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Wir schaffen Wissen – heute für morgen

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Use of SERPENT at PSI/EPFL for thermal system analysis.

Outline

Activities Involving SERPENT at PSI/EFPL

BWR analysis with SERPENT/SIMULATE-3 code sequence

- **Motivations**
- **Methodology : Two-Step Approach**
- **Results**
  - Cross Sections
  - Full core Comparison

Modeling of CROCUS with SERPENT/PARCS code sequence

- **Motivations**
- **Methodology**
- **Results**

Conclusion and Outlook

Activities Involving SERPENT at PSI/EFPL

For fast system analysis

- **See Sandro Pelloni's presentation**

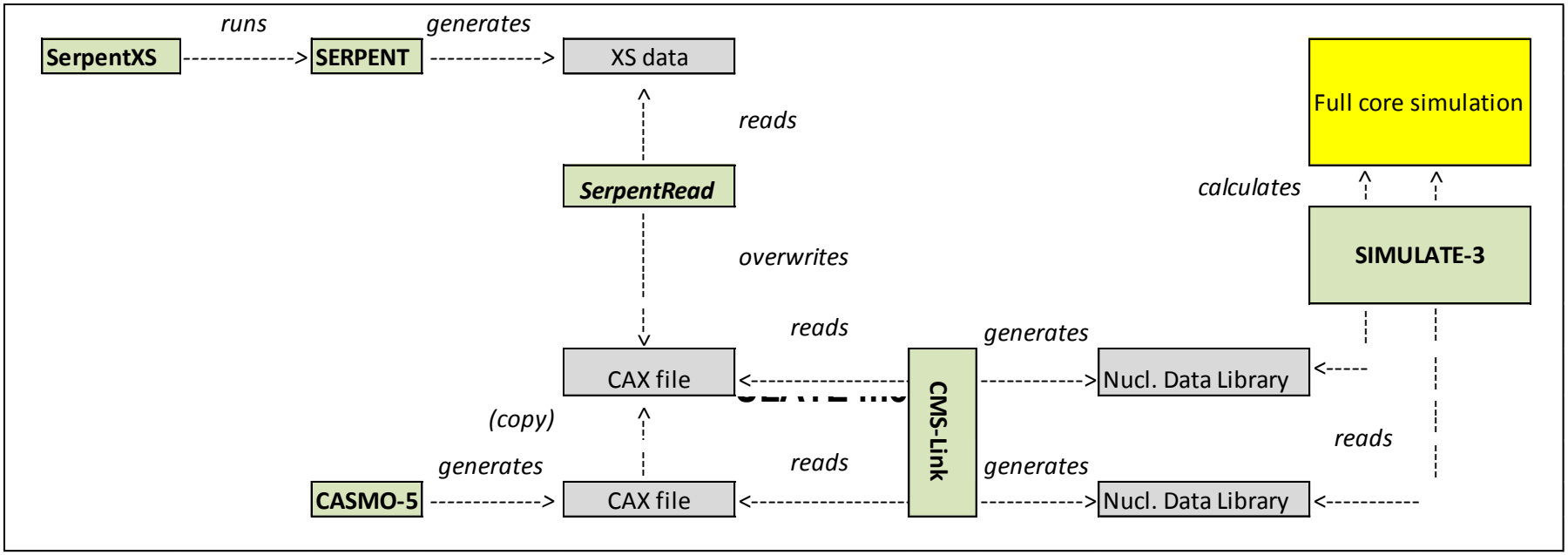
For thermal system analysis

- **Development of SERPENT/SIMULATE-3 scheme for BWR core analysis**
- **Reflector modelling with SERPENT for PWR Core analysis (reduce bias near reflectors)**
- **Use of SERPENT for Burnup Credit**
  - Validation of SERPENT for depletion (against P.I.E data)
  - Coupling of SERPENT to FALCON
- **Assessment of SERPENT for long term decay (geological repository)**

At Ecole Polytechnique Federale de Lausanne

- **Use of SERPENT/PARCS to model steady state and transient behavior CROCUS research reactor**
- **Long term goal is to update Safety Report of CROCUS with state-of-the-art methods**

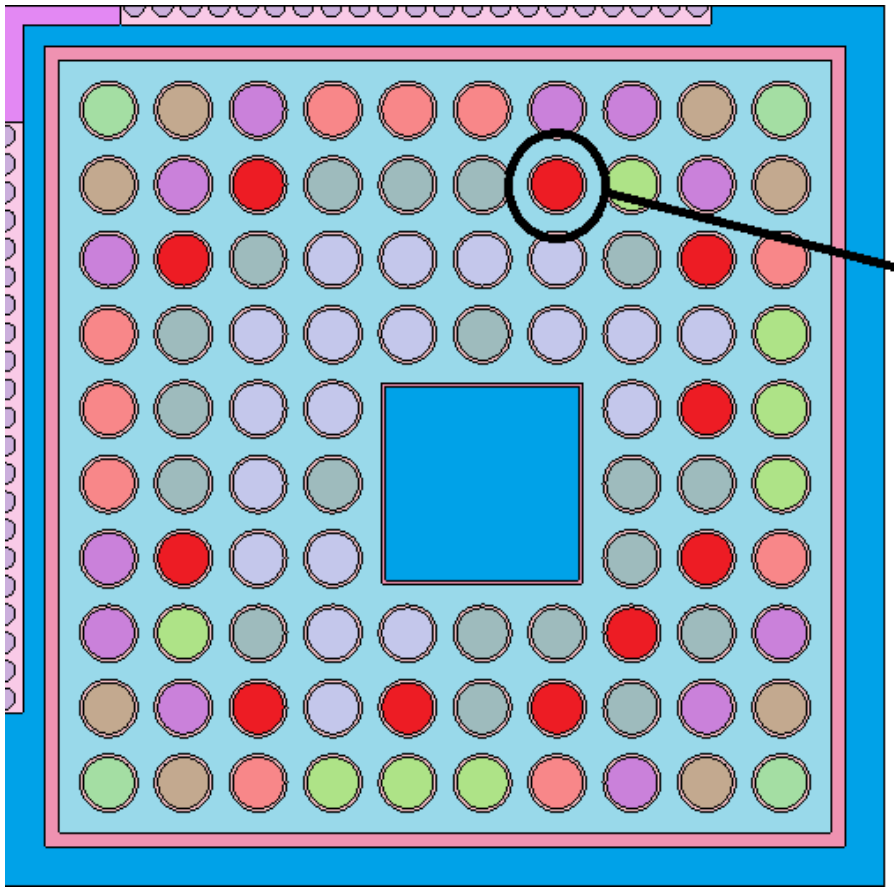
BWR analysis with SERPENT/SIMULATE-3 sequence



Approach:

- **Use CASMO output (Cax file) as vector to insert SERPENT XS into SIMULATE-3**
- **List of CASMO nuclear data being overwritten using SERPENT results:**
  - 2 group constants and assembly discontinuity factors (D from B1 calculation)
  - Consistency with other information (Xe microscopic xs for example) may not be insured.
- **First compare XS between CASMO and SERPENT, then SIMULATE-3 calculations for a BWR full core**

Assembly Model



Based on ATRIUM-10 Specifications

SERPENT Models

- 10000x(500+20) n
- 6000x(100+20) n – "Low Neutron Count"

Stochastic Uncertainty

- *k-inf*: std ≈ 30/100 pcm
- Cross sections: std ≈ 0.03/0.1%

History/Branch Case Matrix

S3C default history/branch case matrix not used

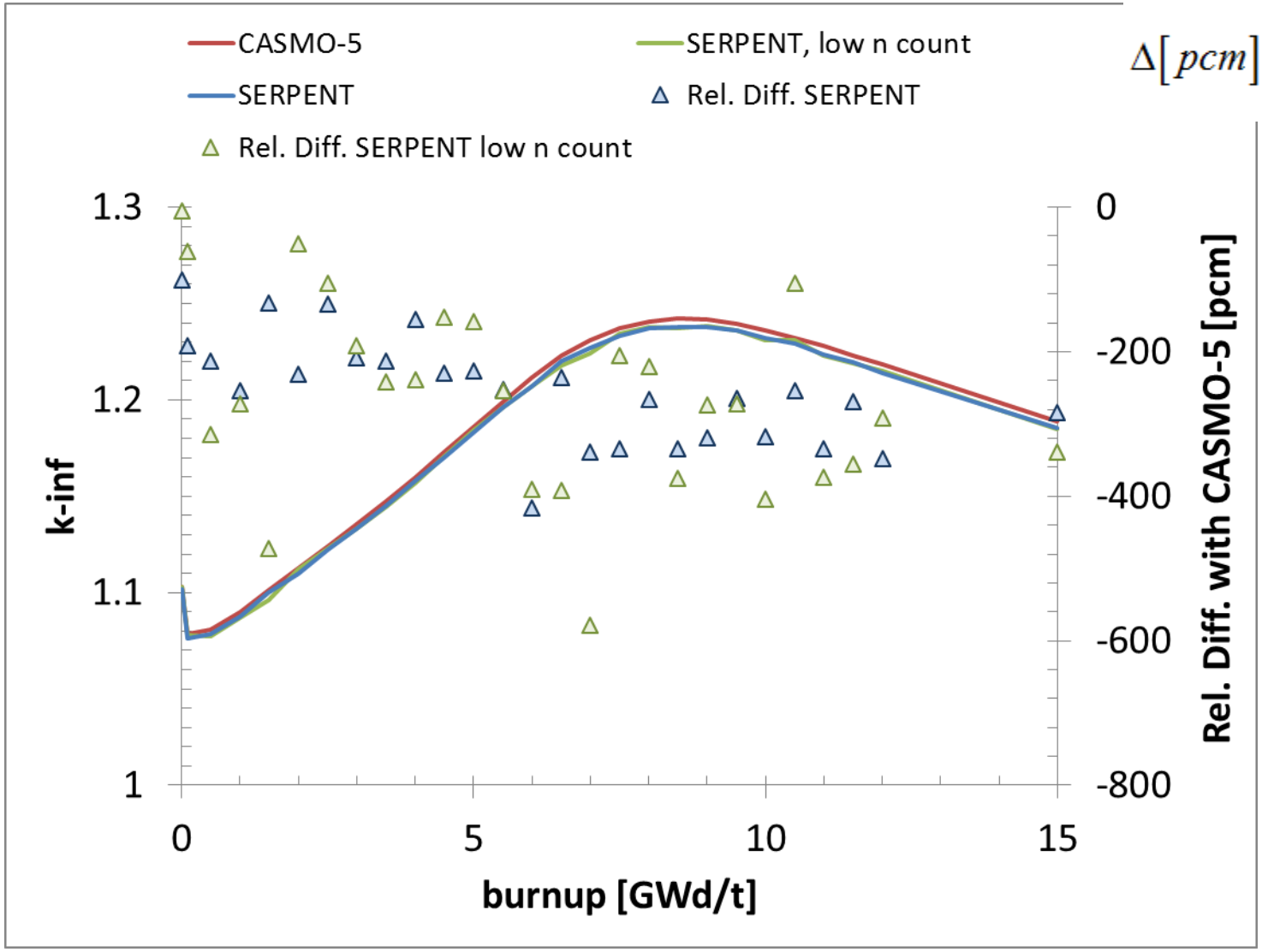
- Too computationally expensive
- Simplified to be acceptable for SIMULATE-3

CPU cost for 136 transport calculations

- 20min for CASMO-5
- 24h for SERPENT (4 processors)

History	Branch		Transport Calculations
Reference	Depletion (Void 40%, fuel temperature 729 K, moderator temperature 559 K)		26
	Branches	Void 40%	5
		Void 80%	5
		Rodded	5
		Fuel temperature 559 K	5
		Fuel temperature 1500 K	5
		Coolant/moderator temp. 293 K, [Void 0]	5
Void 0	Depletion (Void 0%, fuel temperature 729 K, moderator temperature 559 K)		24
	Branches	Void 40%	5
		Void 80%	5
		Rodded	5
		Fuel temperature 559 K	5
		Fuel temperature 1500 K	5
		Coolant/moderator temp. 293 K, [Void 0]	5
Rodded	Reference (Void 40%, fuel temperature 729 K, moderator temperature 559 K, rodded)		32
	Branches	Control rod withdrawn	5

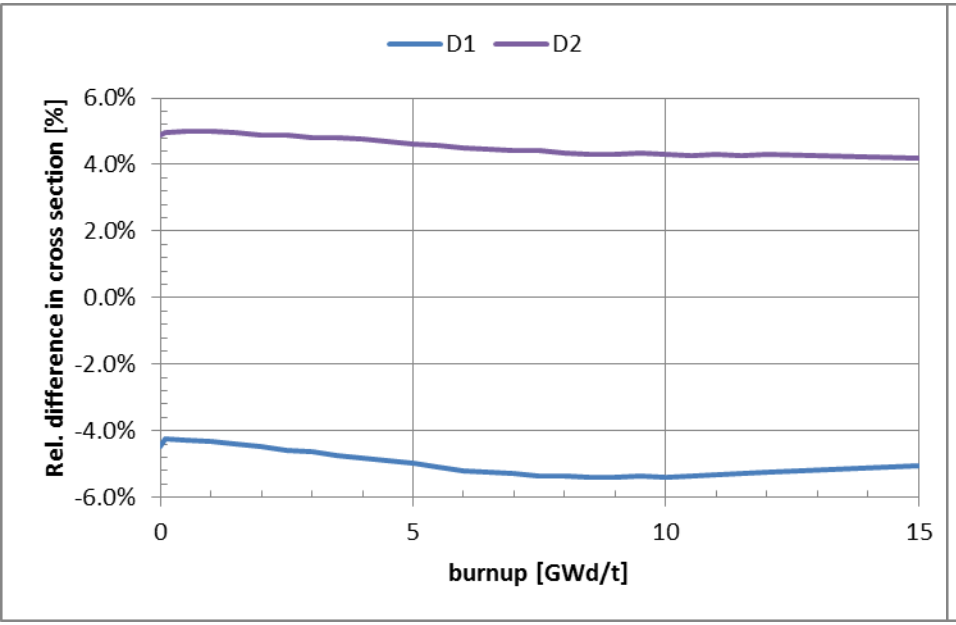
k-inf comparison for Reference History

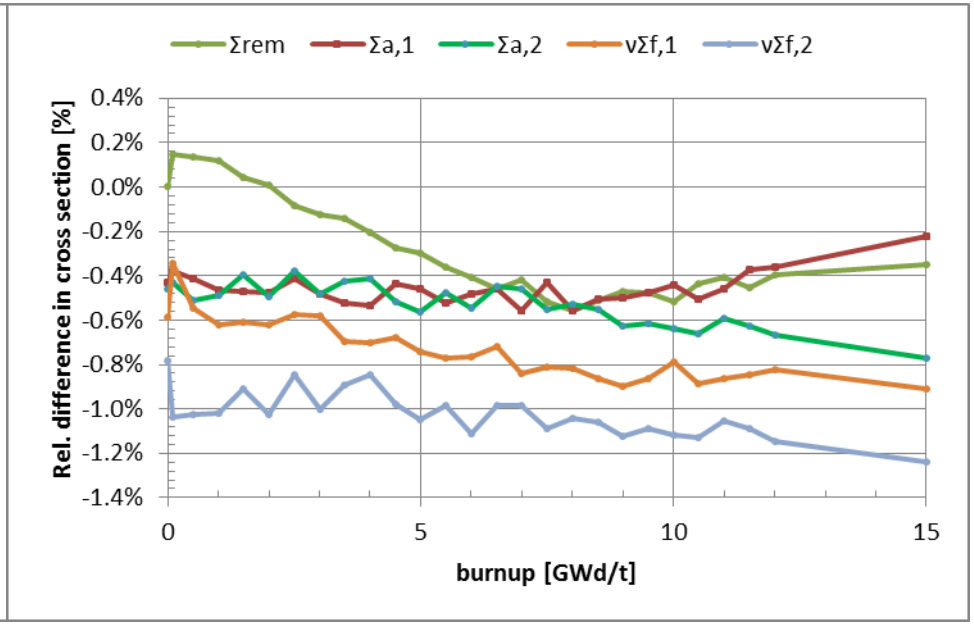


$$\Delta[pcm] = \frac{Q_{SERP} - Q_{C5}}{Q_{C5}} .10^5$$

$$Q = k_{inf}$$

Cross sections Comparison: Reference history





Good agreement besides the diffusion coefficients – known issue

No new error pattern with exposure

- Slight decrease of difference with burnup for removal xs
- Slight increase of difference with burnup for absorption

$$\Delta[\%] = \frac{Q_{SERP} - Q_{C5}}{Q_{C5}}.100$$

$$Q = \Sigma$$

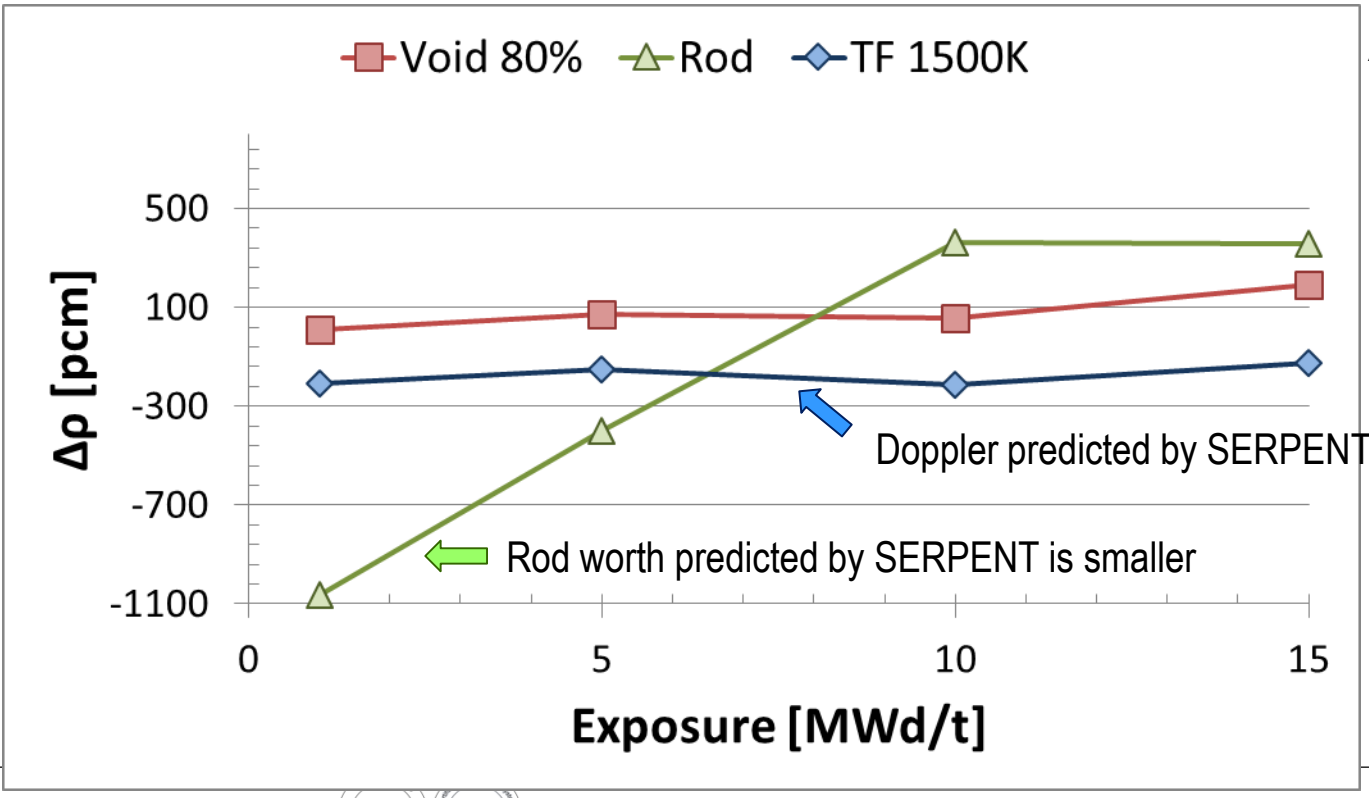
Reactivity differences between CASMO-5 and SERPENT

Reactivity differences between CASMO-5 and SERPENT due to perturbation of instantaneous variables – branch calculations

- **80% void, Insertion of control rod, 1500K Fuel Temperature**

Control Rod Insertion is not captured well

Slight underprediction of Doppler by SERPENT



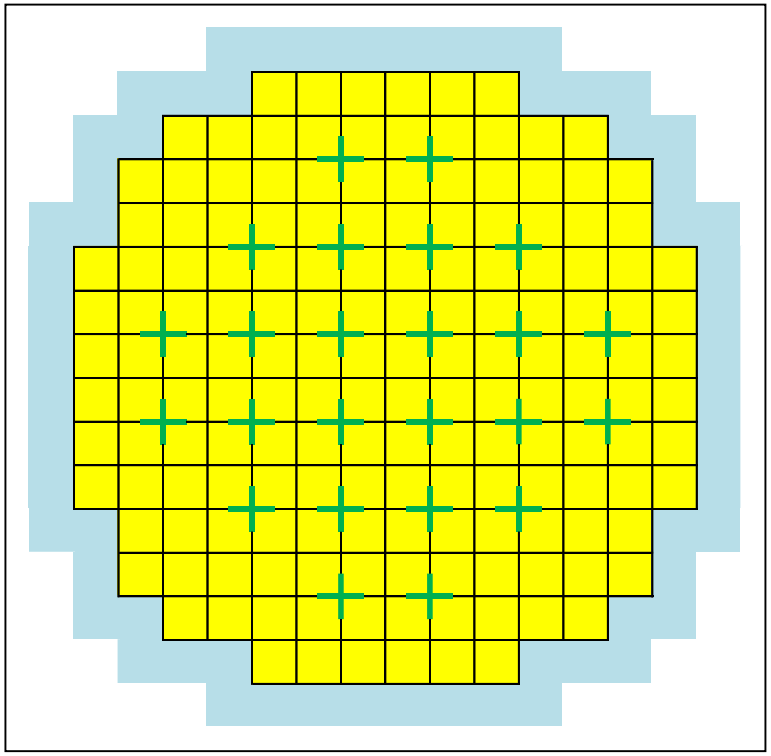
$$\Delta[pcm] = (Q_{\mathrm{SERP}} - Q_{C5}).10^5$$

$$Q = \frac{1}{k_{\mathrm{inf}}^{pert}} - \frac{1}{k_{\mathrm{inf}}^{ref}}$$

BWR Core Model

BWR Core Model

- 224 fuel assemblies
- All identical (!), only one segment
- Reflector XS are generated by CASMO-5



Model leads to unrealistic power shape

Comparison of CASMO-5/SIMULATE-3 and SERPENT/SIMULATE-3

- At Hot Zero Power (no control rods)
- During a reactor cycle (8.5 MWd/T)

k-eff Comparison

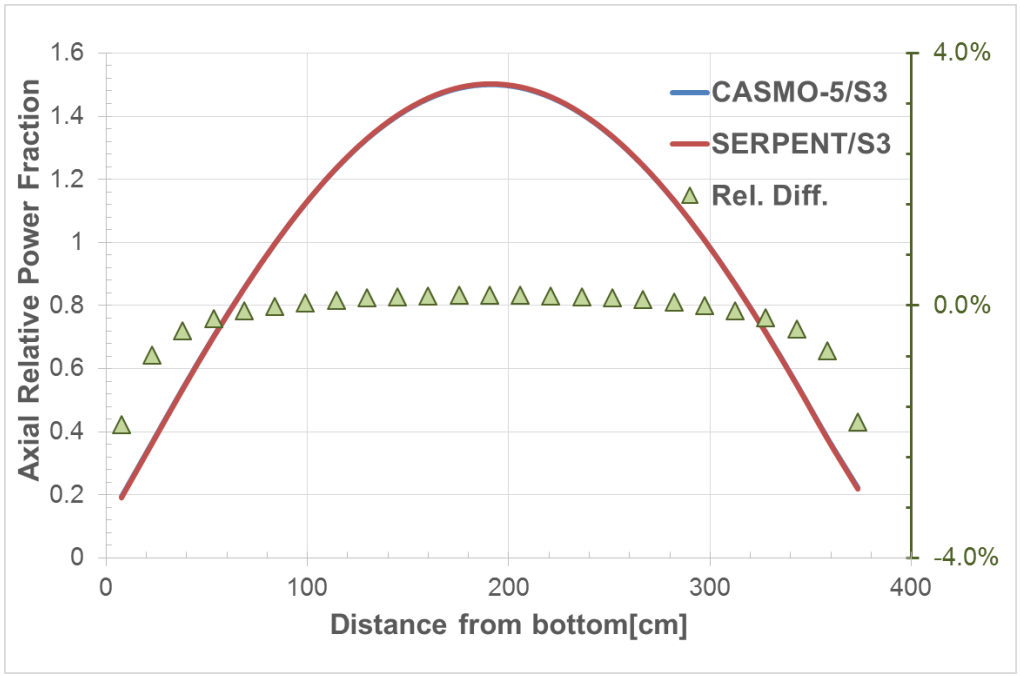
Case		k-eff C5/S3	Δk/k [pcm]	Δk/k [pcm] Low n count model
HZP		1.10561	-148	82
HFP		1.03527	-112	224
Cycle Calculation				
Exposure	0.1	1.03470	-228	-62
	1	1.06164	-94	-7
	2	1.11522	-84	-39
	4	1.13155	-419	-218
	6.5	1.12566	-488	-319
	8.5	1.12343	-459	-277

Conclusion

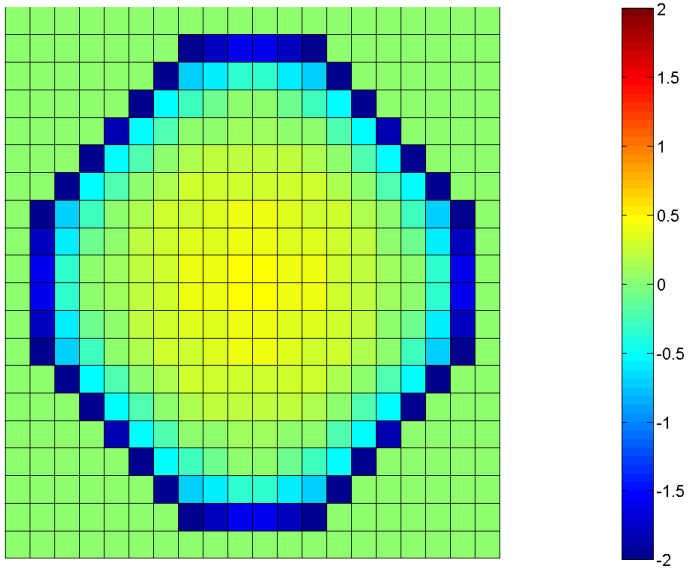
- Acceptable agreement at HZP and HFP
- Increase of discrepancies with exposure
- Large increase of discrepancies at 0.1 GWd/T due to inconsistency in Xe/Sm information
- Effect of stochastic uncertainty is large (~200pcm)

RPF Comparison – Hot Zero Power

Axial Relative Power Fraction



Radial Relative Power Fraction



Relative Difference Expressed As:

$$\Delta[\%] = \frac{Q_{SERP/S3} - Q_{C5/S3}}{Q_{C5/S3}}.100$$

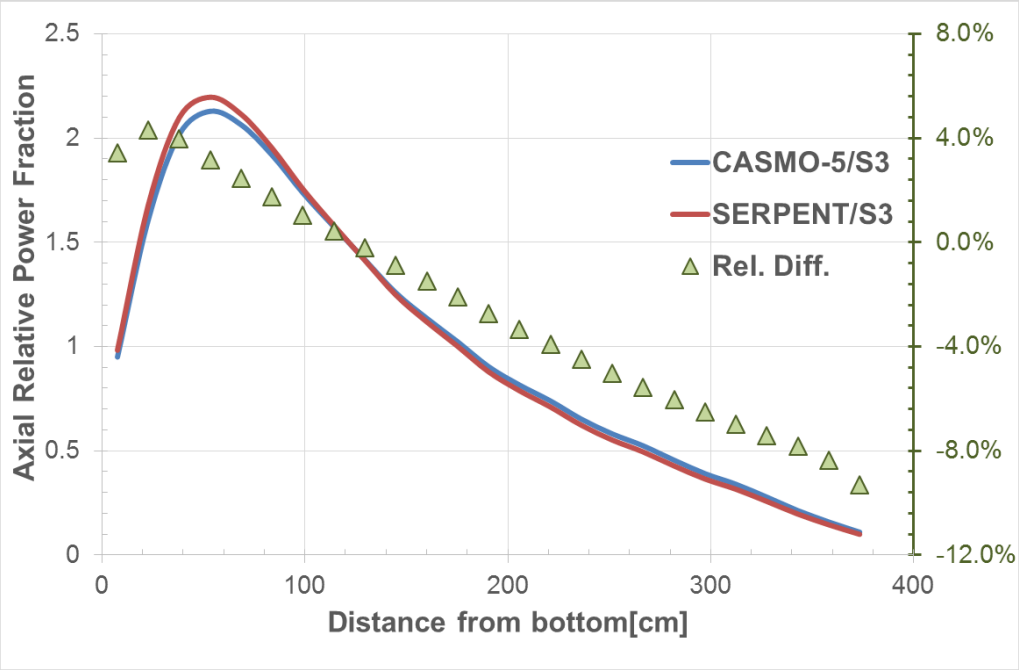
Overall good agreement

- **Difference in diffusion coefficients are seen near the reflectors**
- **SERPENT/SIMULATE-3 overpredicts leakage**

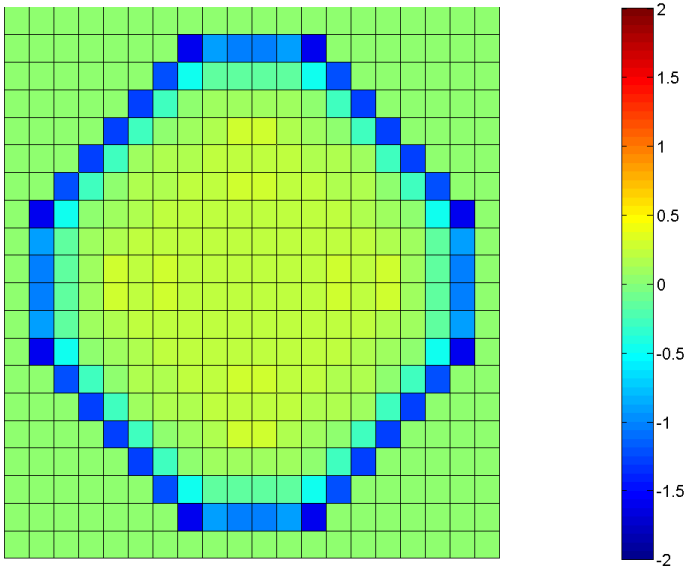
$$Q = RPF$$

RPF Comparison – Hot Full Power – Beginning of Life

Axial Relative Power Fraction



Radial Relative Power Fraction



Relative Difference Expressed As:

$$\Delta[\%] = \frac{Q_{SERP/S3} - Q_{C5/S3}}{Q_{C5/S3}}.100$$

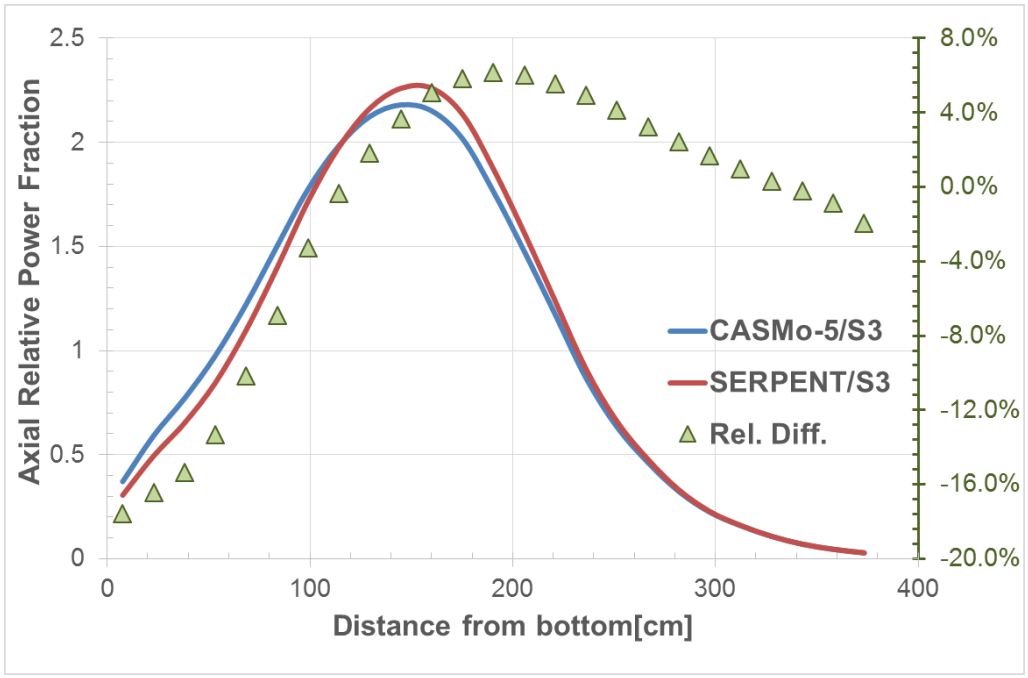
Overall good agreement

- Overprediction of the power peaking by SERPENT/SIMULATE-3
- Difference due to handling of instantaneous variables only
- Consistent with cross section comparison
- SERPENT/SIMULATE-3 overpredicts leakage

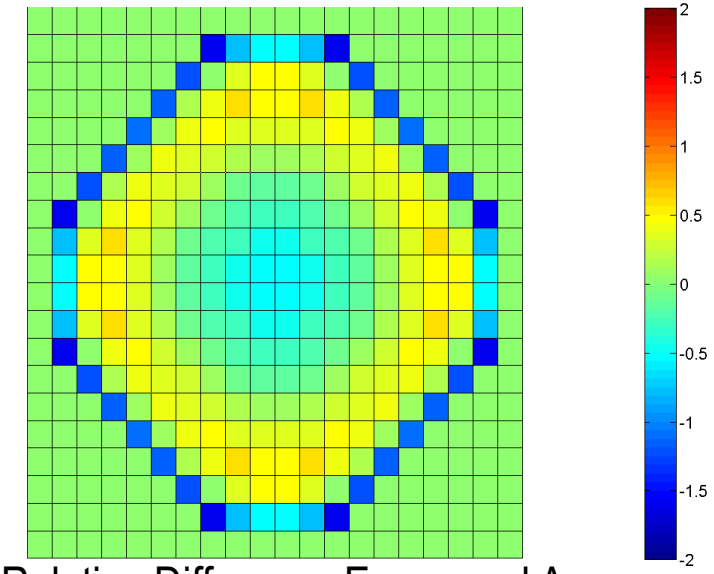
$$Q = RPF$$

RPF Comparison – Hot Full Power – End Of Cycle

Axial Relative Power Fraction



Radial Relative Power Fraction



Relative Difference Expressed As:

$$\Delta[\%] = \frac{Q_{\mathrm{SERP}/S3} - Q_{C5/S3}}{Q_{C5/S3}}.100$$

$$Q = RPF$$

Agreement degrades with exposure

- **Differences due to branch and history effects**
- **Radial RPF: underprediction of power by SERPENT/SIMULATE-3 at high exposure**

Conclusion

Good agreement between CASMO-5 and SERPENT for BWR XS generation

- Except for diffusion coefficients
- Similar behavior with exposure
- Cost of SERPENT calculations is large and may be prohibitive for fuel segments

Comparison of BWR full core calculation with SIMULATE-3

- Acceptable agreement at HZP and HFP
- Increase of discrepancies with exposure
- Large increase of discrepancies at 0.1 GWd/T due to inconsistency in Xe/Sm information
- Effect of stochastic uncertainty is surprisingly large

PARCS/SERPENT analysis of the CROCUS Reactor

CROCUS is a zero power (100W) educational and research reactor

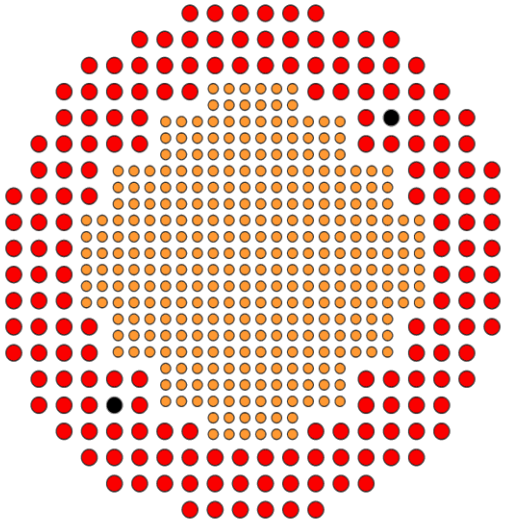
- Mix of UO2 and Umetal fuels
- H2O moderated
- Started operation in 1983 (EPFL)

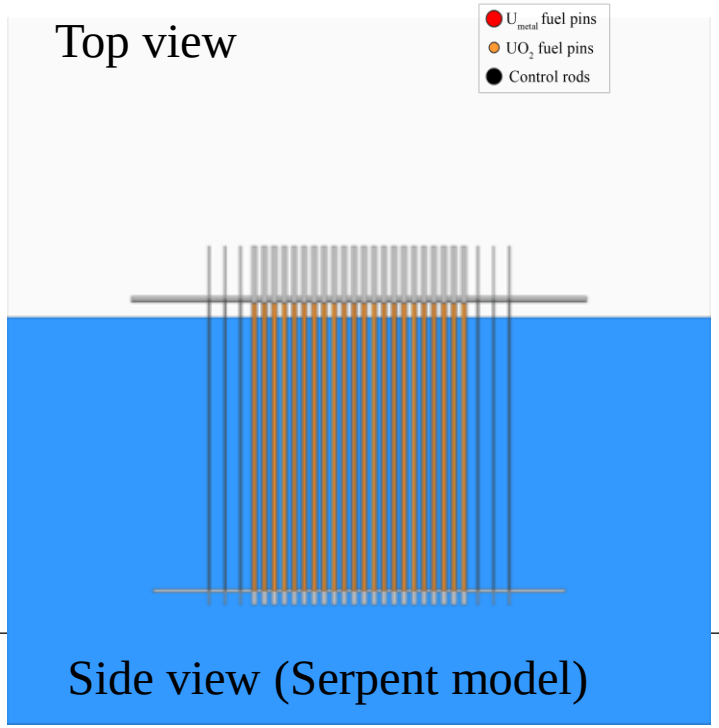
Current Modelling

- 4 zones, 2G diffusion
- Point kinetics
- Simplified Thermal Hydraulic

Goal is to improve current modelling capabilities

- TRACE/PARCS/SERPENT code scheme
- Today focus on PARCS/SERPENT





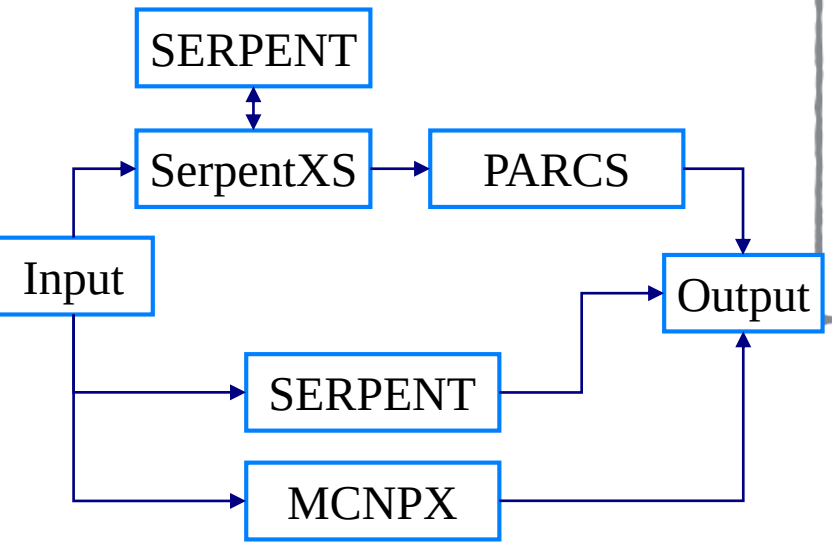
PARCS/SERPENT Code Sequence [1]

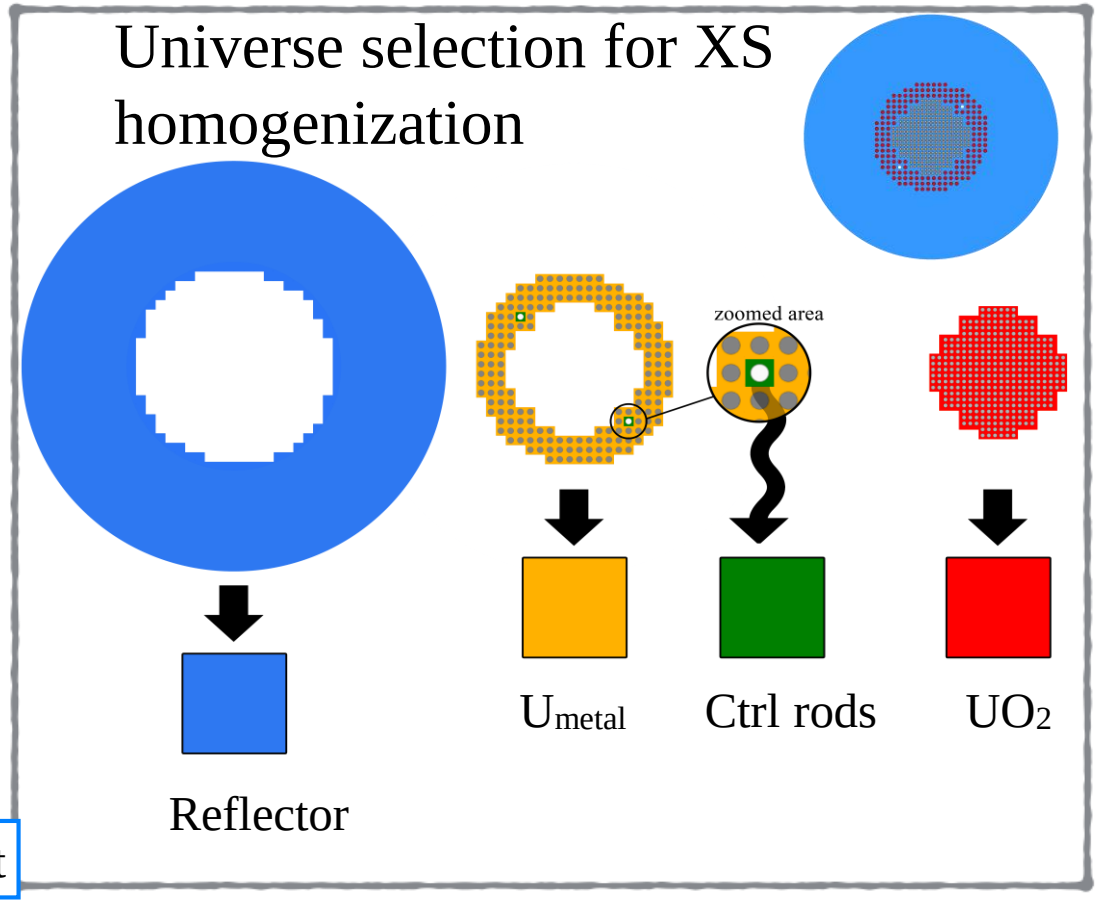
SERPENT v1.1.19 for XS generation

SerpentXS for XS formatting

Methodology

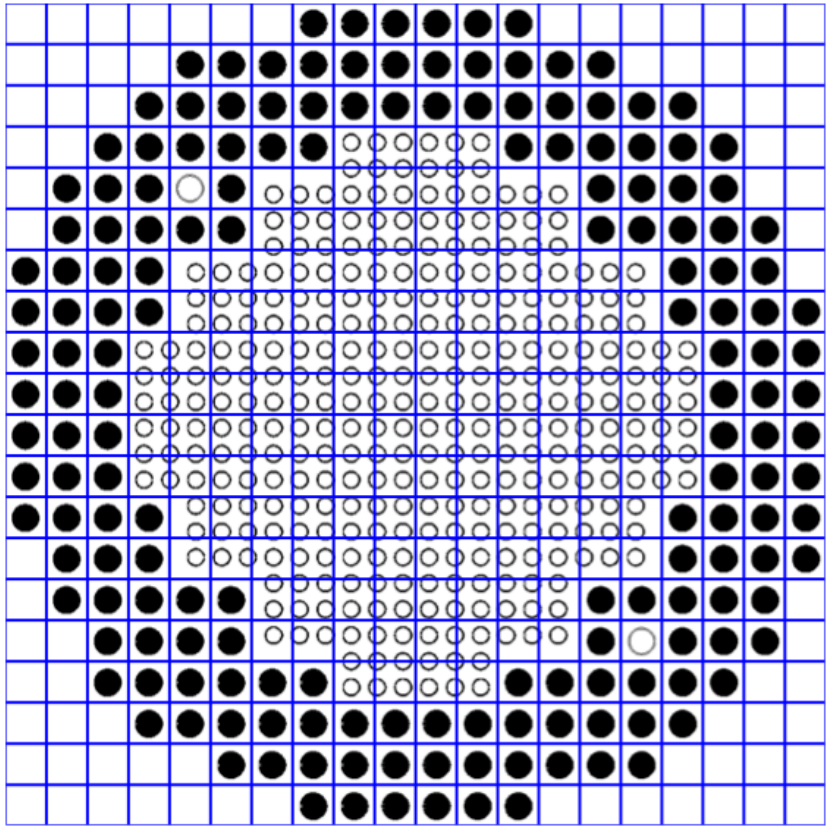
- **Using full core solution for XS generation**
- **2G XS**





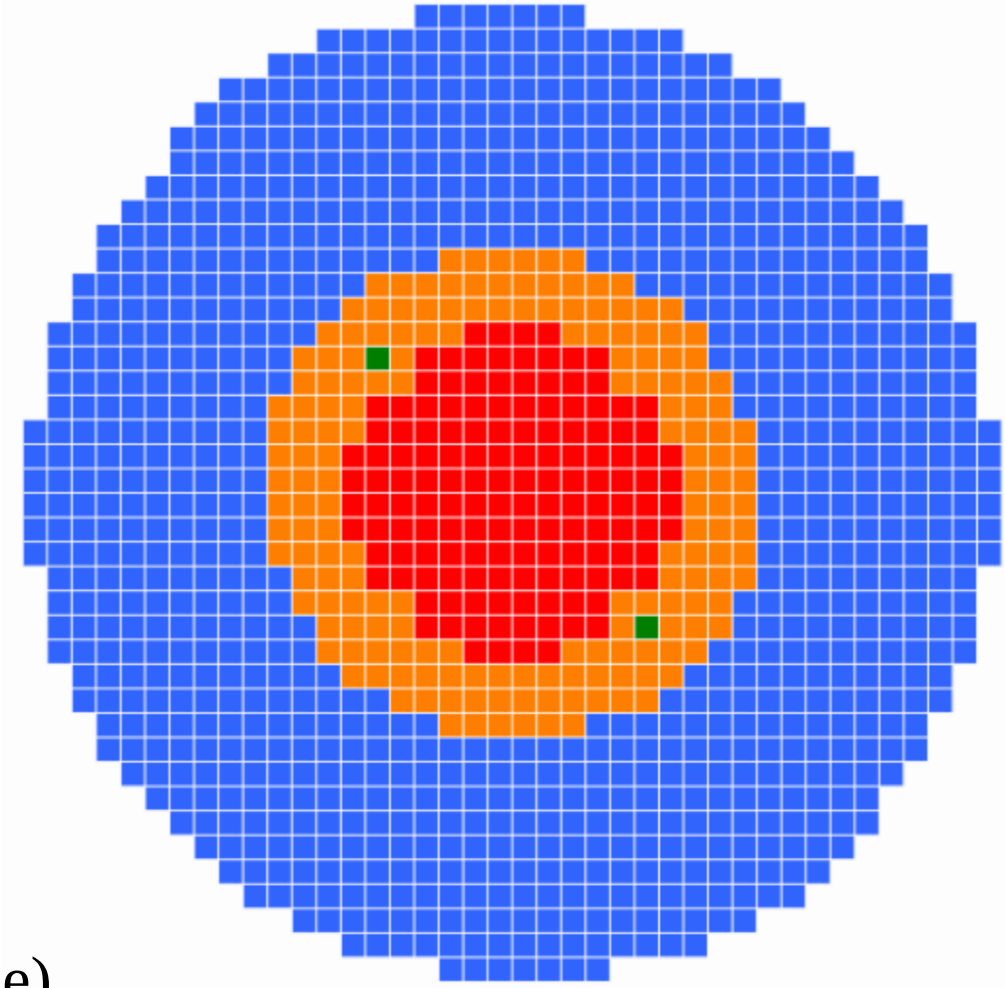
PARCS/SERPENT Code Sequence [2]

U_{metal} cell size for PARCS nodes



PARCS nodes ⇔ UO_2 fuel pins becomes complex (see inner lattice)

PARCS model



Four set of cross sections

Comparison of PARCS/SERPENT vs. SERPENT

Eigenvalue comparison

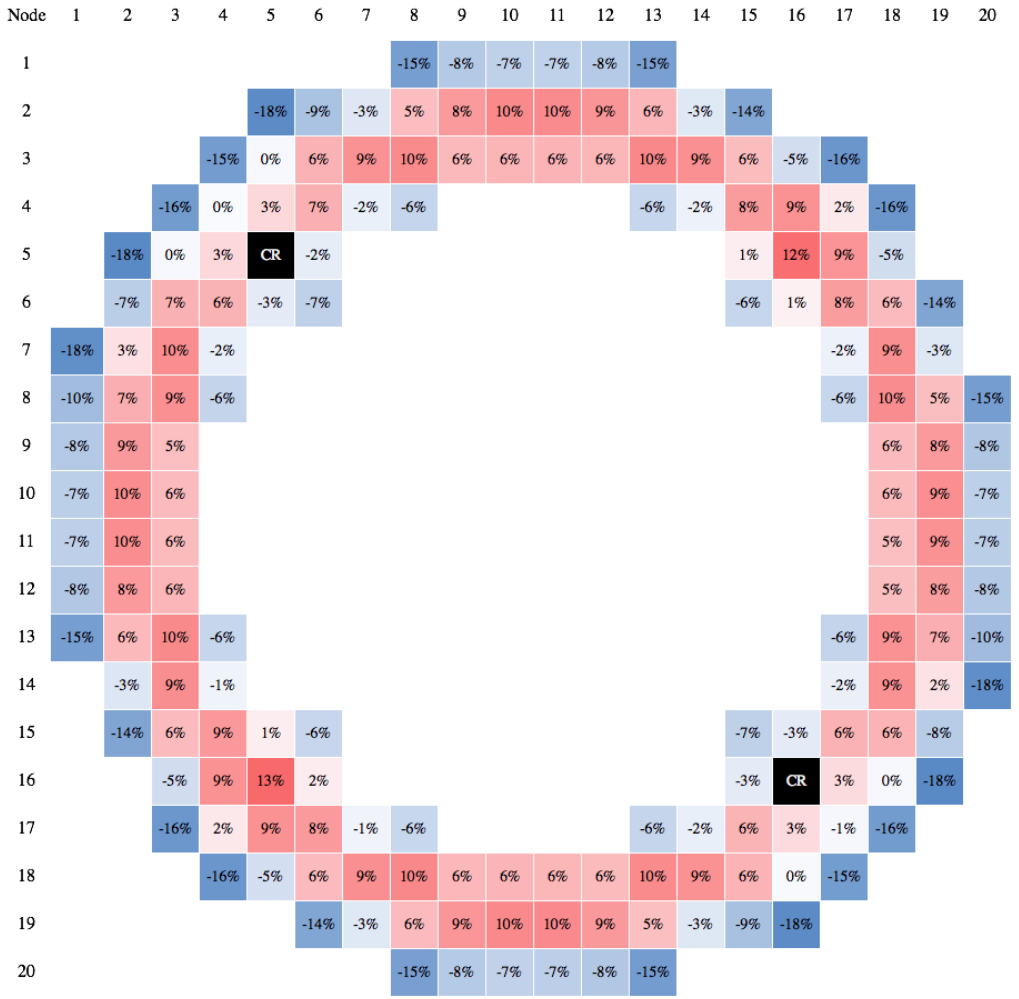
Model	keff	Rel. Diff. [pcm]
SERPENT	1.00189 ± 5 pcm	-
MCNP5	1.00202 ± 5 pcm	13
PARCS	0.99793	-385

Ctrl. rod worth comparison

Model	Reactivity Worth (Δρ)	Rel. Diff. [pcm]
Serpent	169 ± 6 pcm	-
MCNP5	174 ± 7 pcm	5 ± 9
PARCS	136 pcm	-33

Relative power fraction % difference

$(RPF_{PARCS} - RPF_{Serpent})/ RPF_{Serpent}$



Comparison carried out only over the outer lattice, and thus assuming: $P_{OuterLat}^{Serpent} = P_{OuterLat}^{PARCS}$

Conclusion

Development of a SERPENT/PARCS code sequence for the modeling of the CROCUS reactor

- Development of an adequate homogenization scheme thanks to SERPENT
- Development of an approximate core model with PARCS

Comparison to direct SERPENT solution is not completely satisfactory

- Eigenvalue is within 400pcm
- Control rod worth is within 30pcm
- Large discrepancies in power prediction

Future work

Continue Assessment of SERPENT/SIMULATE-3 code sequence for BWR analysis

- Real core model
- Overwrite more CASMO information with SERPENT data
- Move to SERPENT 2

Improvement of SERPENT/PARCS CROCUS model

- Consider a more detailed energy group structure
- Use B1 definition for the diffusion coefficient
- Validates model against experimental measurements
- Extend to transient analysis

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Thank you for your attention, Questions?