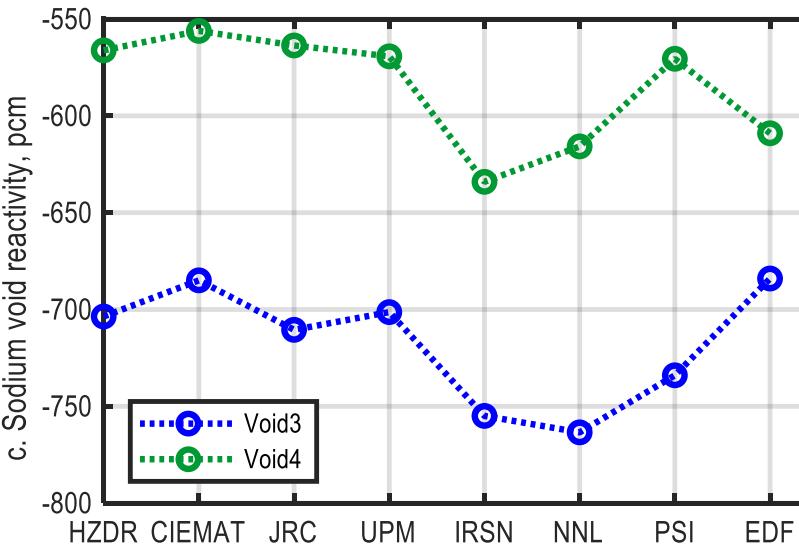
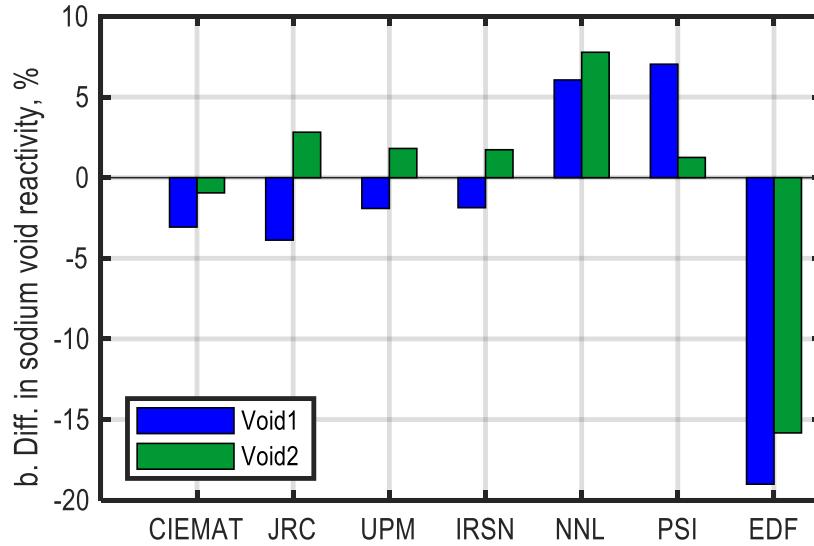
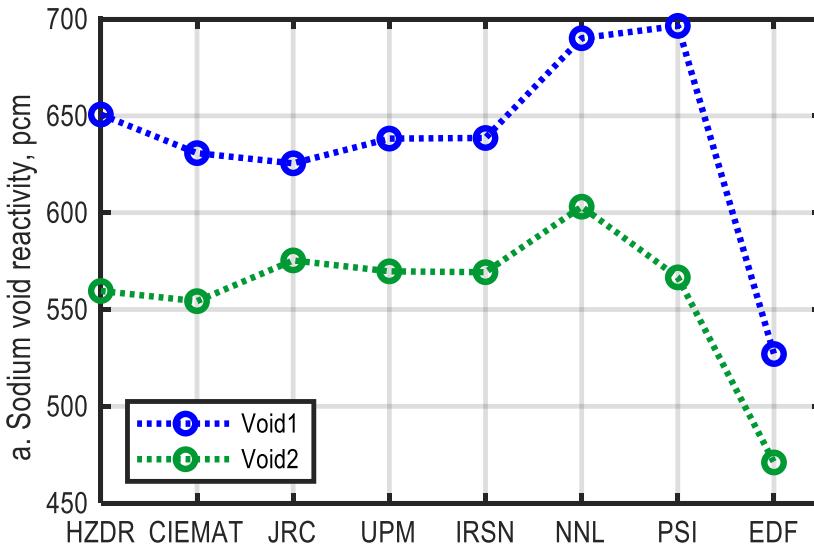
- Voiding scenarios
 - Case 1: void IF
 - Case 2: void OF
 - Case 3: void above IF
 - Case 4: void above OF
 - Case 5: void all

Treatment of inter-assembly Na gap



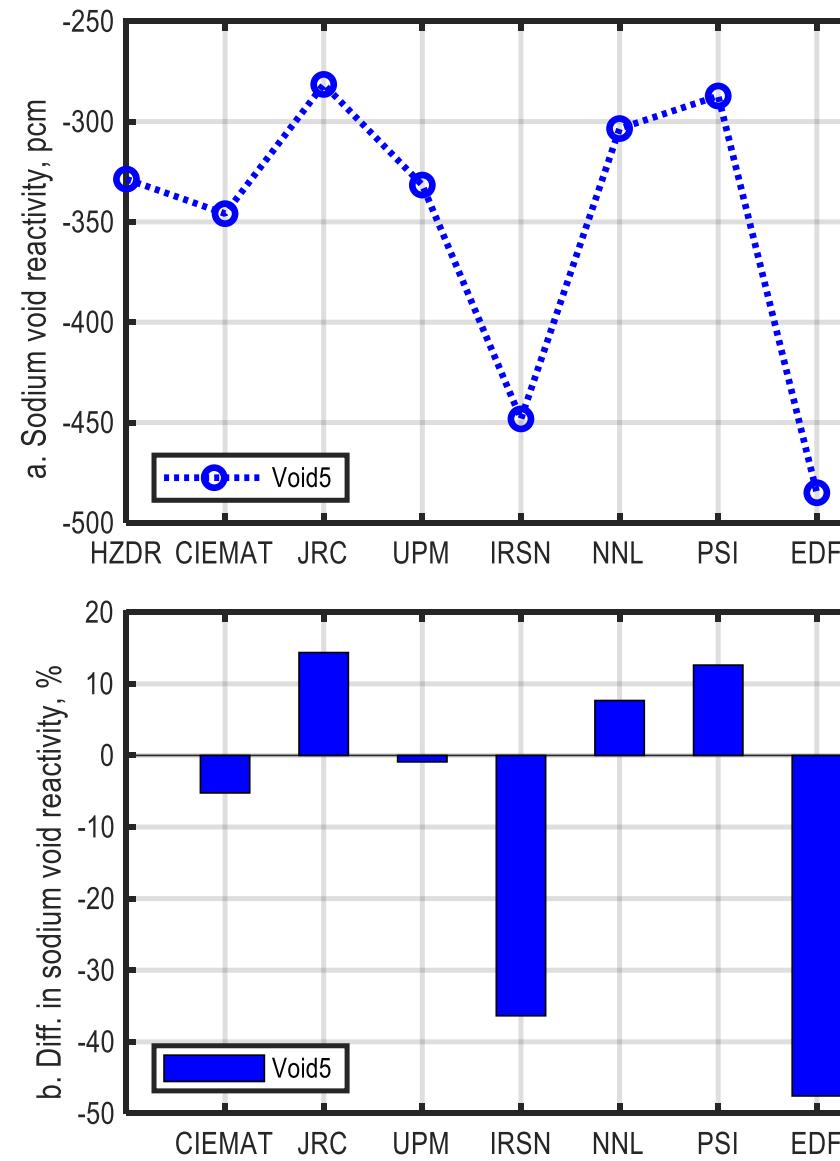
Reference	Case 1 Void IF	Case 2 Void OF	Case 3 Void above IF	Case 4 Void above OF	Case 5 Void all
OF Fissile	IF Fissile	OF Fissile	OF Fissile	OF Fissile	OF Fissile
OF Fertile	IF Fertile	OF Fertile	OF Fertile	OF Fertile	OF Fertile

Sodium void reactivity (Void 1, 2, 3 and 4)

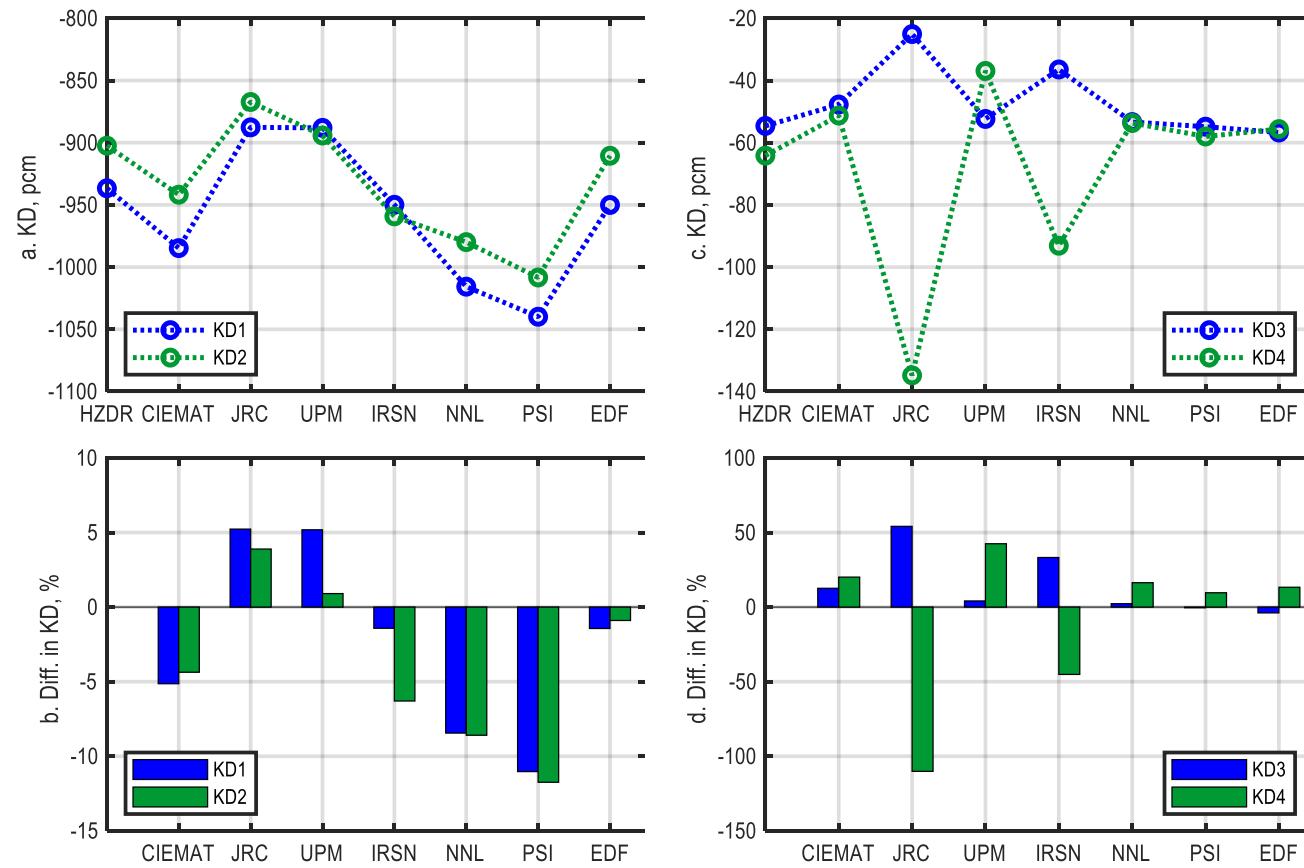


Sodium void reactivity (Void 5)

- Corresponds to the full core voiding
- Combination of two large effects
 - Positive effect due to the voiding of the fissile zones
 - Negative effect due to the voiding of the Na plenum
- Good agreement between MC codes
 - Differences beyond statistical precision are mainly due to the differences in processing of the basic JEFF-3.1 library
- Difference between ERANOS of PSI and EDF
 - A possible reason - different treatment of non-multiplying media (plenum, reflectors, control rods, etc.)



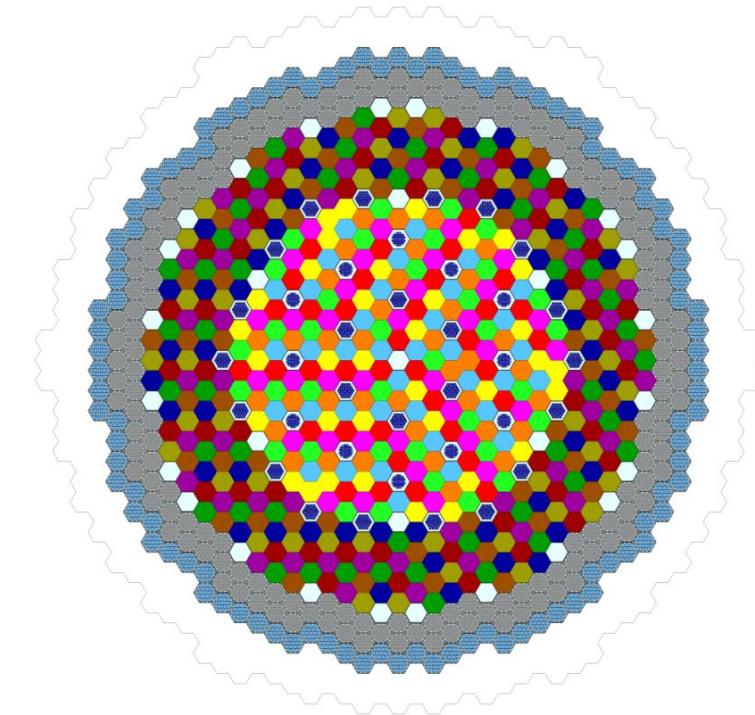
Doppler constants



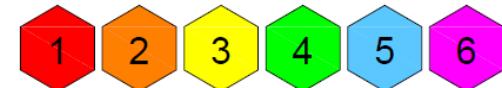
- KD3 and KD4 are problematic parameters
- Net reactivity effect is low → the results are sensitive to the MC statistics

Multi-batch burnup

- Main objective – establishing the equilibrium core state
- 6-batch fuel management
- 1/6th of the core is replaced after each cycle
- 362 EFPD fixed fuel cycle length
- 2172 EFPD total in-core residence time
- No reshuffling – fixed FA locations
- Modeling of 3 full in-core residence periods (i.e.18 cycles)



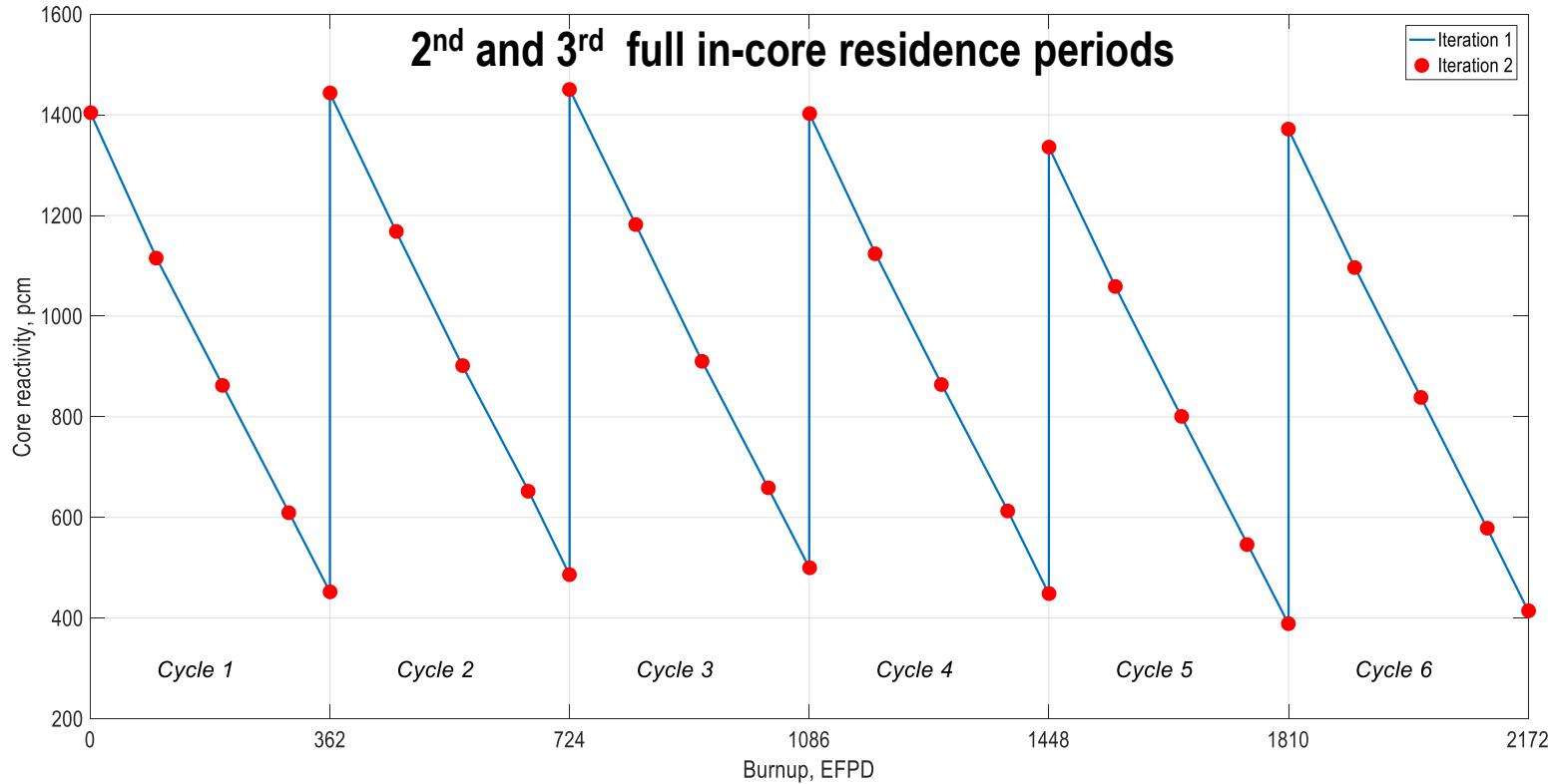
Inner fuel 216 S/A (6 batches ×36)



Outer fuel 288 S/A (6 batches ×48)

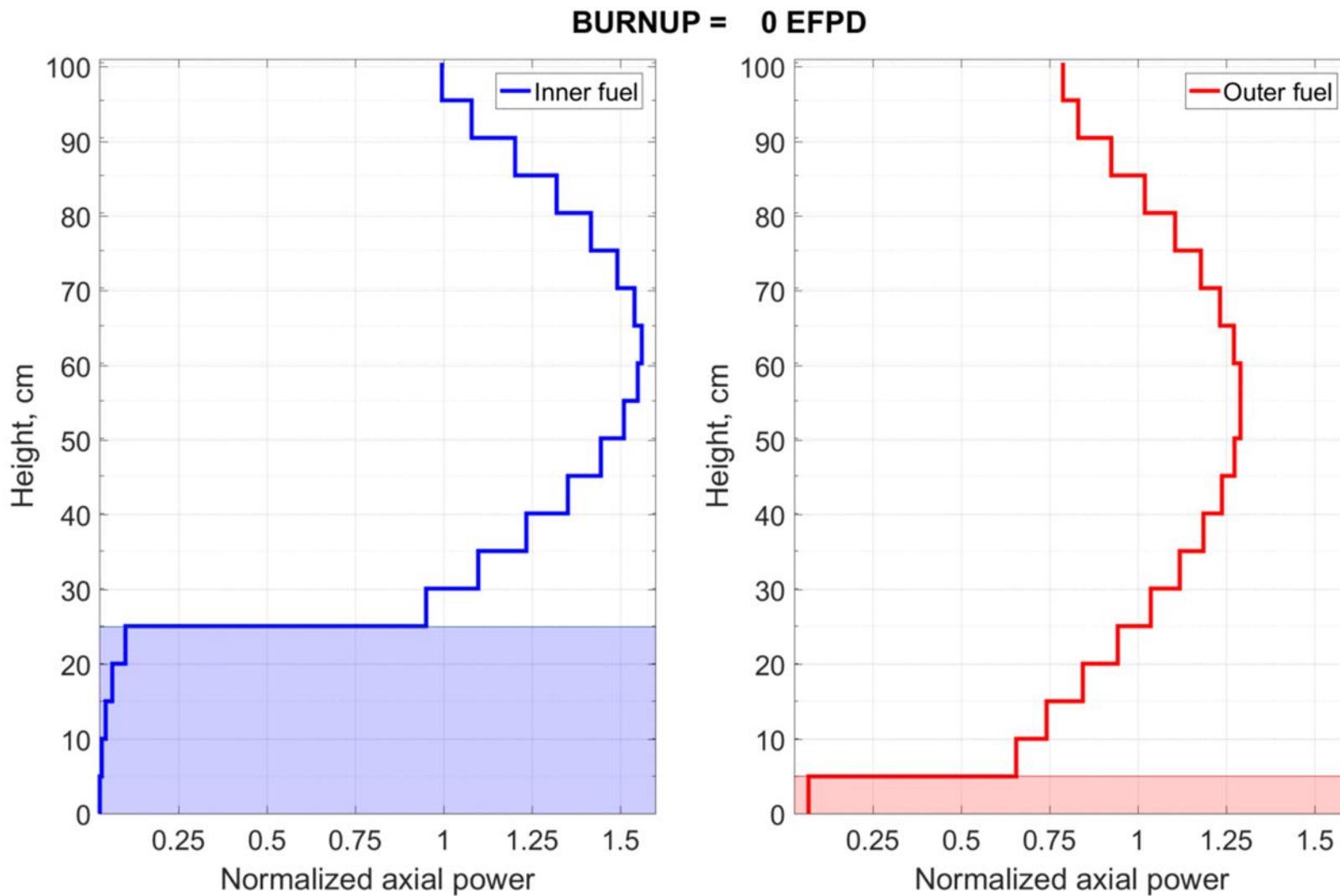


Multi-batch burnup: core reactivity

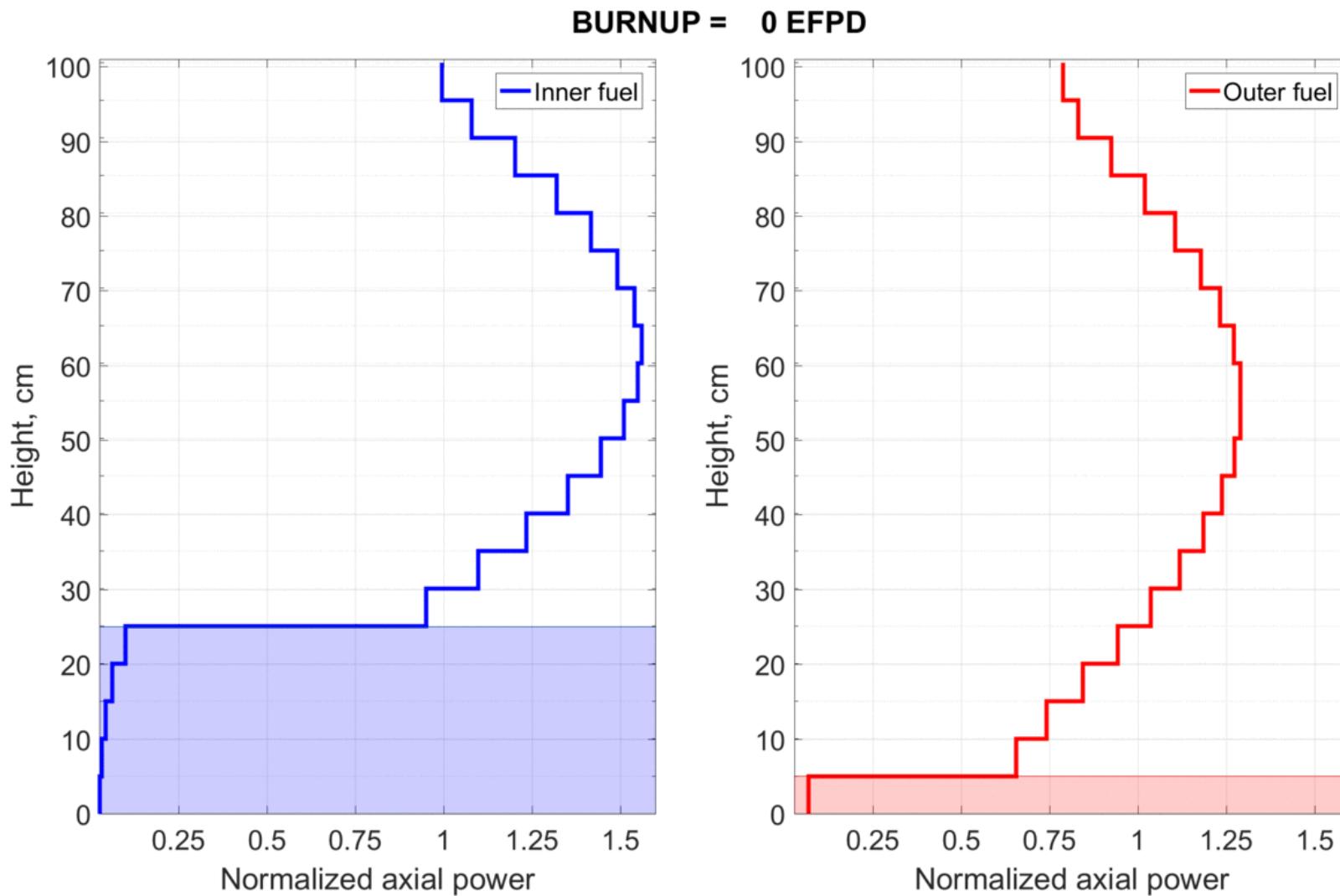


- Cycle-to-cycle behavior of the core is approximately identical
- BOC reactivity is 1400 pcm vs 4000 pcm for initial core
- Average core burnup is about 58.2 MWd/kg
- EOC state of Cycle 6 considered as EOEC state

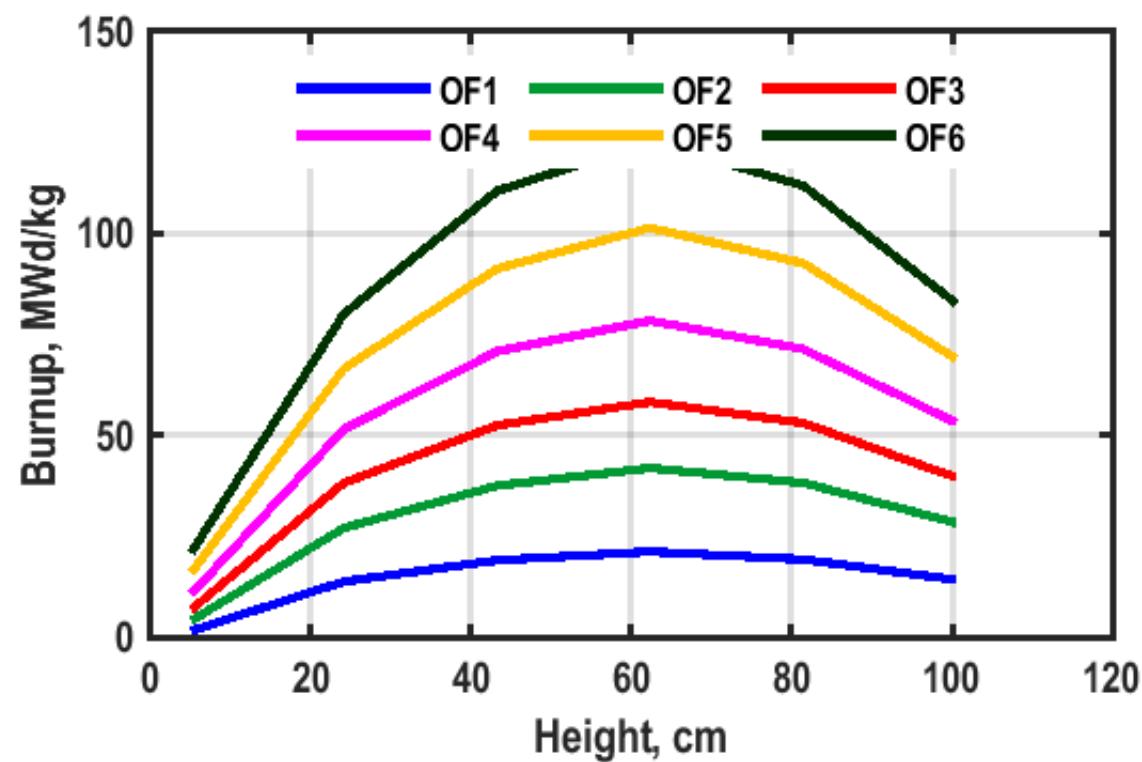
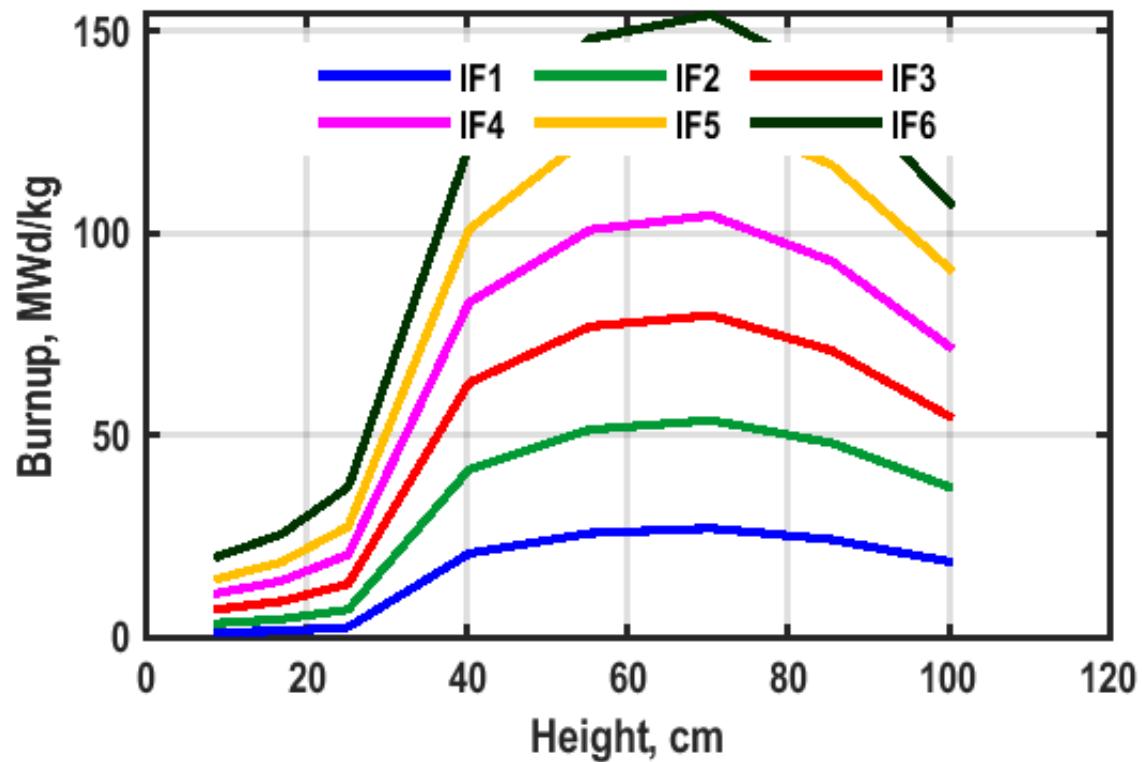
Multi-batch burnup: evolution of axial power profiles



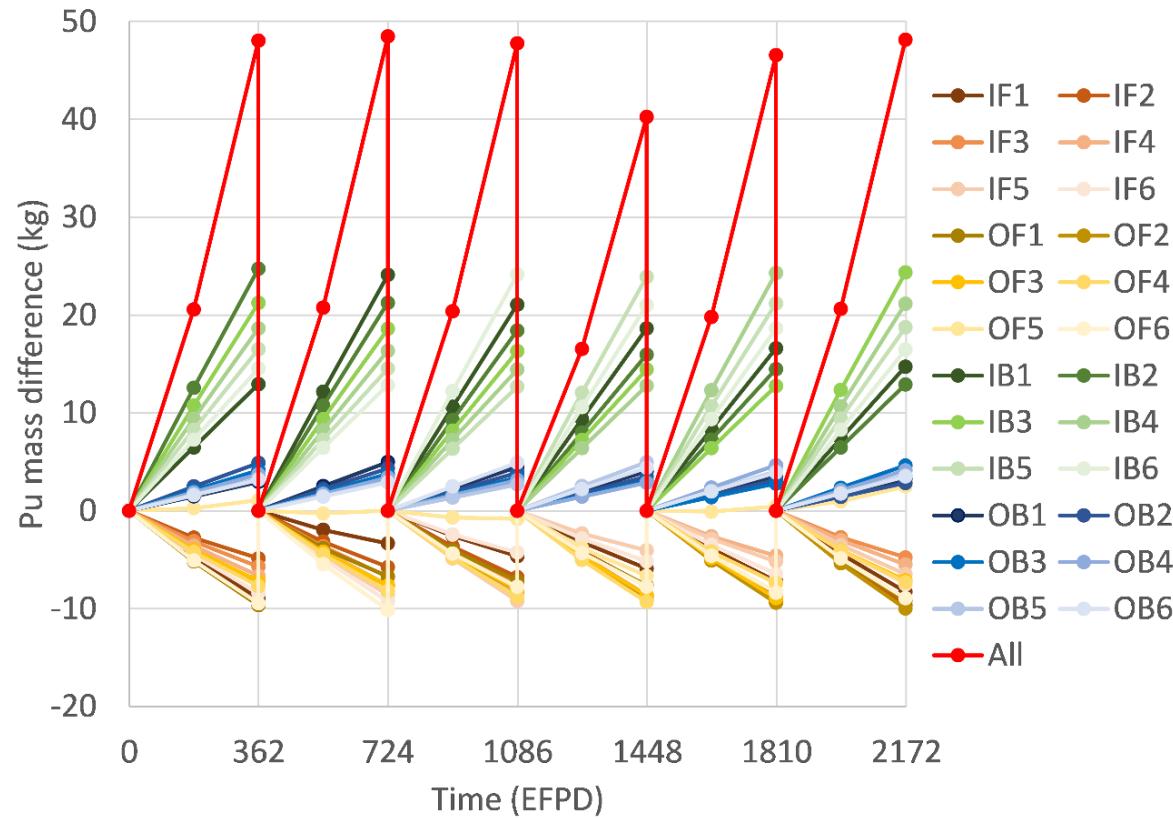
Multi-batch burnup: evolution of axial power profiles



Batch-wise axial burnup profiles at EOEC

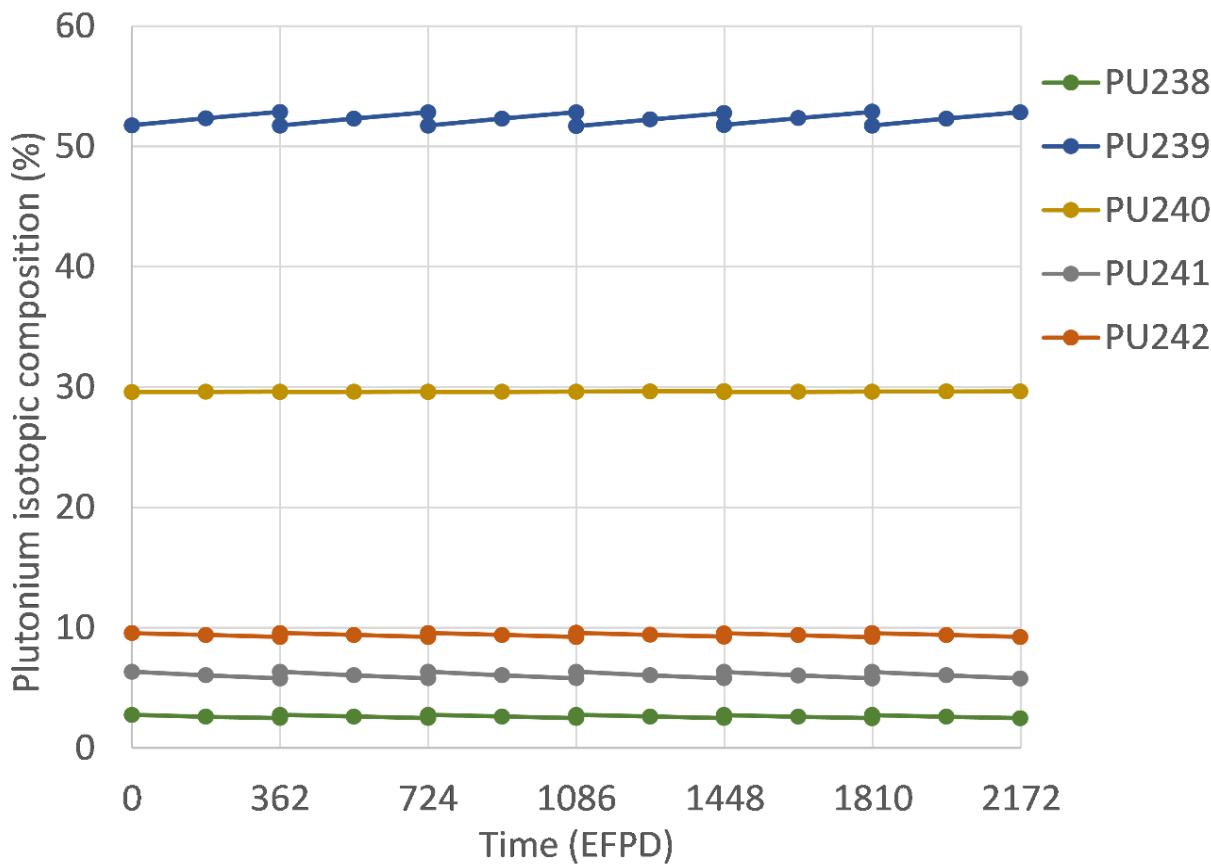


Multi-batch burnup: evolution of Pu mass



- ~50 kg of Pu are bred during one batch = Pu mass increase of 0.4% per year
- Pu production is strongly distributed in the core
- Iso-breeder behaviour

Multi-batch burnup: evolution of Pu vector



- Pu vector is practically constant
- Mild oscillation is due to small difference between the initial and discharged Pu composition.

EOEC core state serves as basis for follow-up analyses

- Assessment of safety relevant parameters
- Detailed spatial distribution of Doppler constants and sodium void reactivity
- Decay heat distribution
- Coupled core thermal hydraulics and neutronics simulations.
- System behavior in selected accident scenarios (both protected and unprotected).

Some relevant publications

- A. Rineiski et al. "Core Safety Measures in ESFR-SMART," PHYSOR 2018
- A. Rineiski et al. "New ESFR-SMART core safety measures and their preliminary assessment" , ASME J of Nuclear Rad Sci., under review
- E. Fridman et al. "Neutronic Analysis of the European Sodium Fast Reactor: Part I - Fresh Core Results," ASME J of Nuclear Rad Sci., NERS-20-1056, <https://doi.org/10.1115/1.4048905>
- E. Fridman et al. "Neutronic Analysis of the European Sodium Fast Reactor: Part II - Burnup Results," ASME J of Nuclear Rad Sci., NERS-20-1067, <https://doi.org/10.1115/1.4048765>

Thank you for your attention!