INVAP's experience using Serpent code for cell and core calculations

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Presentation Overview

1- Introduction – Why using Serpent ?

2- Serpent coupling with INVAP Calculation line at several levels

3-Examples using Serpent as Cell Code

4-Examples using Serpent as Core Code

5-Conclusions

1- Introduction – Why Serpent?

- Monte - Carlo Codes are used mainly in the Nuclear Engineering Department:
  - ✓*Criticality Calculations (Reactors, Fuel Storages)*
  - ✓*Shielding Calculations (Coupled N,P)*
  - ✓*Ex-Core Facilities design & performance evaluation in RR*
  - ✓*Code to Code comparisons*
  - ✓*Detailed flux profile calculations*
- *INVAP deterministic Calculation Line (CONDOR CP/HRM cell code + CITVAP finite differences diffusion core code) is coupled with MCNP through NDDUMP code (internal development) → Evaluations can be performed with burnup dependence*
- *NDDUMP can handle* composition changes: fuel management & thermalhydraulic feedback

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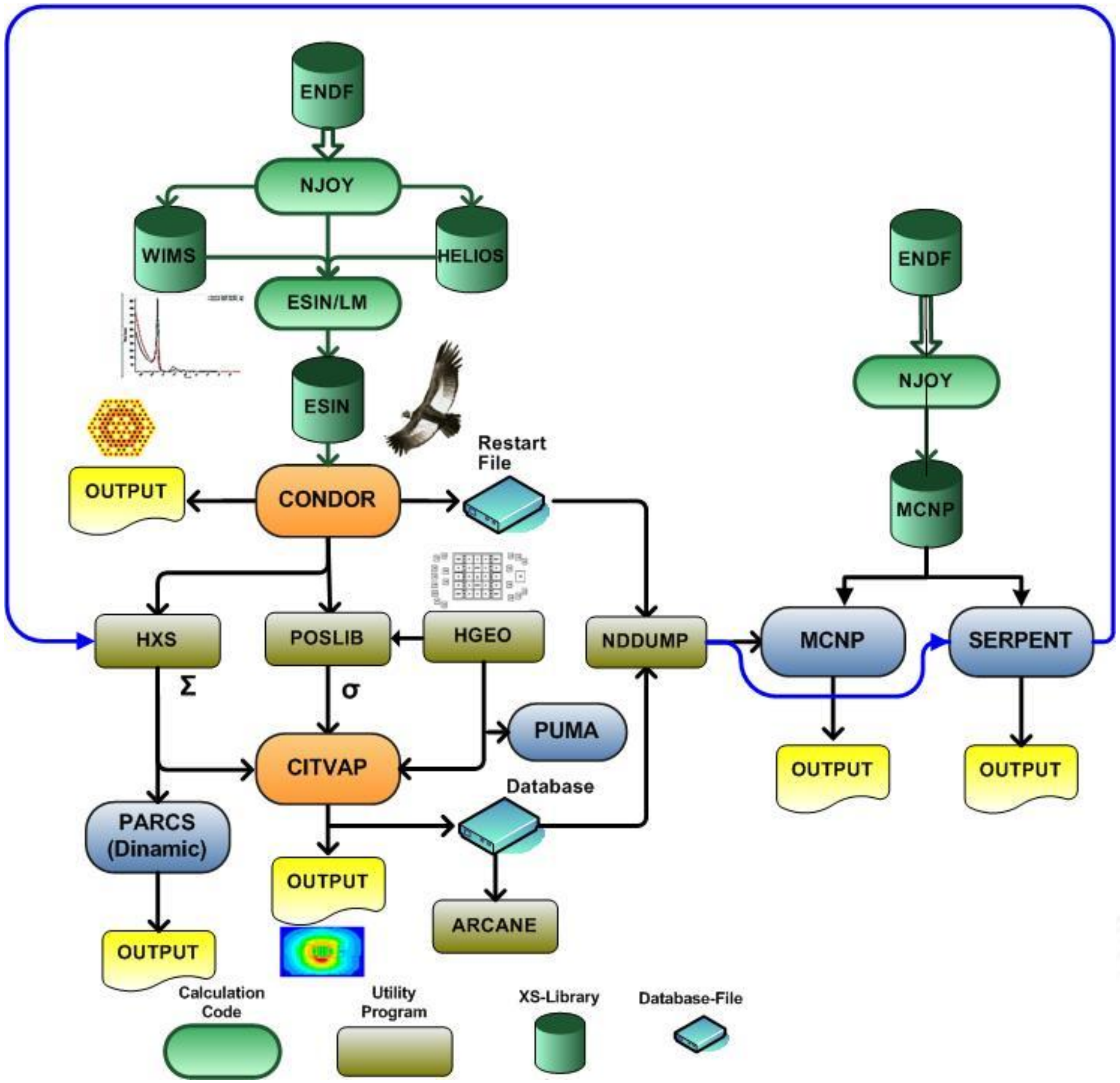
1- Introduction – Why Serpent?

- ***Original motivation to use Serpent (2010) in INVAP***:
  - ✓Obtain condensed parameters (macroscopic XS) for IN-CORE and EX-CORE devices with high heterogeneity for Research Reactors
  - ✓Additional comparisons for burnup dependent cell-level calculations for MTR including burnable poisons with a different physical approach
- ***Today's motivation to use Serpent in INVAP:***
  - ✓Increase in Serpent Capabilities + Parallelization → Complex core models may be developed, including burnup and compared with other calculations
  - ✓Core-level Calculations using compositions obtained from other codes
  - ✓Additional comparisons including burnup at cell-level calculations for diverse fuel designs using a different physical approach

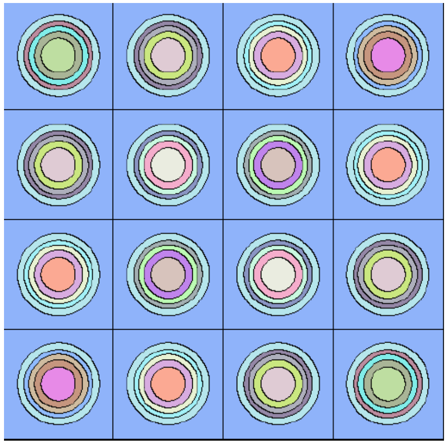
2 –Calculation Line



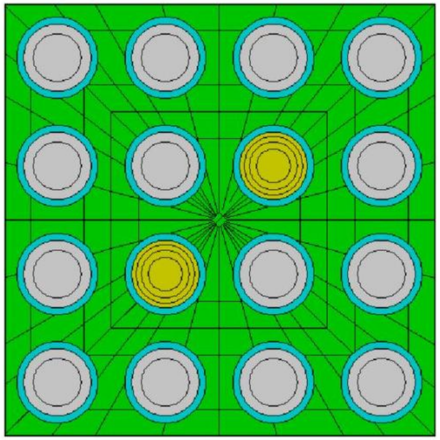
→ Serpent was tested as Cell Code and Core Code for diverse cases

3.1- Examples at cell level
(Code to code - Numerical benchmark)

- Numerical benchmark for a BWR cell with Gadolinium pins including burnup. Results comparison with Condor 2.61 code [1].



Serpent 1.1.7

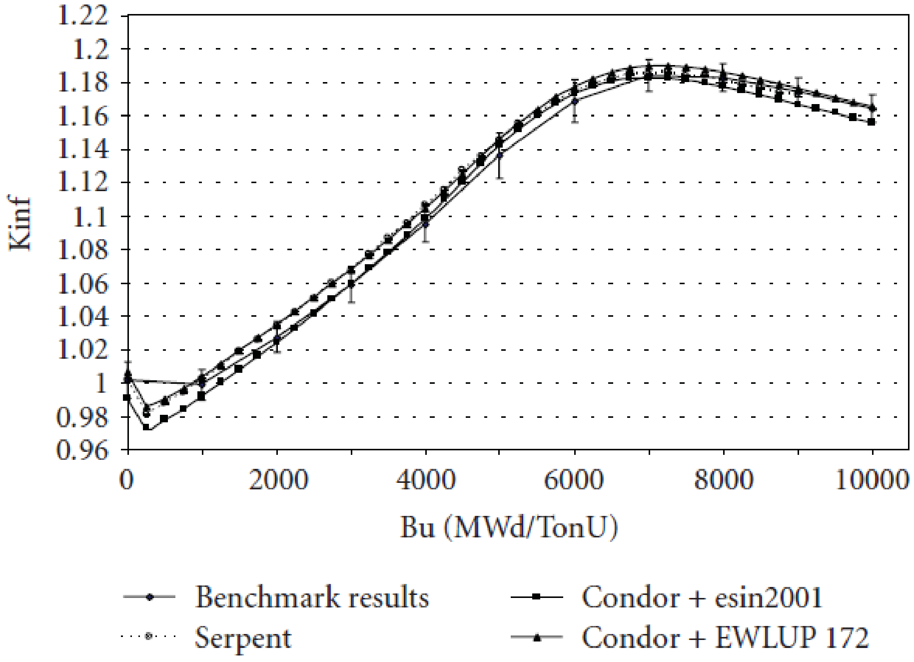


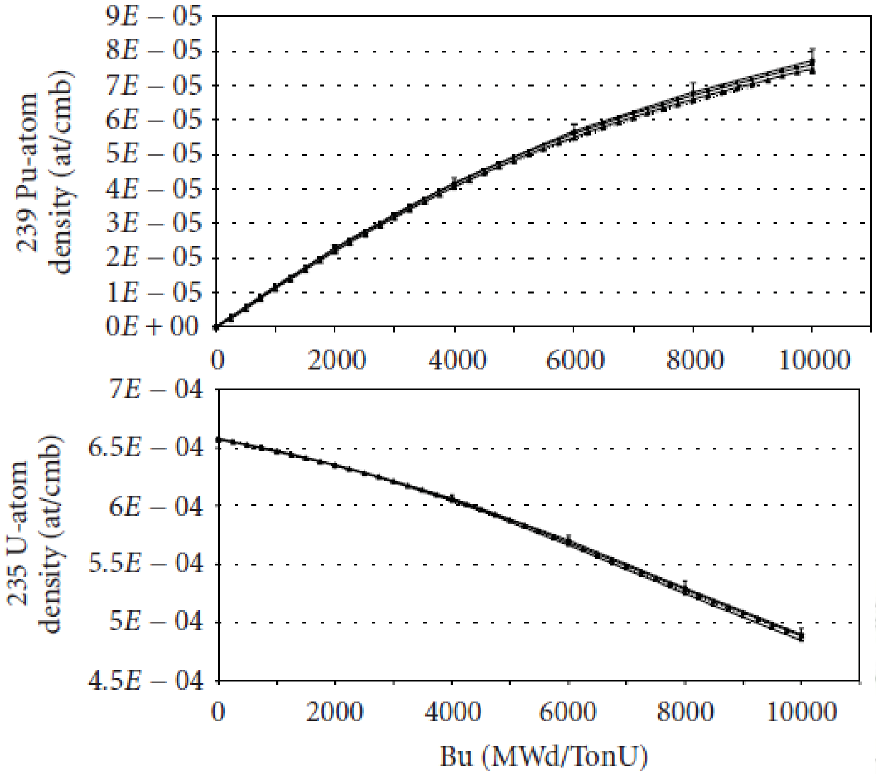
Condor 2.61

✓Kinf vs BU
✓^{235}U vs BU
✓^{239}Pu vs BU
✓^{155}Gd vs BU
✓^{155}Gd vs radii
✓Flux profiles

[1] Calculations for a BWR Lattice with Adjacent Gadolinium Pins Using the Monte Carlo Cell Code Serpent v.1.1.7 - Diego Ferraro and Eduardo Villarino - Science and Technology of Nuclear Installations
Volume 2011

3.1- Examples at cell level
(Code to code - Numerical benchmark)





^{155}Gd Radial distribution at 2000MWd/tonU in the poisoned pin

Mean radius (cm)	^{155}Gd numerical density [at/cmb]				
	Benchmark	Benchmark Stdev	*Serpent*	*Condor*+esin2001	*Condor*+EWLUP172
0.125	1.29E-04	3.4E-06	1.28E-04	1.28E-04	1.29E-04
0.302	1.20E-04	3.3E-06	1.18E-04	1.18E-04	1.19E-04
0.393	9.41E-05	3.8E-06	9.25E-05	9.00E-05	9.31E-05
0.467	4.95E-05	8.6E-06	4.71E-05	4.26E-05	4.60E-05

Good agreement for all parameters

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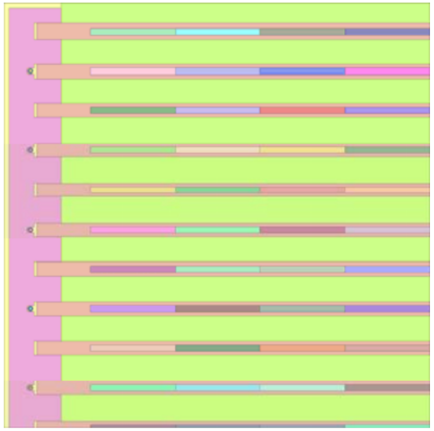
3.2- Examples at cell level

(Serpent as cell code + Experimental Benchmark)

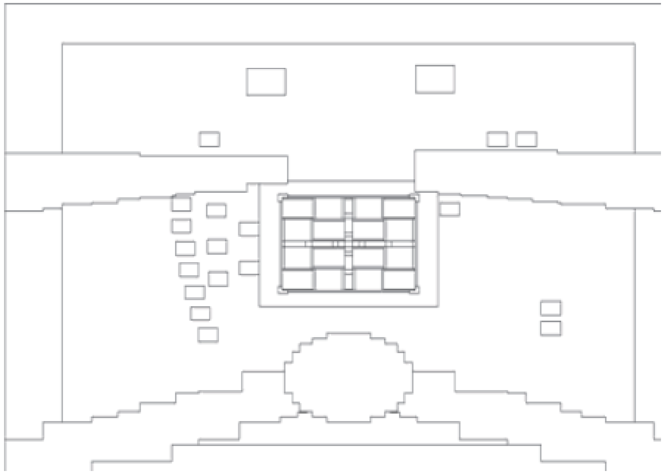
•Serpent v1.1.14 is used to model the MTR fuel assemblies and control rods from OPAL (Open Pool Australian Light-water) reactor to obtain few-group constants (XS and Diff coef) with burnup dependence [2].

•*Those XS and Diff coef are introduced in Core-Models*

•*Experimental critical positions are calculated with Core Models.*



Serpent 1.1.14



CITVAP 3.6

Comparisons w/ Condor:

✓Kinf vs BU at cell level

✓Frame fluences

✓XS

Core calculations:

✓Critical points

✓CR worth

[2] OPAL Reactor Calculations using the Monte Carlo Code Serpent - *D.Ferraro, E.Villarino* - 4th International Symposium on Material Testing Reactors, Oarai, Japan, December 5-9, 2011

3.2- Examples at cell level
(Serpent as cell code + Experimental Benchmark)

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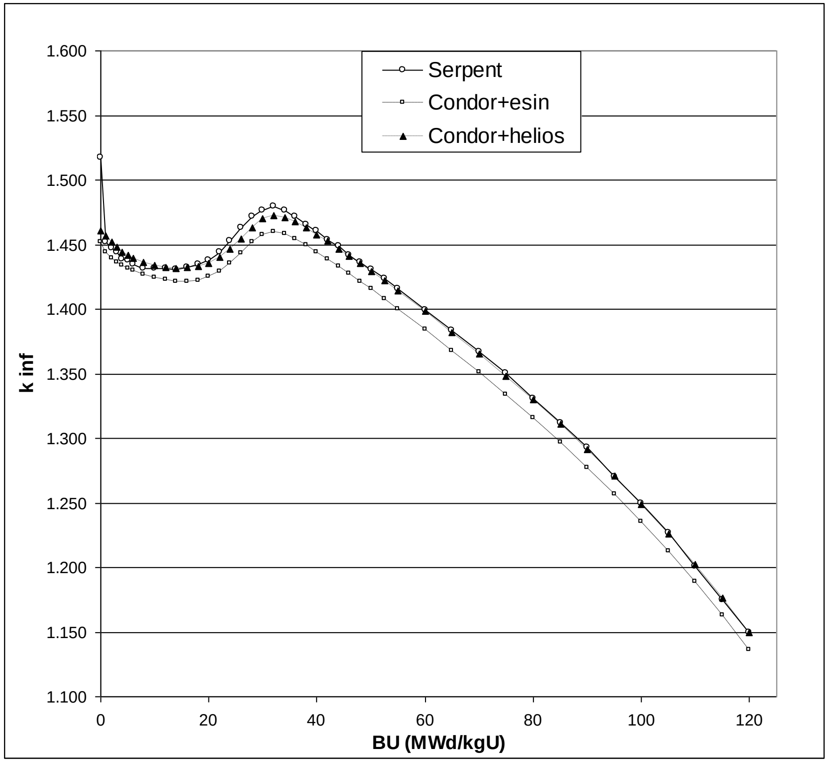
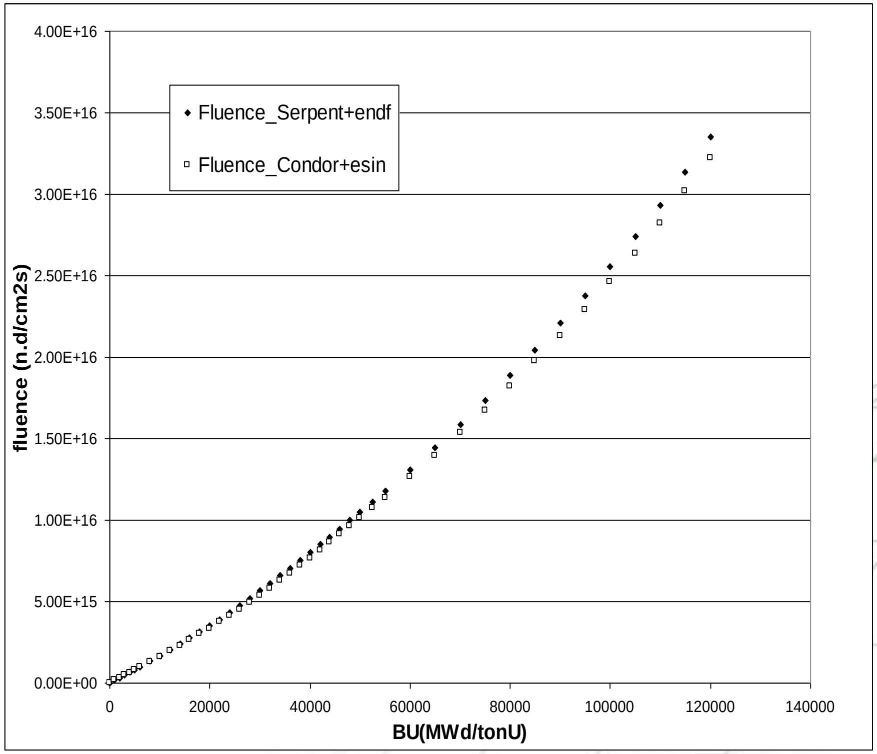
Comparisons w/ Condor:

✓Kinf vs BU at cell level



✓Frames fluence

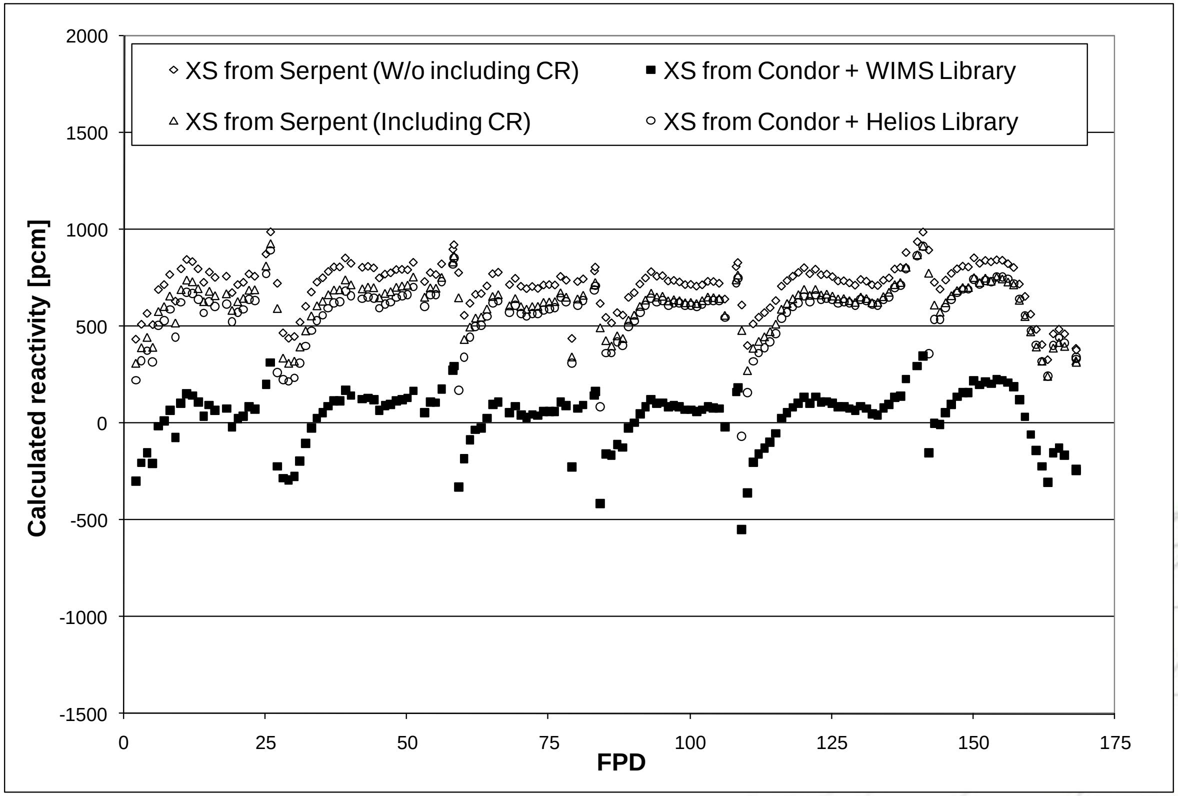


Good agreement for relevant parameters

3.2- Examples at cell level

(Serpent as cell code + Experimental Benchmark)

✓Results using Condensed and Homogenized XS from Serpent Models in CITVAP core code for critical CR positions (measured – Cycles 10 to 15)



Results are consistent with **experimental** measurements and results from Condor models at cell level

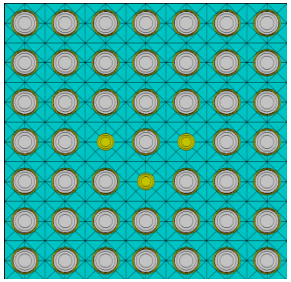
3.3- Examples at cell + core level

(Code to Code Serpent as Cell and Core Code)

•*Code to Code comparison for a concept core design of a generic Low Power Research Reactors is carried out using several codes and approaches and codes [3]:*

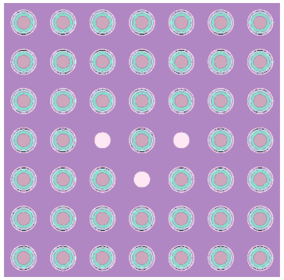
- ***a. Cell Model + Core Model***
- *b. Full Core Model*

CONDOR v2.5 (2-D Cell)
+
CITVAP v3.8.03 (3-D Core)

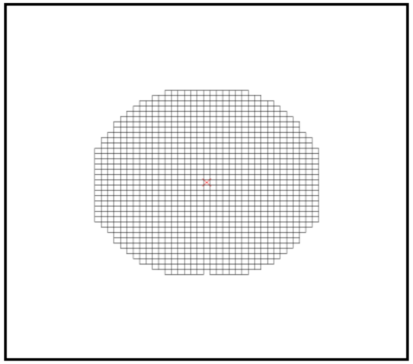


CONDOR Cell model

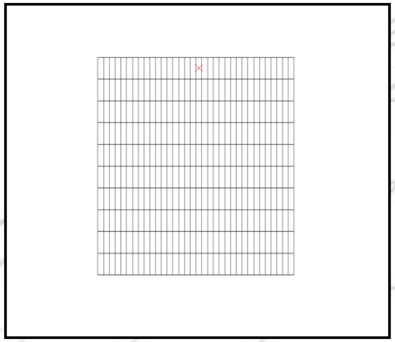
Serpent1 v1.14 & Serpent2 v1.15
(2-D Cell)
+
CITVAP v3.8.03 (3-D Core)



Serpent Cell model



CITVAP CORE model x-y cut



CITVAP CORE model y-z cut

[3] Low Power Research Reactor Calculations Using Deterministic and Stochastical Transport Codes - 6th International Symposium on Material Testing Reactors - Bariloche, Río Negro, Argentina - October 28-31, 2013

3.3- Examples at cell + core level

(Code to Code Serpent as Cell and Core Code)

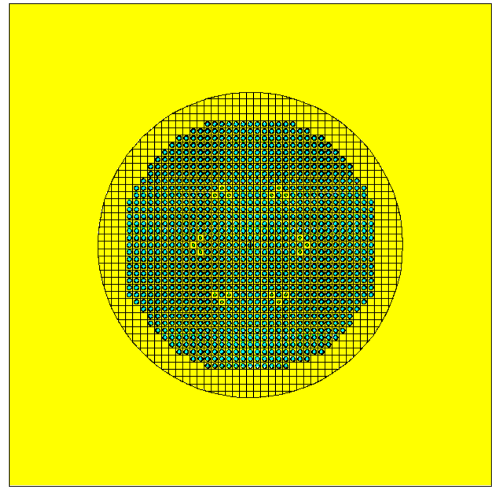
- ***Different Approaches:***
  - a. *Cell Model + Core Model*
  - ***b. Full Core Model***

MCNP5 v1.6 (full 3-D Core)

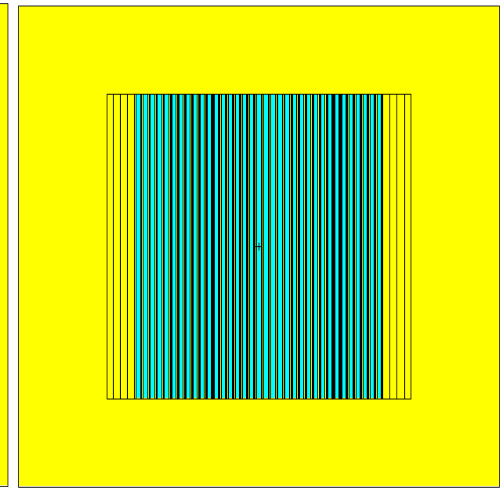
Cases w/o Burnup
Libraries analyzed:
•ENDF/B VII.0
•ENDF/B VI.6
•ENDF/B VI.1

Serpent2 v1.15 (full 3-D Core)

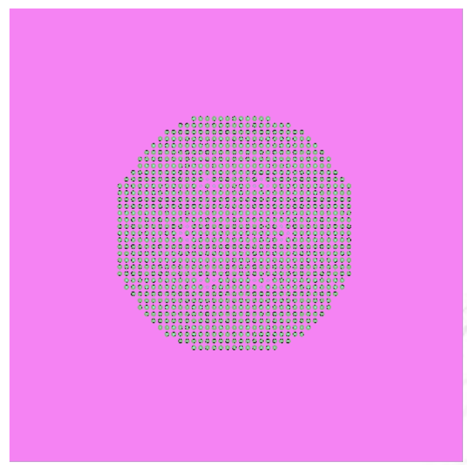
Burnup available /
10 axial zones



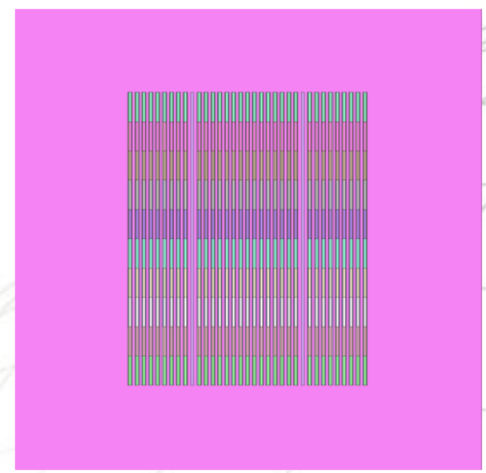
MCNP5 model x-y cut



MCNP5 CORE model y-z cut



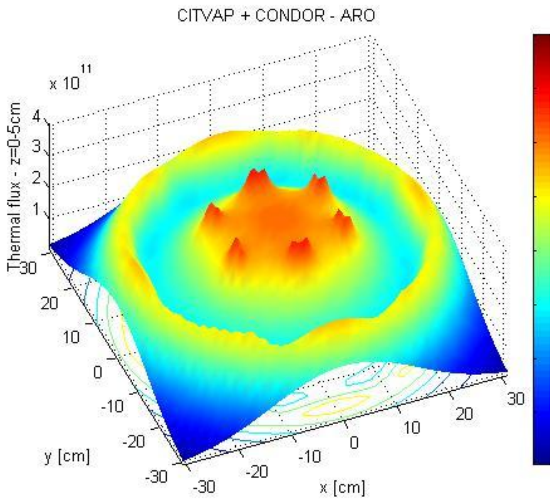
Serpent2 model x-y cut



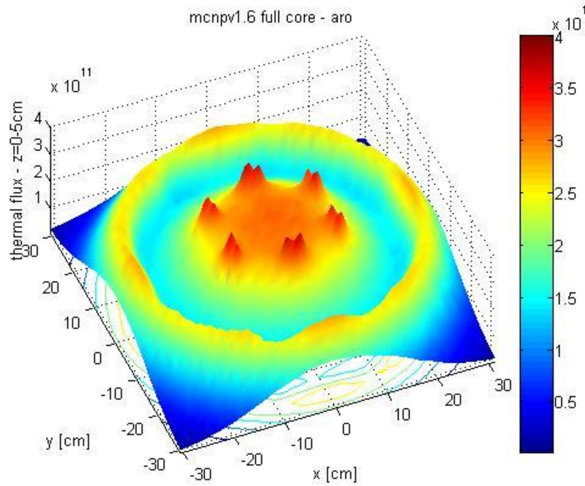
Serpent2 model x-z cut

3.3- Examples at cell + core level
(Code to Code Serpent as Cell and Core Code)

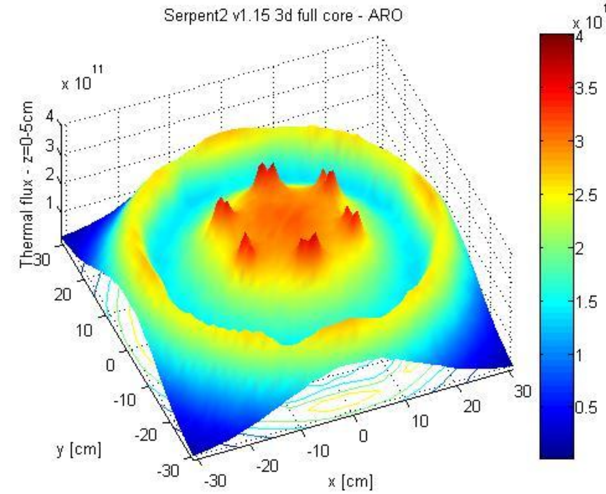
✓ ***Thermal Flux maps for Fresh & Clean Cores (Central Axial Zones) – All Rods Out:***



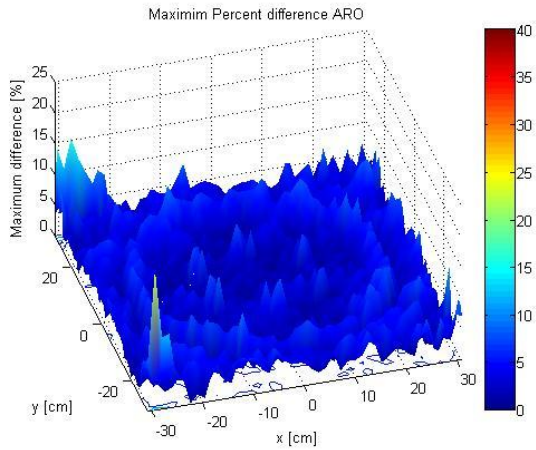
CITVAP 3.8



MCNP5 1.6



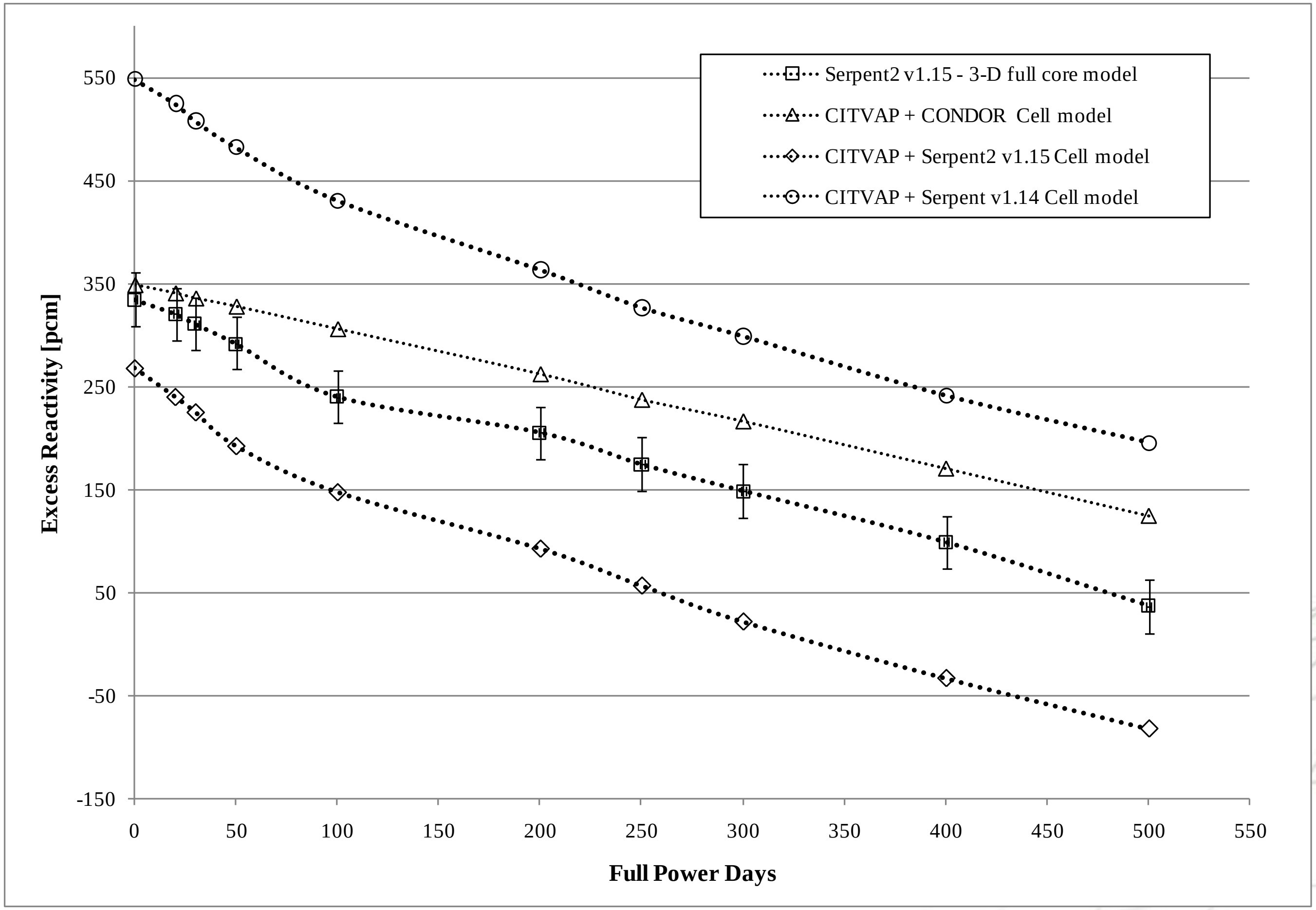
Serpent 2 1.15



- Good agreement exists for all calculation codes
- Differences in light water zones w/ Deterministic Calculation line is maximized

3.3- Examples at cell + core level
(Code to Code Serpent as Cell and Core Code)

✓ ***Reactivity vs burnup:***



•Good agreement exists for all calculation codes
•Serpent used as cell or code code

4 - Examples at Core Level
(Experimental benchmark - Preliminary)

What if we use Serpent as Core Code?

- 3-D full core model for OPAL Research Reactor in Serpent 2 1.21
- Simplified models for most relevant experimental facilities are included.
- Results for these models are presented and compared with experimental data from Reactor Commissioning. [4].

✓Complex inputs
✓High resources demand (CPU & RAM)
✓Big files!
✓Parallel calculation is compulsory

✓Critical positions (from commissioning)
✓Keff vs BU (1st cycle)
✓Flux profiles

[4] “Opal Reactor Full 3-D Calculations Using The MonteCarlo Code Serpent 2” – D. Ferraro and E. Villarino. Abstract presented in 2014 IGORR: International Group on Research Reactors 17th to 21st November *2014*

4 - Examples at Core Level
(Experimental benchmark - Preliminary)

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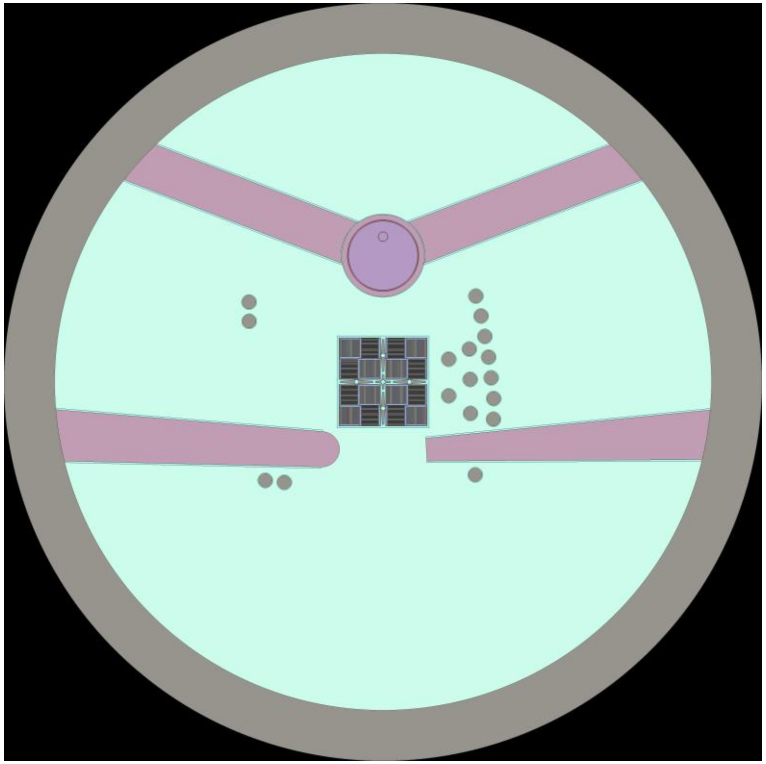
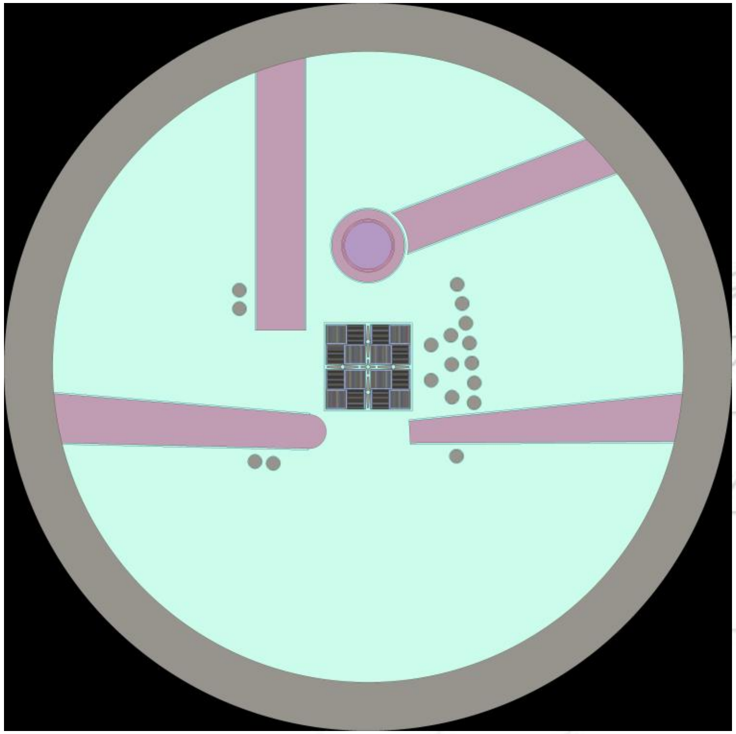
Developed model:

✓Simplified models for most relevant experimental facilities are included.

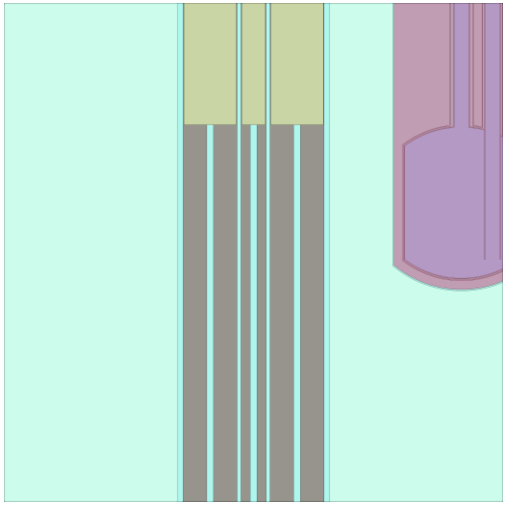
✓Some facilities are excluded (NTD)

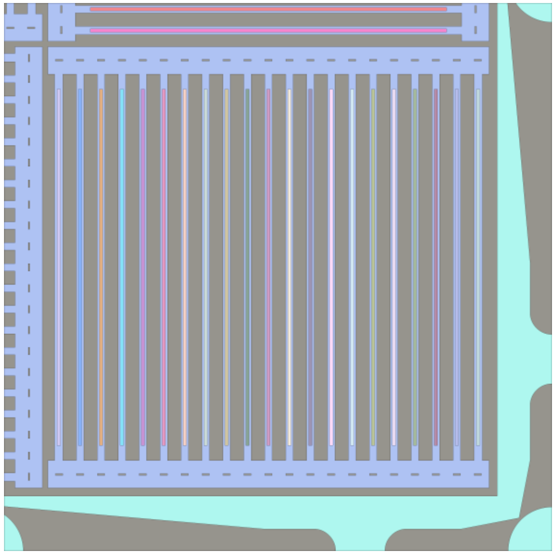


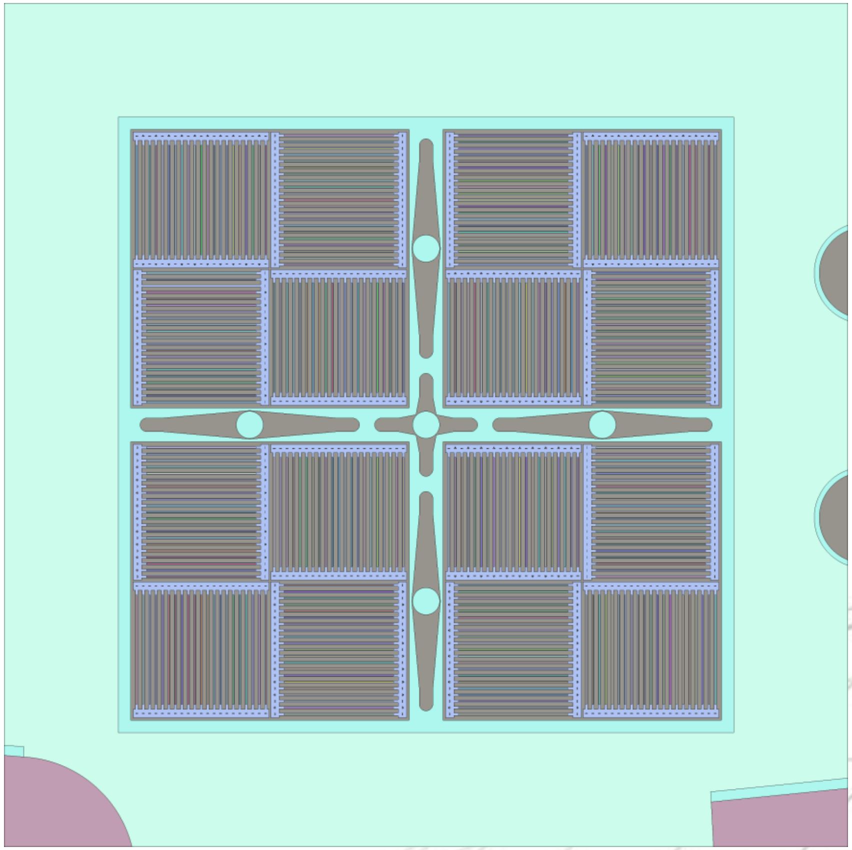


4 - Examples at Core Level
(Experimental benchmark - Preliminary)

Developed model:

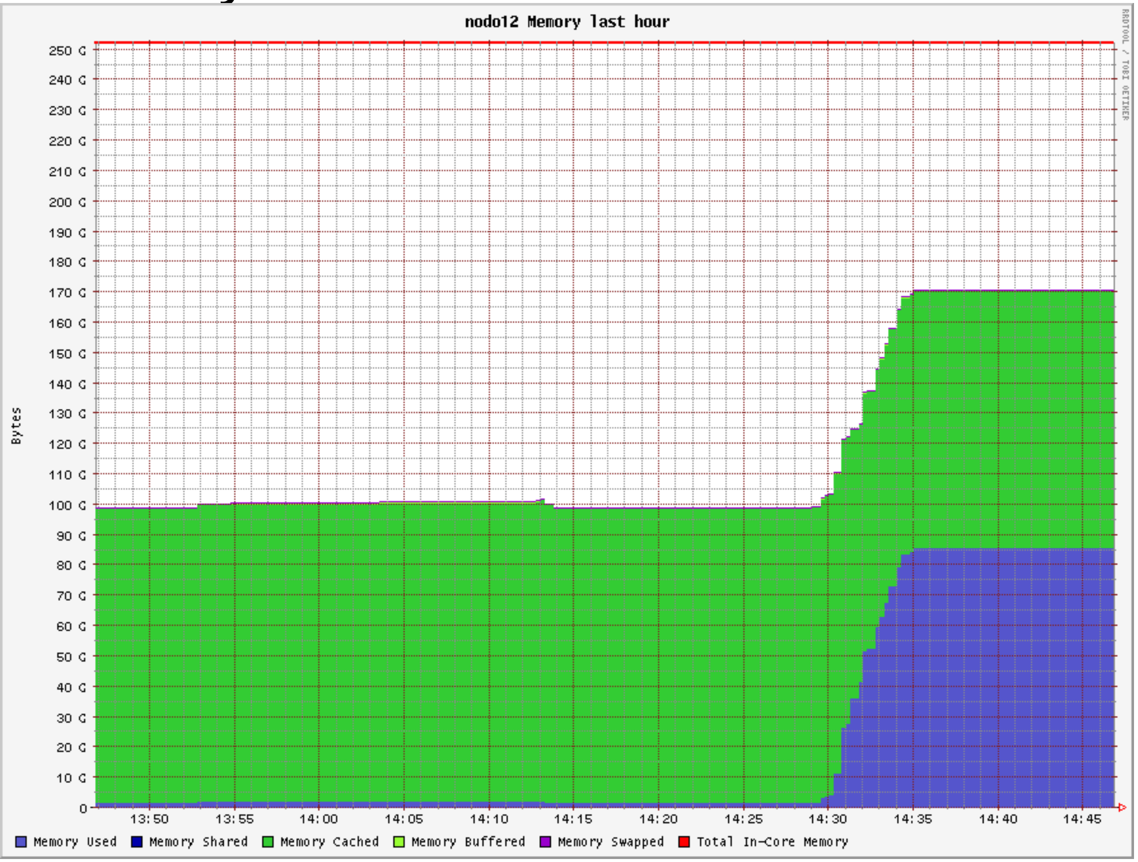


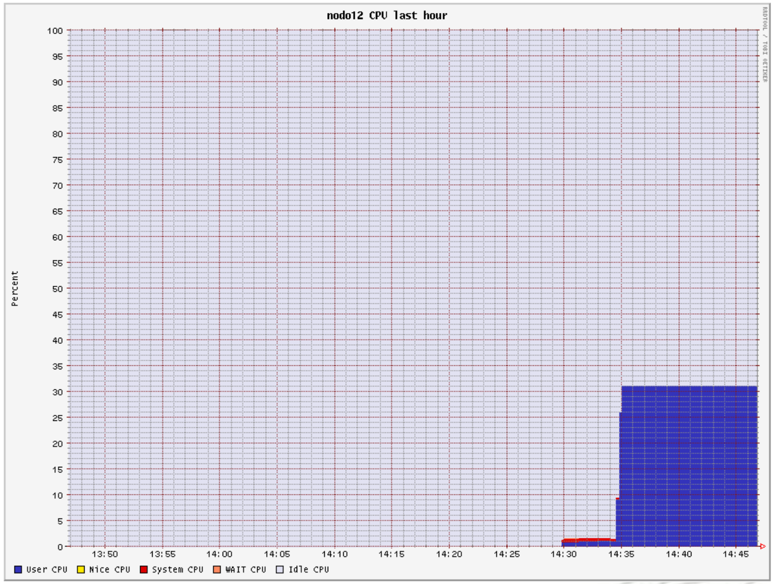




4 - Examples at Core Level
(Experimental benchmark - Preliminary)

Memory issues:



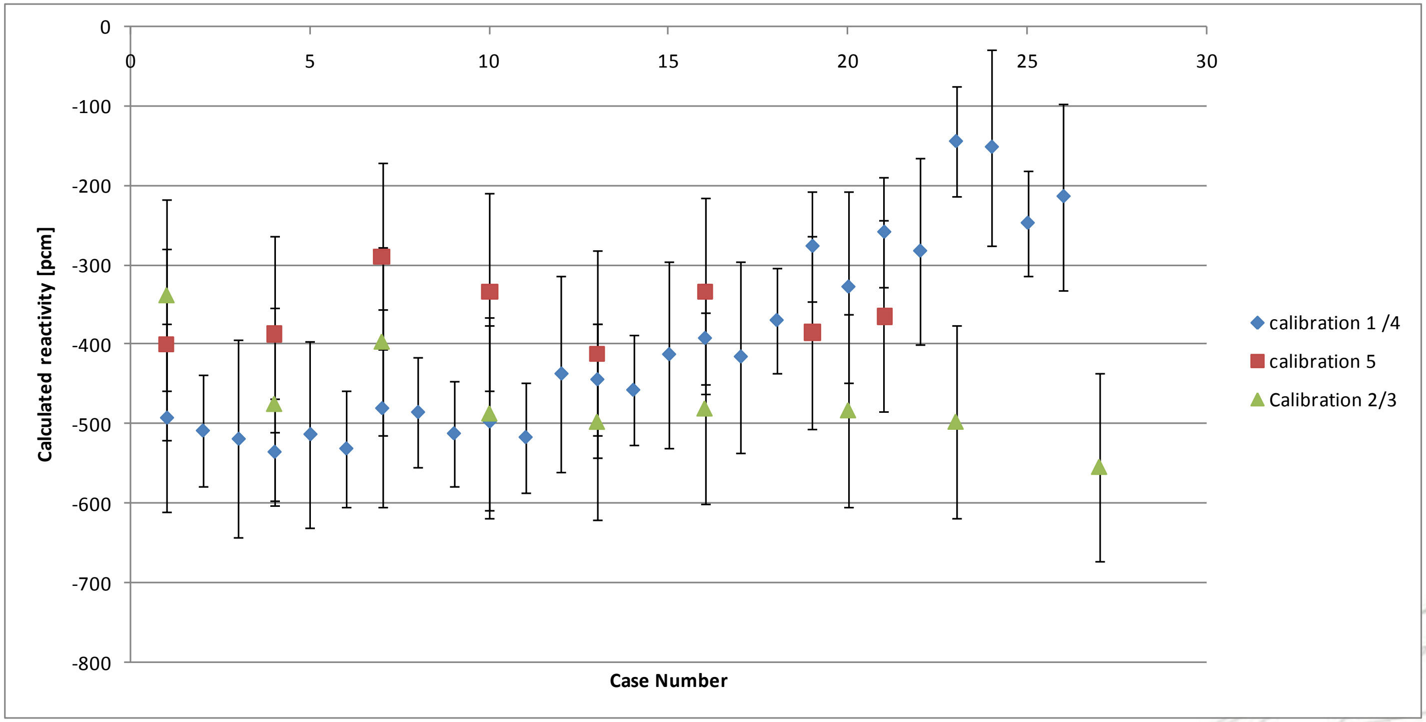


→80GB RAM (20 processors from 64 total)

→Mainly due to material subdivisions – dependence with egrid

4 - Examples at Core Level
(Experimental benchmark - Preliminary)

✓Critical points - Measurement from commissioning (CR calibrations - Cold no Xe)



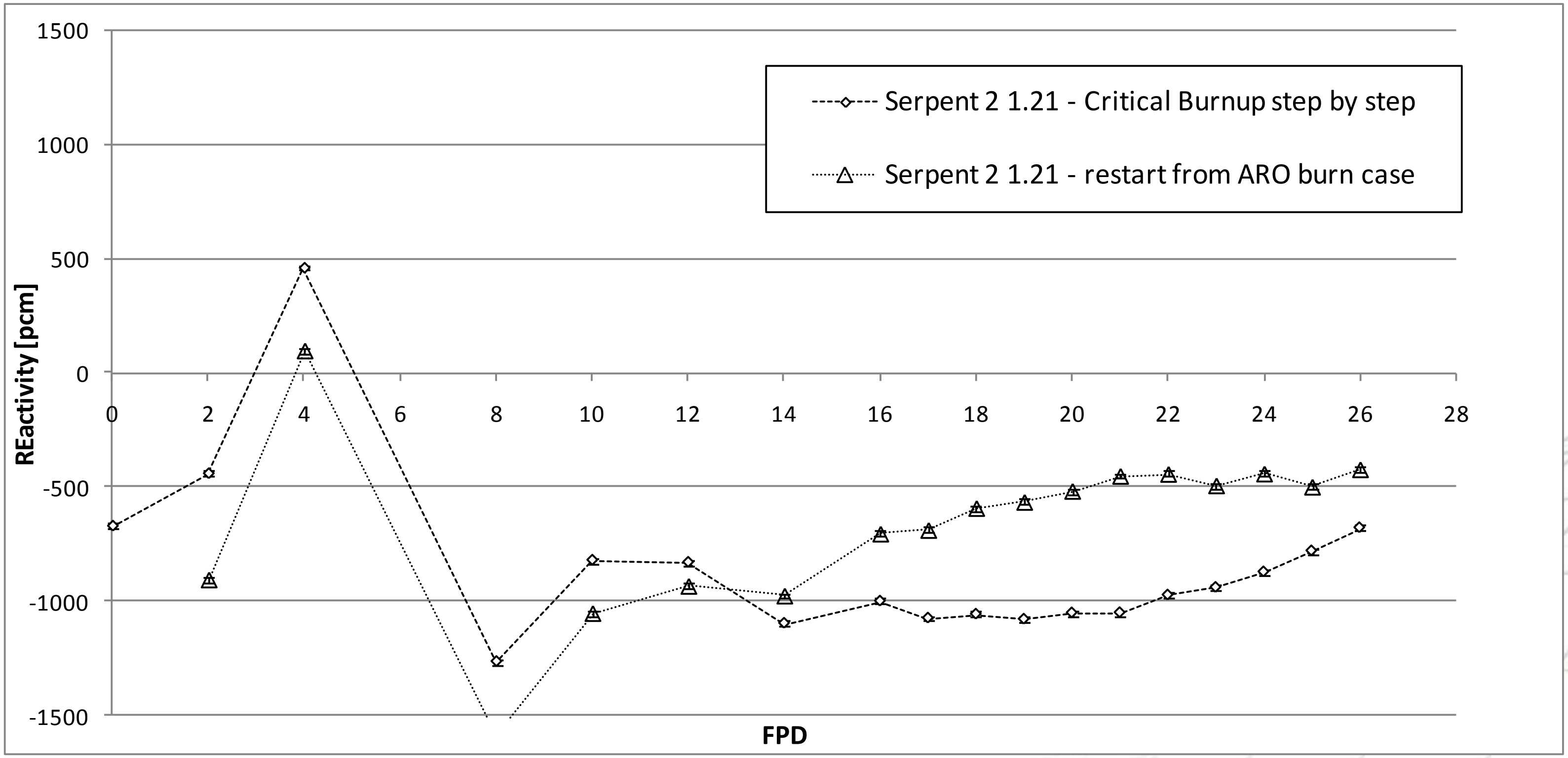
→Good agreement with experimental measurements!!

✓Kinetic Parameters

	CITVAP	MCNP	Serpent 2
βeff [pcm]	768	770	766
Λ [μs]	171	172	175
α [1/s]	45	45	44

4 - Examples at Core Level
(Experimental benchmark - Preliminary)

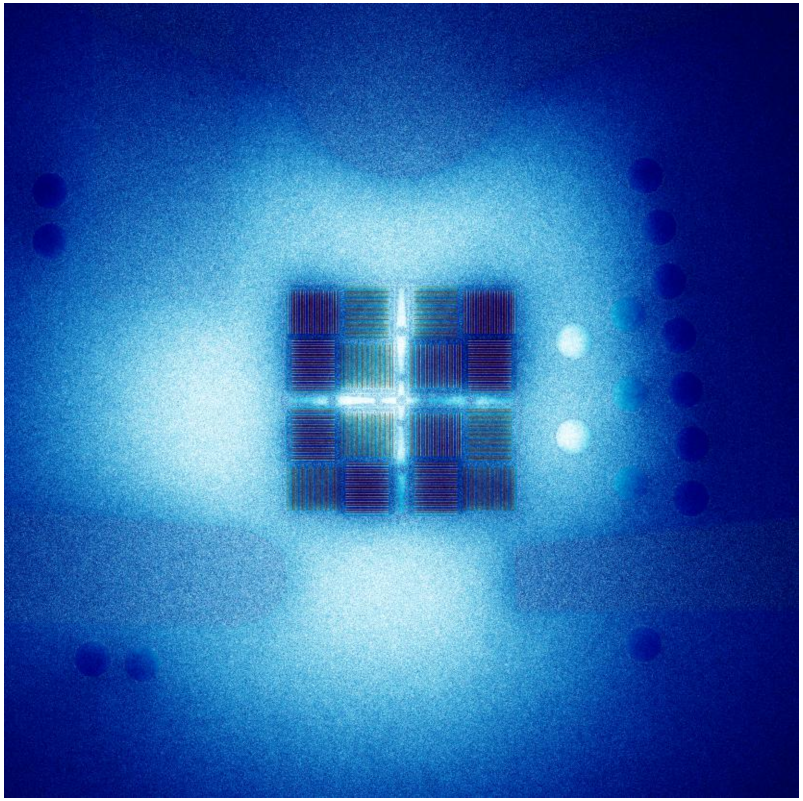
✓Full Core Burnup Calculations – Performed step by step with CR in Critical positions - Measurement from commissioning 1st cycle operation (Hot w/Xe – calculation performed with FPD)



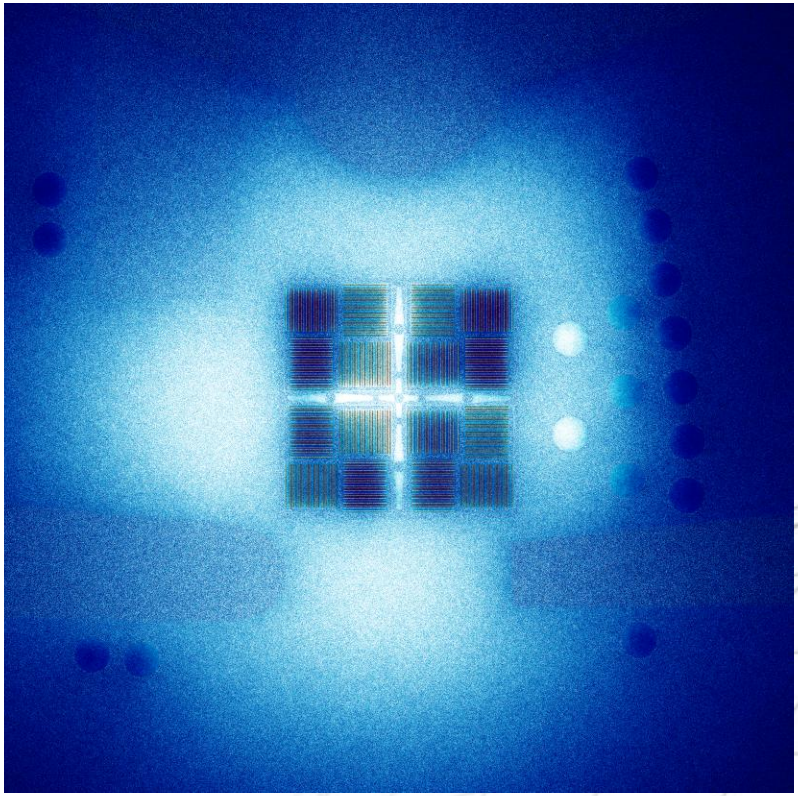
→Xenon not in equilibrium for several points
→Good agreement with experimental measurements
→Refueling?

4 - Examples at Core Level
(Experimental benchmark - Preliminary)

✓Mesh plotter results (ARO) & mesh detector results :



BOC - ARO

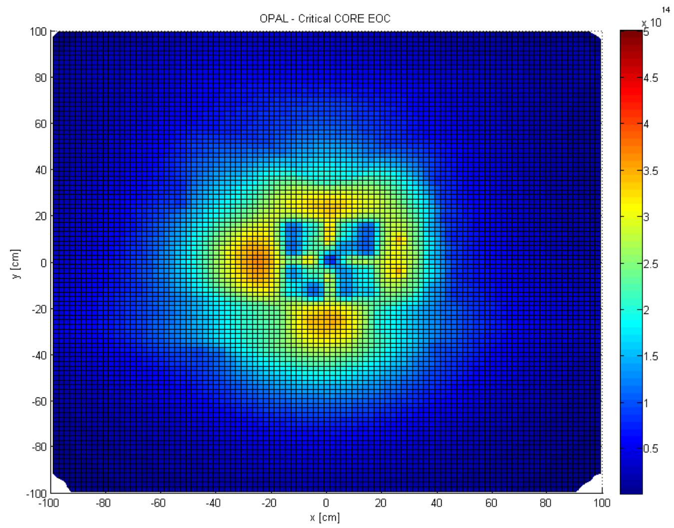


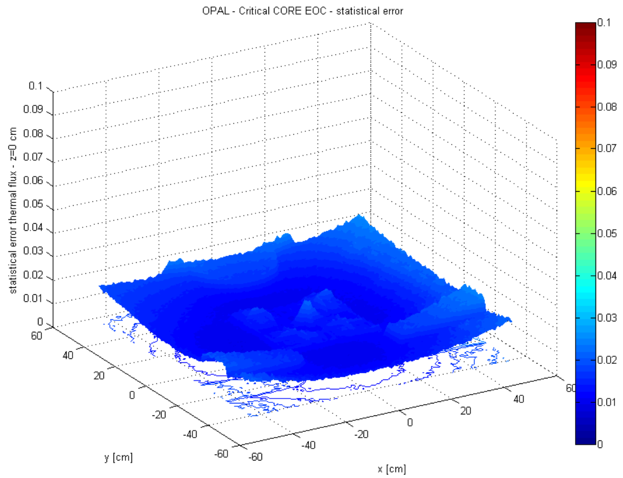
EOC - ARO

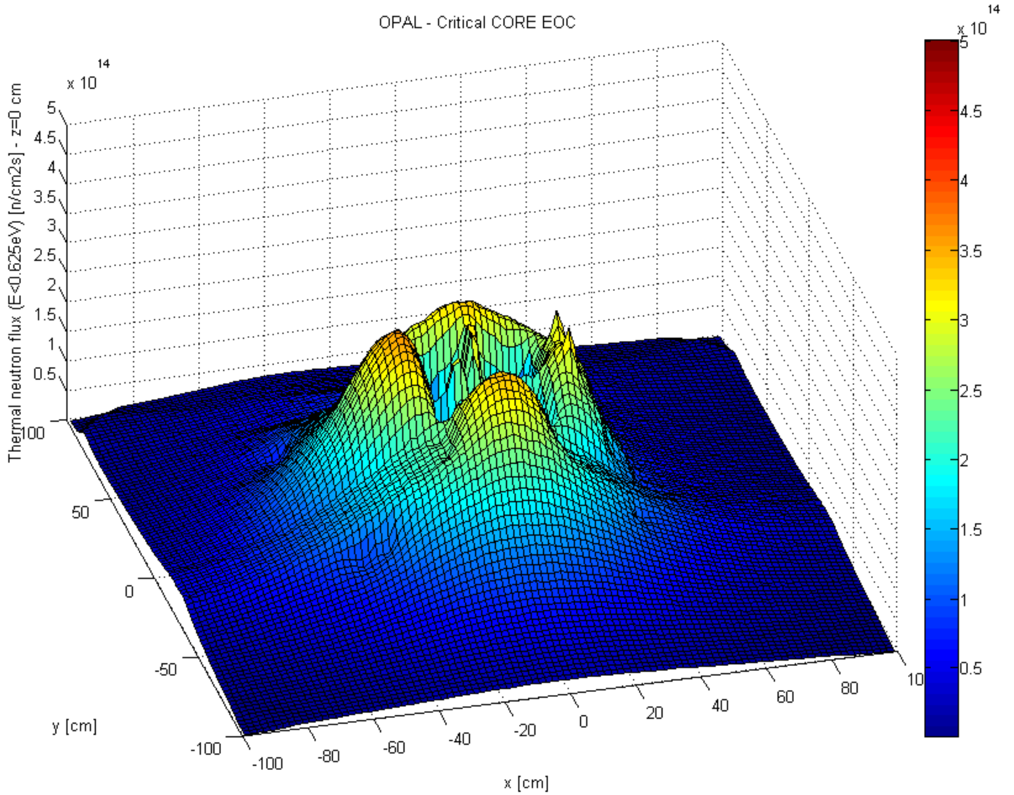
→Results as expected

4 - Examples at Core Level
(Experimental benchmark - Preliminary)

✓Mesh thermal neutron flux detector results :



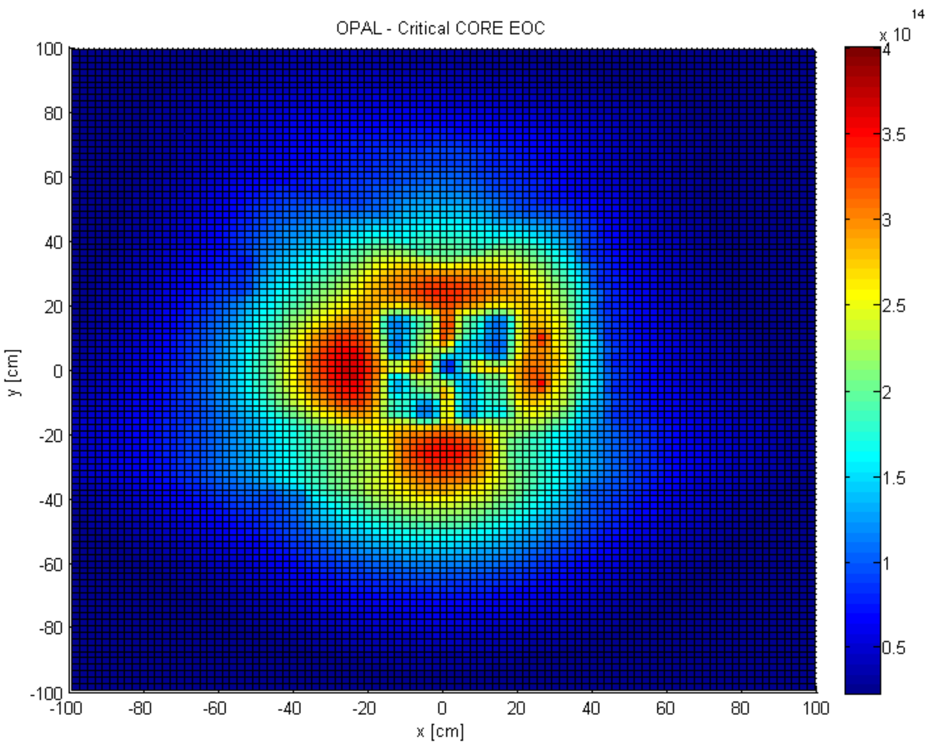


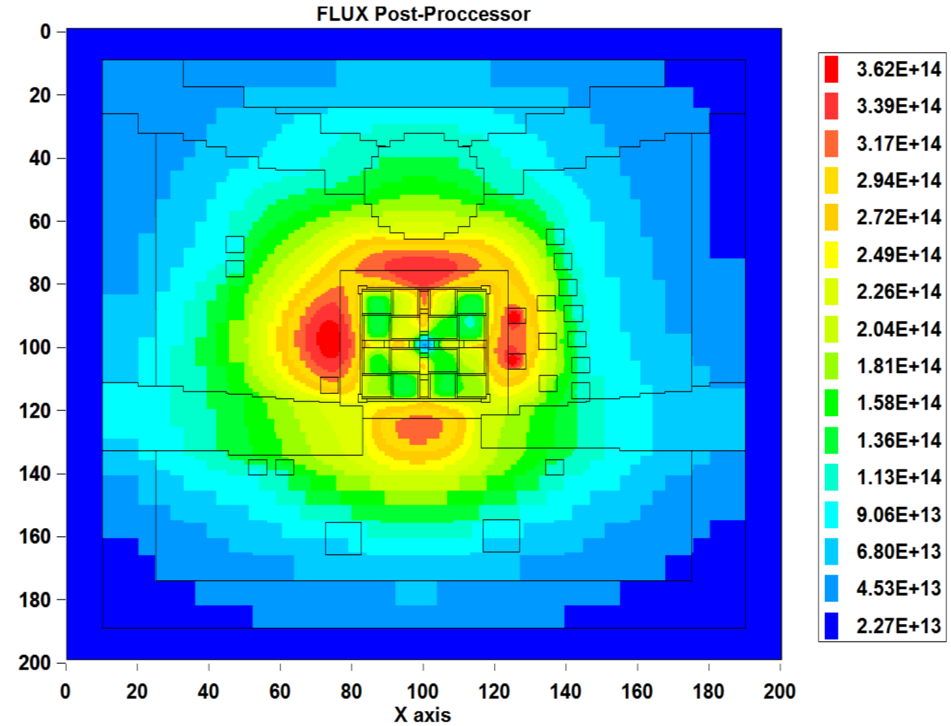


→Results as expected
→Good statistical convergence

4 - Examples at Core Level
(Experimental benchmark - Preliminary)

✓Mesh thermal neutron flux detector results - comparisons :

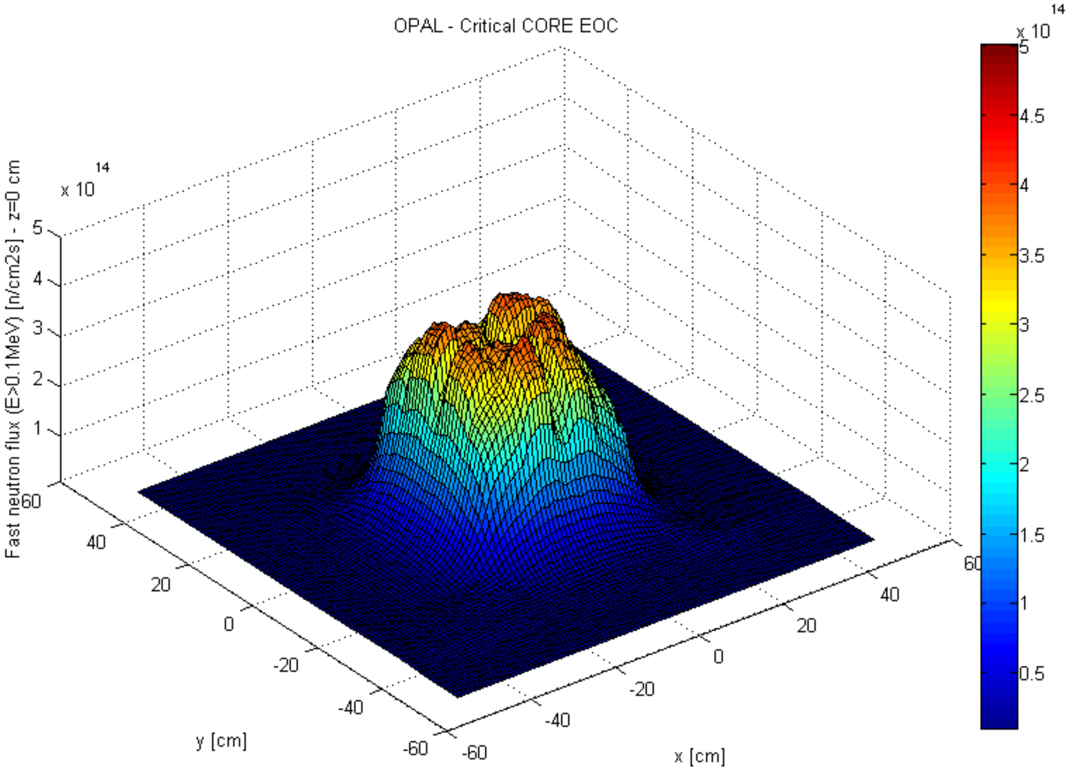


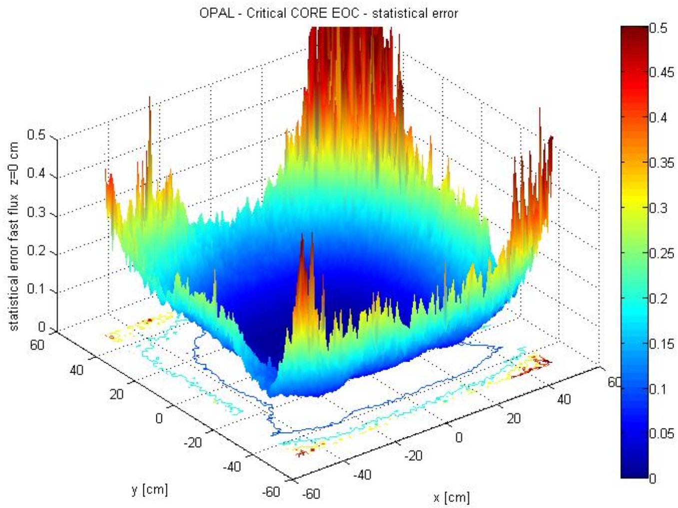


→Comparison vs. CITVAP (differences up to ~5%)

4 - Examples at Core Level
(Experimental benchmark - Preliminary)

✓Mesh fast neutron flux detector results :





→Results as expected
→Convergence is poor for positions far from core

4- Conclusions

- Good agreement is observed using Serpent for Core and Cell calculations in Code to Code comparisons.
- Good agreement is observed using Serpent for Core and Cell calculations at experimental comparisons.
- Full core calculations including burnup are feasible in MTR reactors, considering:
  - ✓ High memory resources requirement is expected.
  - ✓ Fuel management capabilities are to be required.
- Serpent provides an alternative approach to face high heterogeneity problems in RR.

Thanks for your attention!