

Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

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**European benchmark on the ASTRID-like low-void-effect core characterization: neutronic parameters and safety coefficients
(Paper 15361, Session 3.05-II)**

General framework

- European Sustainable Nuclear Industrial Initiative (ESNII) addressing needs for demonstration of prioritized Generation-IV fast reactor technologies.
- Sodium-cooled Fast Reactor (SFR): reference solution.



Accurate modeling and assessment of SFR safety essential.

Neutronics, first step, several benchmarks:

-Superphénix (PNC/CEA),
-BN-600 design modifications and control rod withdrawal Phénix end-of-life experiments (IAEA).

Ongoing:

-Large SFR with different fuel compositions (OECD-NEA WPRS),
-Advanced Sodium Technological Reactor for Industrial Demonstration, ASTRID (DOE/CEA).

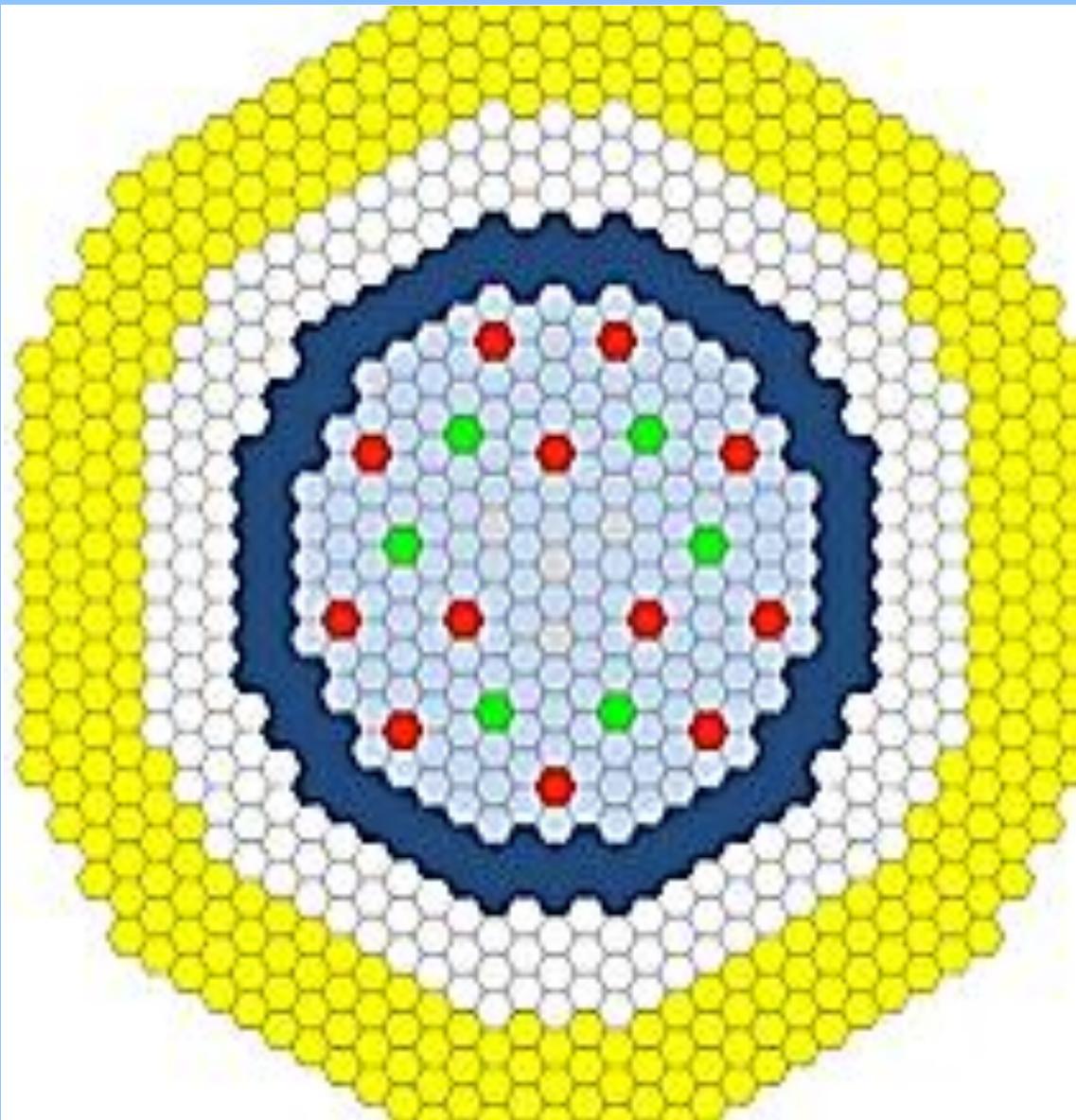
- ESNII+ WP6 (Core safety), new benchmark:

Assess viability and applicability of state-of-the-art tools and databases for safety analyses of low-void-effect cores (CFVs) targeting ASTRID.

Low-void-effect core (CFV), this study

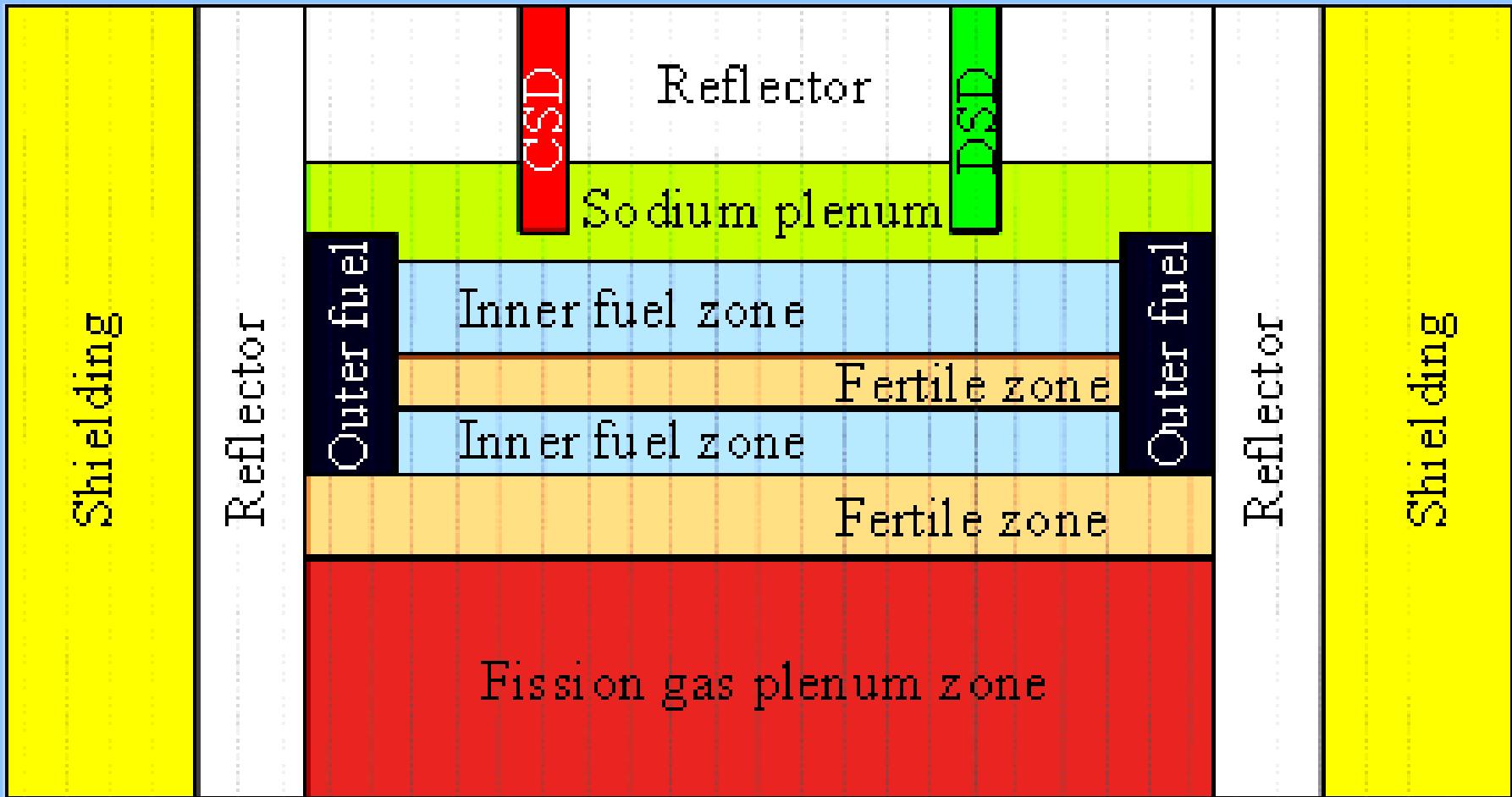
- Highly heterogeneous: Several driver zones, inner fertile zone, large sodium plenum above  Enhanced leakage, overall coolant void worth negative. **Challenging.**
- MOX fueled, 1500 MWth, 291 hexagonal wrapped fuel subassemblies (SAs).
SA: 217 pins, triangular arrangement.
- Two radial regions: Different Pu content and axial zoning.
 - Inner core: 177 SAs, total active height 1.1 m.
0.2 m thick internal axial blanket  Reduced power peaking.
 - Outer core: 114 SAs, no internal blanket, total active height 1.2 m.
30 cm thick axial blanket below inner and outer core regions.
- Three rings radial reflector SAs and four rows radial shielding SAs.
- Regulation, compensation and safety:
12 control rod SAs (CSDs), 6 safety rod SAs (DSDs), 4 diluent SAs: inner core region.

CFV radial/azimuthal layout



Inner core SAs	177
Outer core SAs	114
DSD SAs	6
CSD SAs	12
Diluent SAs	4
Radial reflector SAs	216
Radial shielding SAs	354

CFV axial layout



Benchmark definition

- Operating conditions, prescribed end of cycle compositions.
- Perturbations according to guidelines harmonizing modeling approaches: ensuring that relevant phenomena contributing to each reactivity coefficient be accounted for.

To determine:

- Core multiplication factor and kinetic parameters,
- Power distribution,
- CSD S-curve,
- Doppler constant,
- Coolant void worth.

Participating European institutions (8)

Institute	Address	Country
CEA	Commissariat à l'énergie atomique et aux énergies alternatives, Cadarache, F-13108 Saint-Paul-lez-Durance	France
CIEMAT	Spanish National Research Centre for Energy, Environment and Technology, Av. Complutense 40, 28040 Madrid	Spain
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit mbH, Boltzmanstraße 14, 85748 Garching	Germany
HZDR	Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden	Germany
JRC	European Commission, Joint Research Centre, Institute for Energy and Transport, P.O. Box 2, NL-1755 ZG Petten	the Netherlands
KIT	Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen	Germany
PSI	Paul Scherrer Institut (PSI), 5232 Villigen PSI	Switzerland
UPM	Universidad Politécnica de Madrid, Jose Gutierrez Abascal 2, 28006 Madrid	Spain

Computational tools (10 codes, 4 basic data libraries)

Institution	Code or data	Code	Library
KIT		KANEXT (Variant)	JEFF-3.1.1
PSI	-E	ERANOS-2.2-N (ECCO, Variant)	JEFF 3.1
CEA		ERANOS-2.3 (ECCO, Variant, Bistro), PARIS	JEFF-3.1
GRS		Helios-1.12/ FEM-DIFF-3D	HELIOS
PSI	-S	Serpent2	JEFF-3.1
HZDR	-J	Serpent2	JEFF-3.1
	-N		ENDF/B-VII.0
UPM		SCALE6.2 beta (KENO-VI)	ENDF/B-VII.0
CIEMAT		MCNP6.1	JEFF-3.1.1
JRC		MCNP5/MCNPX, MCNP6	JEFF-3.1

Deterministic codes

- KArlsruhe Neutronic EXtendable Tool (KANEXT), successor of KAPROS -3D nodal transport Variant
- European Reactor ANalysis Optimized calculation System (ERANOS): -Lattice code ECCO (CP method) -2D discrete-ordinates Bistro
- 3D discrete-ordinates transport PARIS
- 3D diffusion FEM-DIFF-3D, lattice code Helios-1.12 (CP based).

Stochastic codes

- Serpent2 (continuous energy)
- Standardized Computer Analyses for Licensing Evaluation (SCALE): KENO-VI (multigroup)
- MCNP6.1, MCNP5/MCNPX, MCNP6 (continuous energy).

Nuclear Data

- European Joint Evaluated Fission and Fusion Files
- US Evaluated Nuclear Data Library

- JEFF-3.1, JEFF-3.1.1 (majority)
 ENDF/B-VII.0 (Serpent2 and SCALE6.2 beta)
 ENDF/B-VII-based library, HELIOS (Helios-1.12)

Effective multiplication factor and kinetic parameters

Institution -Method	k_{eff}	β_{eff} [10 ⁻⁵]	Λ [10 ⁻⁷ s]
Deterministic methods			
KIT	0.99966	358	4.54
PSI-E	1.00123	366	4.62
CEA	1.00432	356	4.55
GRS	1.00466		
Stochastic methods			
PSI-S	1.00431	347	4.72
HZDR-J	1.00394	357	4.73
HZDR-N	0.99796	344	4.76
UPM	1.00475		
CIEMAT	1.00567	362	4.76
JRC	1.00218	350	4.82

Multiplication factor: Overall spread >2\$.

Deterministic: agreement within 1.4\$.

Stochastic : spread larger (>2\$).

However:

- Agreement of two independent calculations with same code/data (PSI-S, HZDR-J) .

- Agreement JEFF data within ~1\$.

- Discrepancy ENDF/B-VII.0 data

partly explained: UPM: fuel temperature 1200°K instead of 1500°K, no temperature interpolation → smaller k_{eff} expected, but no clear trend (GRS, HZDR-N).

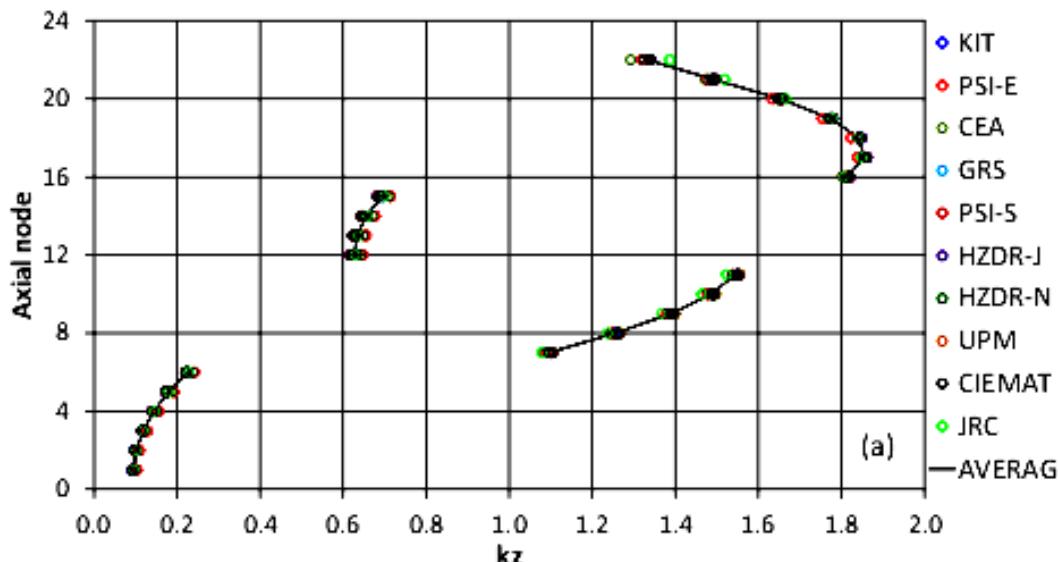
Kinetic parameters:

Overall agreement.

β_{eff} : within 22pcm.

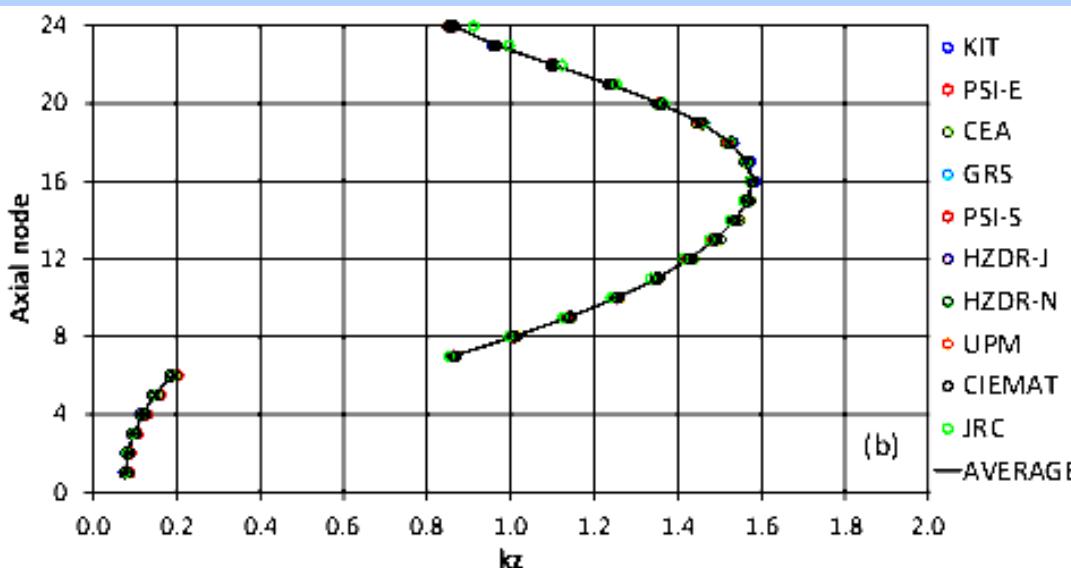
Λ : <10% spread.

Axial power peaking factor



Inner core

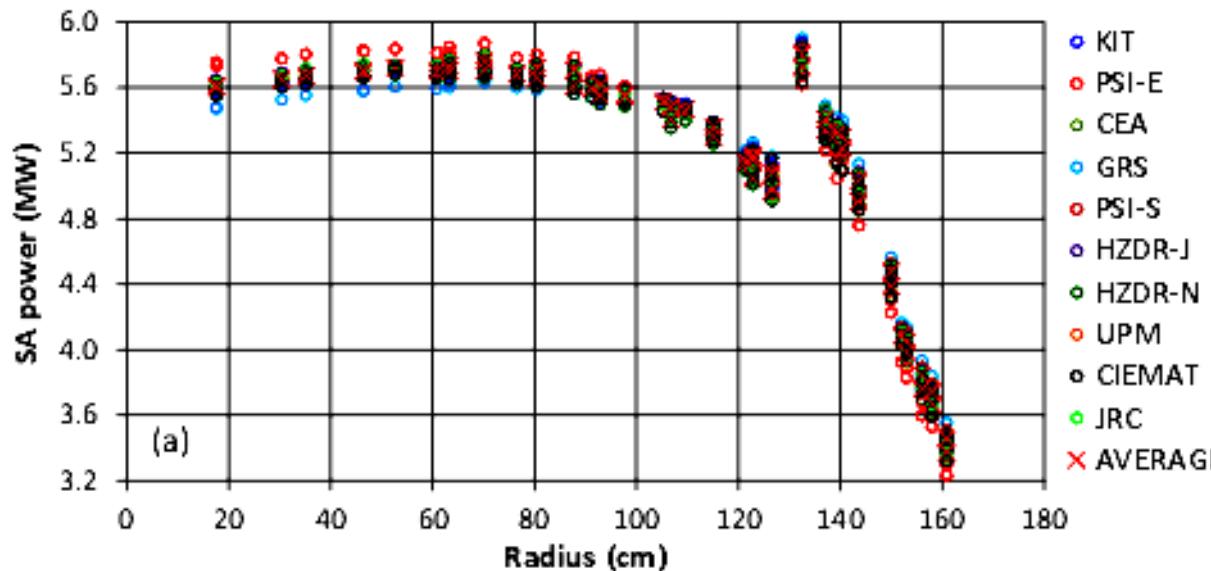
Agreement



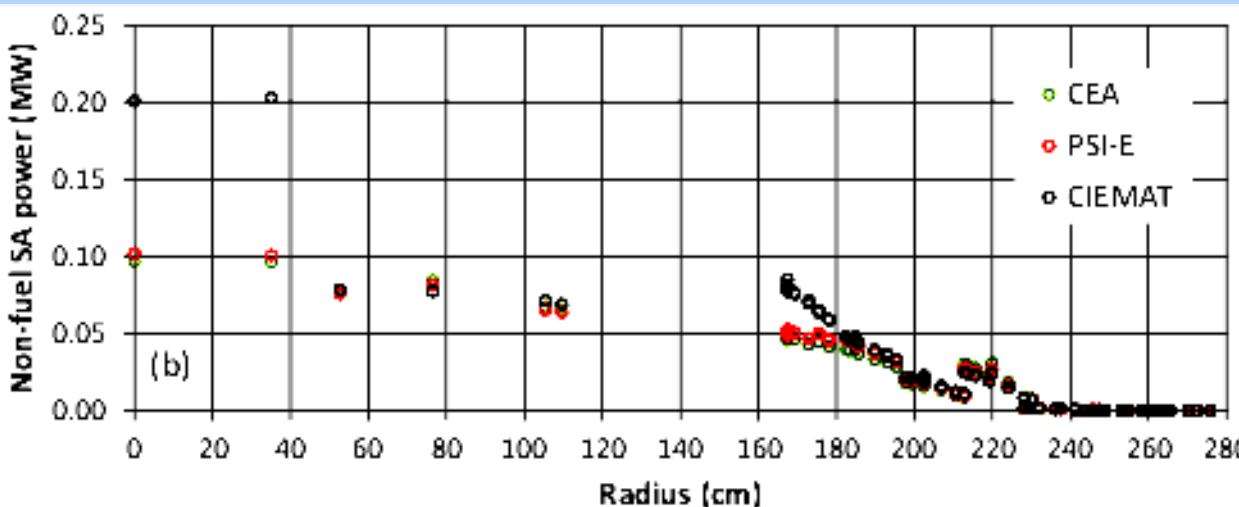
Outer core

Agreement

Radial power distribution

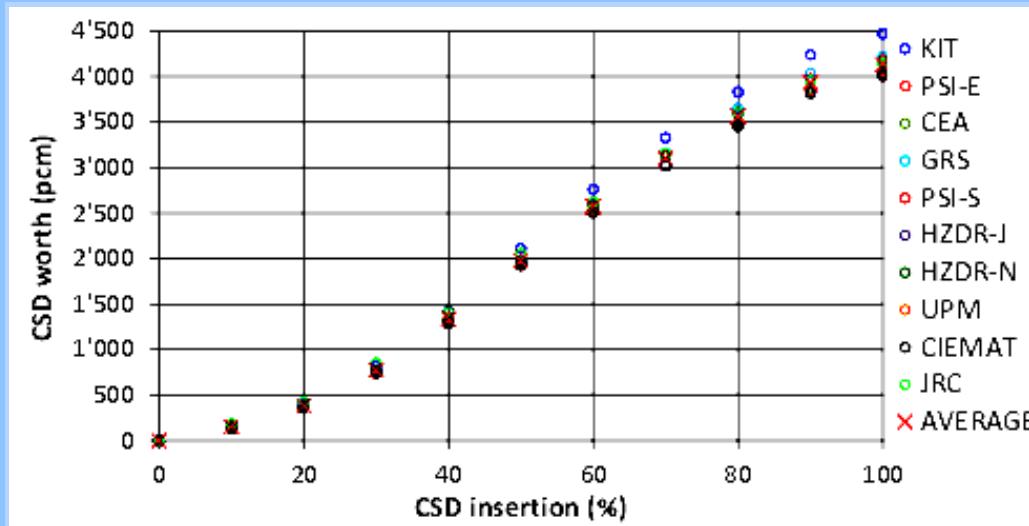


Fuel subassemblies:
Agreement within 10%

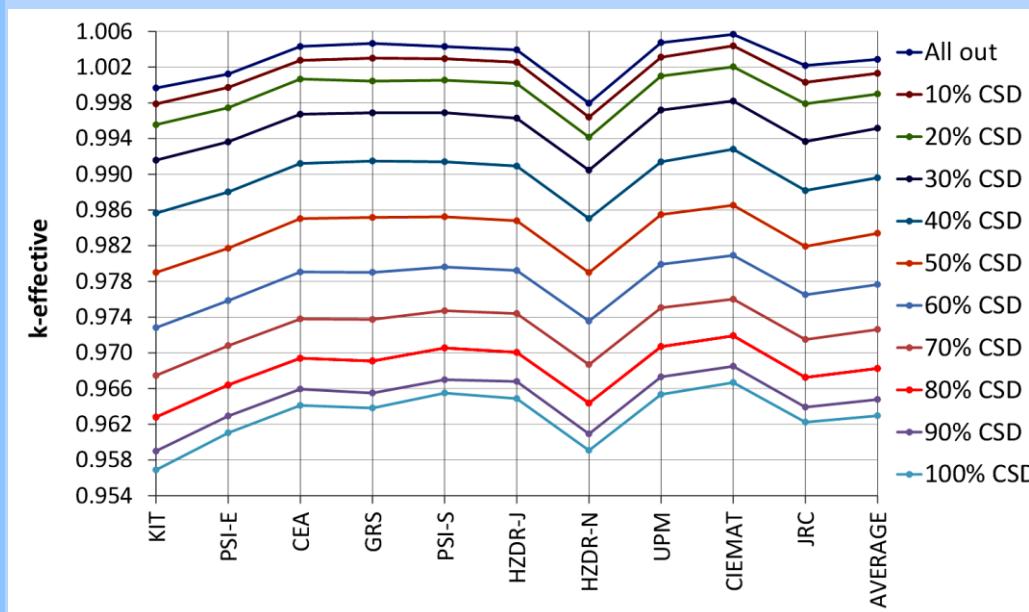


Non-fuel subassemblies:
Disagreement, limited
capabilities
(only ERANOS, MCNP6.1)
Photon transport ?

CSD S-curve; k_{eff} for various insertion positions



CSD worth: agreement except KIT.



Deterministic methods

-KIT: Increasingly lower k_{eff} along with progressive insertion
(spatial self-shielding absorber?).

-ERANOS : systematic CEA > PSI,
 ~ 300 pcm
PSI : current interface method, ECCO.
CEA : equivalence reactivity method.

Stochastic methods:

PSI-S matches HZDR-J (same code/data).

Doppler constant

Institution	Fissile regions		Fertile regions	
	K_{D1}	K_{D2}	K_{D3}	K_{D4}
Deterministic methods				
KIT	-623	-606	-314	-305
PSI-E	-684	-660	-321	-317
CEA	-661	-637	-327	-321
GRS	-576	-615	-278	-283
Stochastic methods				
PSI-S	-661	-572	-335	-255
HZDR-J	-630	-594	-281	-311
HZDR-N	-583	-679	-285	-315
UPM	-584	-619	-273	-303
CIEMAT	-699	-592	-295	-234
JRC	-633	-612	-297	-333

D1: 1500°K → 1200°K D3: 900°K → 600°K

D2: 1500°K → 1800°K D4: 900°K → 1200°K

Fissile average Fertile blanket average
temperature perturbations

Expected from physics:

$|K_{D1}| \text{ slightly } > |K_{D2}|, |K_{D3}| \text{ slightly } > |K_{D4}|$

not fulfilled, especially stochastic (statistical uncertainty? not provided)

“<” instead of “>”

“>” instead of “slightly >”

20% spread for fuel temperature decrease
("only" 15% for temperature increase, ?)

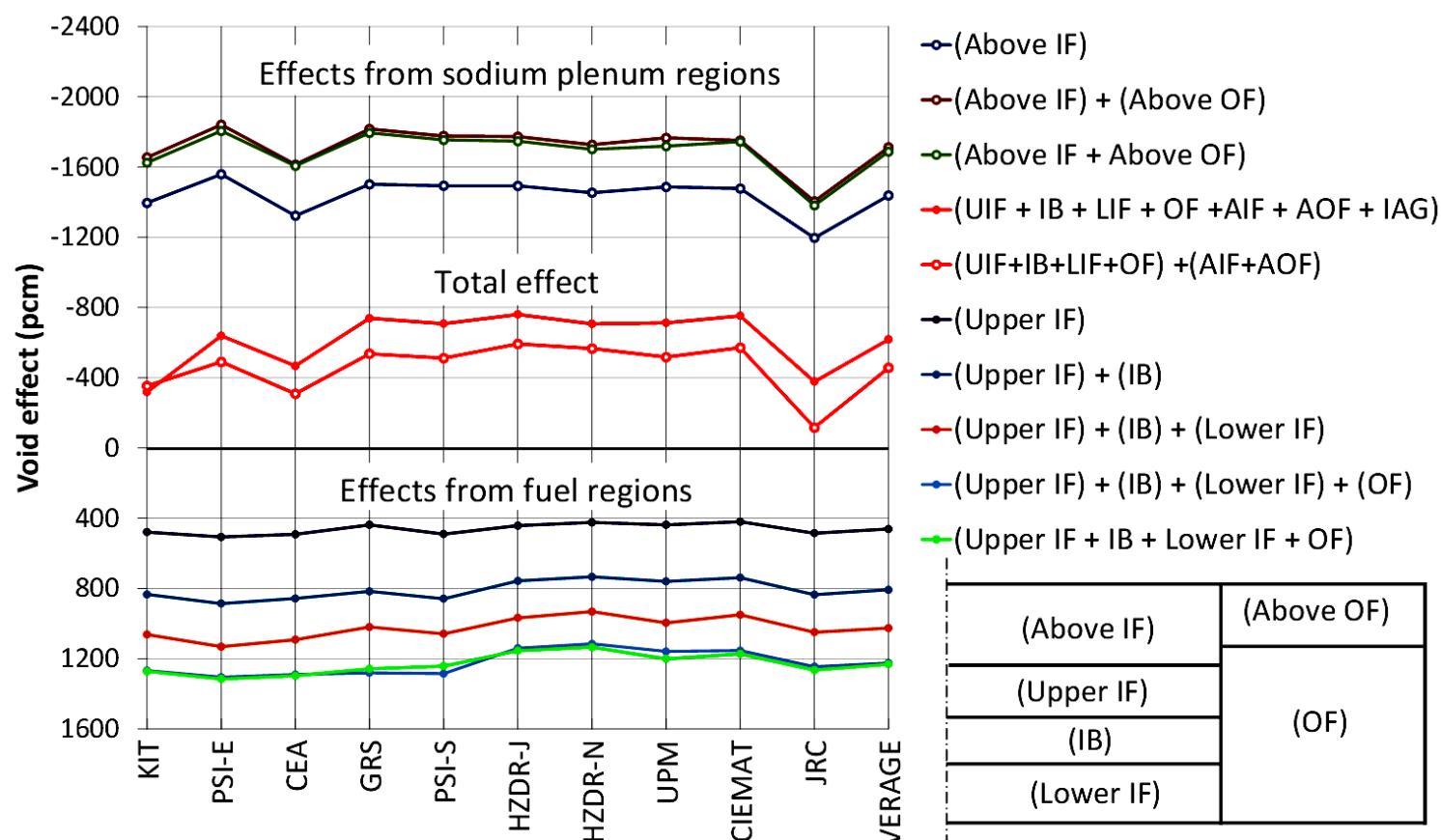
30% spread for fertile blanket temperature
increase (20% for temperature decrease).

Spread too large



Further clarifying investigations required.

Coolant void worth (different scenarios)



Total voiding negative: - 400 pcm
 $= + 1200 - 1600$ pcm
 fuel plenum

Active core regions:
 overall agreement.
 Linearity in space.

Plenum: Larger discrepancies,
 as expected: up to 25% (~400
 pcm).

Conclusions

- ❖ Total voiding negative reactivity effect unanimously confirmed. 
- ❖ Code-to-code comparison → issues requiring clarifications and improvements:
 - Power generation in non-fuel regions.
Enable capability, photon transport needed or not ?
 - Doppler constant: differences up to 30%, largely unexpected.
Simple checks e.g. zero-dimensional models first.
 - Void effect in leakage dominated sodium plenum regions: differences up to 25%.
 - Nuclear data effect (JEFF versus ENDF) mainly on the effective multiplication factor.
- ❖ Ongoing: characterization of other reactivity effects due to
 - Thermal expansions of diagrid, wrapper, fuel and cladding.
 - Coolant temperature effects.
- ❖ Ongoing: Thermal-hydraulic simulation of void evolution in Na plenum.

The study has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the grant agreement n. 605172 (Euratom ESNII+) as well as under grant agreement n. 290605 (PSI-FELLOW/COFUND).

