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Nuclear Compact Reactors

MONTE-CARLO COUPLED DEPLETION CODES EFFICIENCY FOR RESEARCH REACTOR DESIGN

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Introduction

- **TechnicAtome**: specializes in the design, construction, operation and maintenance of compact nuclear reactors

- **Early stages of core design** and industrial studies require a **quick and efficient calculation** of key neutronic parameters at any time
  - Mainly achieved by **deterministic calculation schemes**
  - COCONEUT (COre COnception NEUtronic Tool)

- **Nevertheless**
  - Deterministic codes: **problem dependent** / **V&V process** for **various kinds of cores**
  - Improvement of CPU power: Monte-Carlo burnup calculations for industrial studies

- **Aims of this paper:**
  - Monte-Carlo burnup codes for industrial studies **(TRIPOLI4®, MCNP, Serpent) ?**
  - Describe a case study part of the V&V process undergone by COCONEUT

- **Case study:**
  - A multipurpose dummy core designed by TechnicAtome

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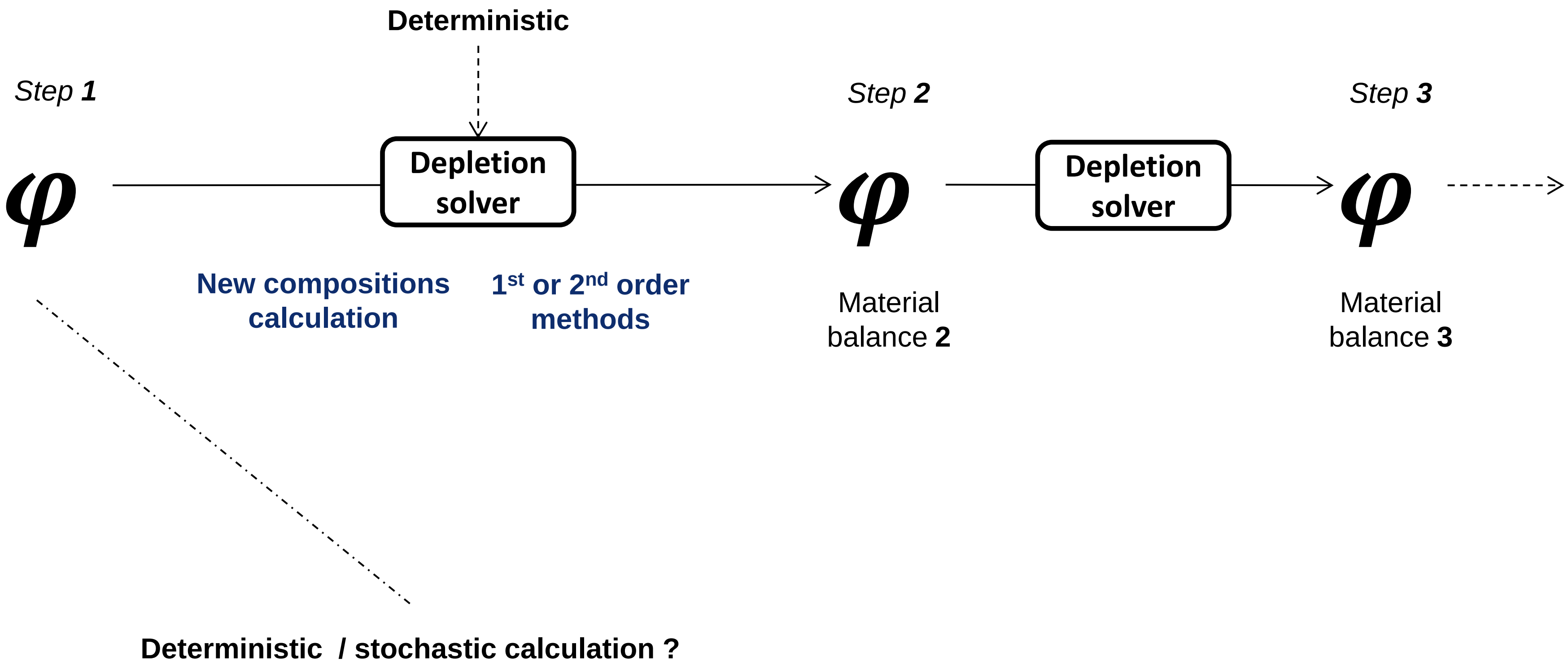
Depletion calculation methods (1/2)

- **General diagram for depletion calculation**



Depletion calculation methods (2/2)

Deterministic approach

- **Fast** method for flux calculation → **industrial studies**
- Cross sections collapsing
- Self shielding
- Spatial mesh
- Time related mesh
- Geometry dependent

Approximations / biases to quantify

Stochastic approach

- Exact 3D geometry
- Punctual XS for flux calculation
- **Slower** than deterministic calculation
- Statistical uncertainties
- Spatial mesh for depletion
- Time related mesh

Results depending on statistical convergence

Uncertainties propagation

Time consuming

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Codes used in this study: MC codes

TRIPOLI4®

- Code developed by CEA (French Alternative Energies and Atomic Energy Comission)
- **Safety studies reference** at TechnicAtome
- Polyvalent code
- Large V&V process

- **Root based interfaces** (pre / post processing)
  - Geometry modification during depletion
  - Refueling module
  - Possibility to develop a tool for uncertainties propagation

MCNP

- **International reference**
- Code largely benchmarked
- Many applications at TechnicAtome
- Assessment of JHR neutronic performances

Serpent

- **Fast**
- New methods (perturbation, coupled physic…)
- Automatic mesh
- Undergoing V&V process

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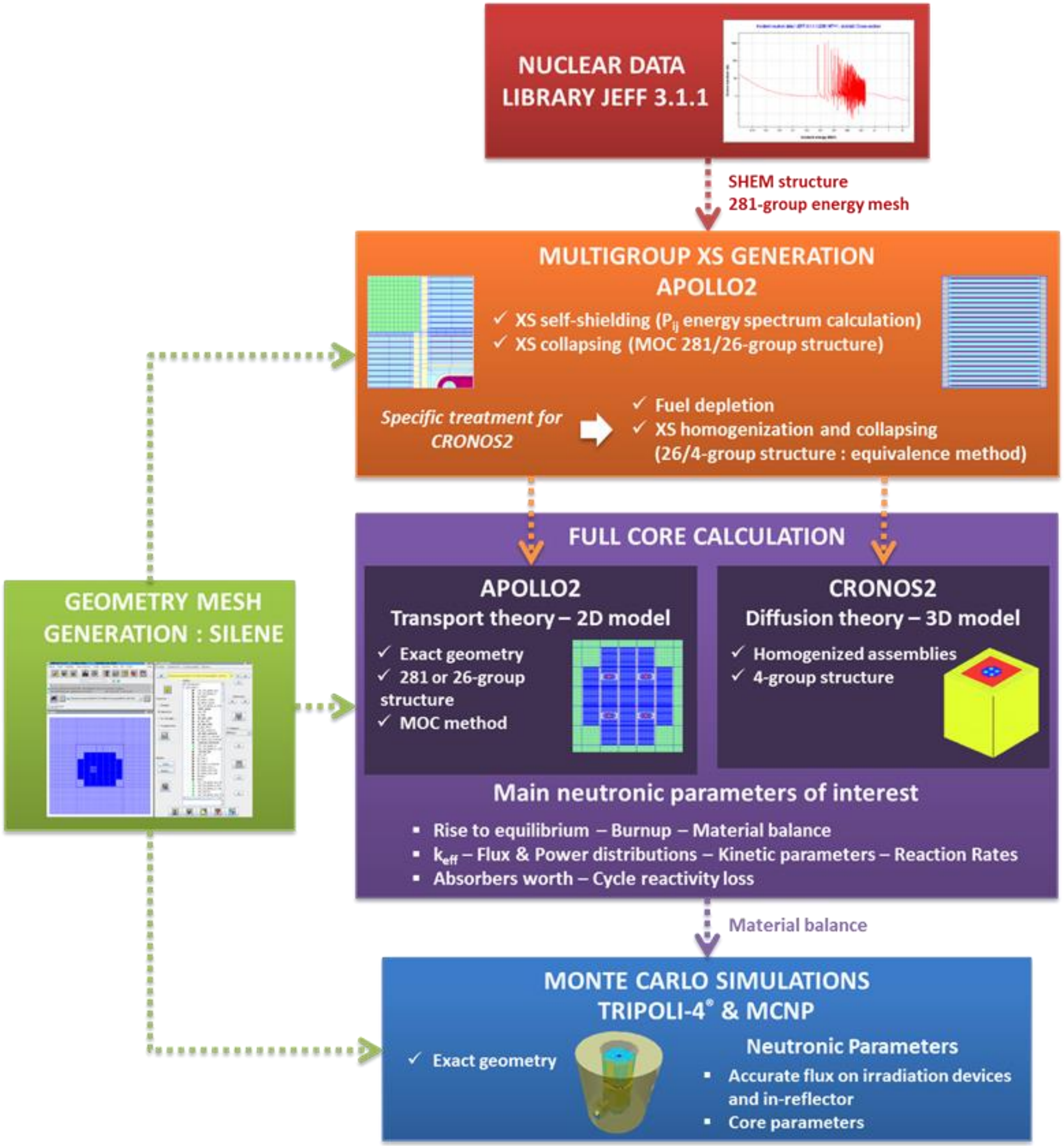
Codes used in this study: COCONEUT scheme



- 1) XS generation
  - Standard FA
  - Supercritical pattern for Absorber FA
- 2) Core calculation
  - 2D model (exact)
  - 3D model

» Validation: fuel pattern and core

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Case study: Dummy core (1/2)

AIMS

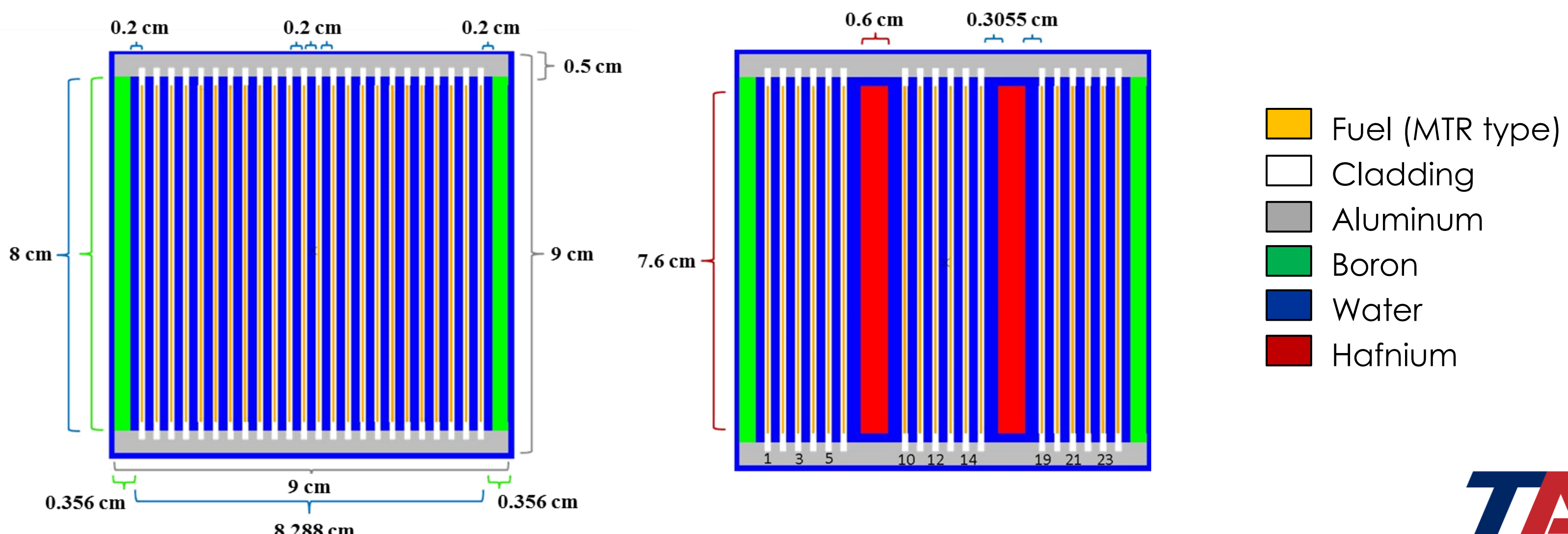
- Comparing methodologies / non-regression tests
- Education and Training object
- Validation and qualification of both calculation and computational techniques
- V&V purposes

DESIGN

- Only describe two assembly types
- Simple to model
- Fuel lattice pattern
- Add components
  - Reflector vessel (heavy water…)
  - Experimental devices
- Add ex-core environment

Depending on the case study

Standard Fuel Assembly (SFA) ***Absorber Fuel Assembly (AFA)***



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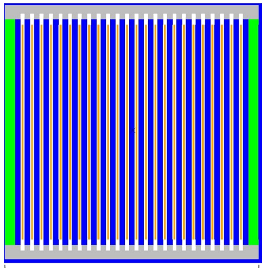
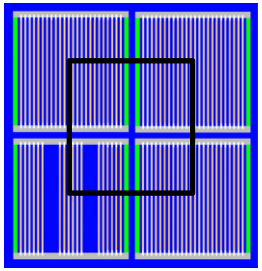
Case study: Dummy core (2/2)

Fuel assembly lattice configuration (2D)

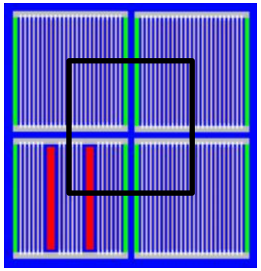
- **3 configurations**
  - Temperature: 300°K
  - Total: **62** depleted medium



SFA



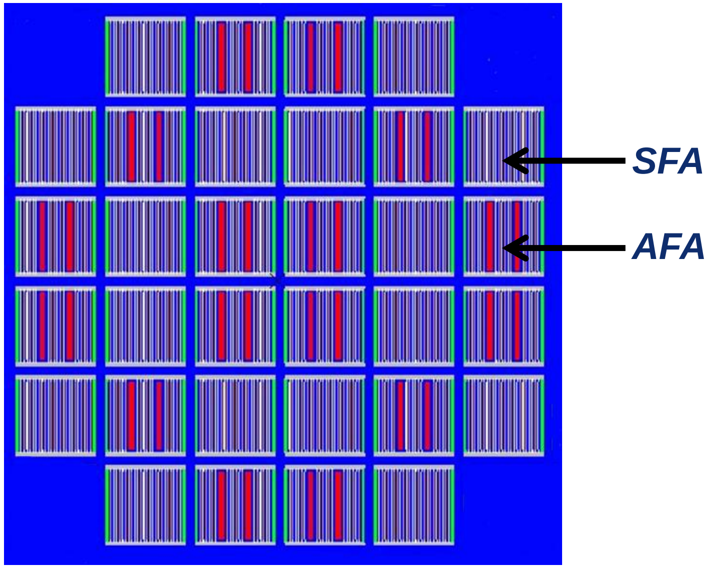
AFA pattern (rod out)

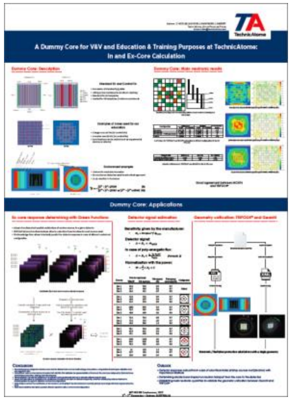


AFA pattern (rod in)

Full core configuration (2D)

- **32 assemblies core**
  - 16 SFA / 16 AFA
  - Reflector / coolant : light water
  - Fuel lattice: 10 cm
  - Total: **672** depleted medium





For more information

Dummy Core for V&V and Education & Training Purposes at TechnicAtome: In and Ex-Core Calculations

S. Nicolas, A. Noguès, L. Manifacier, L. Chabert

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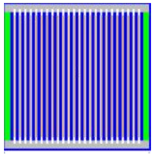
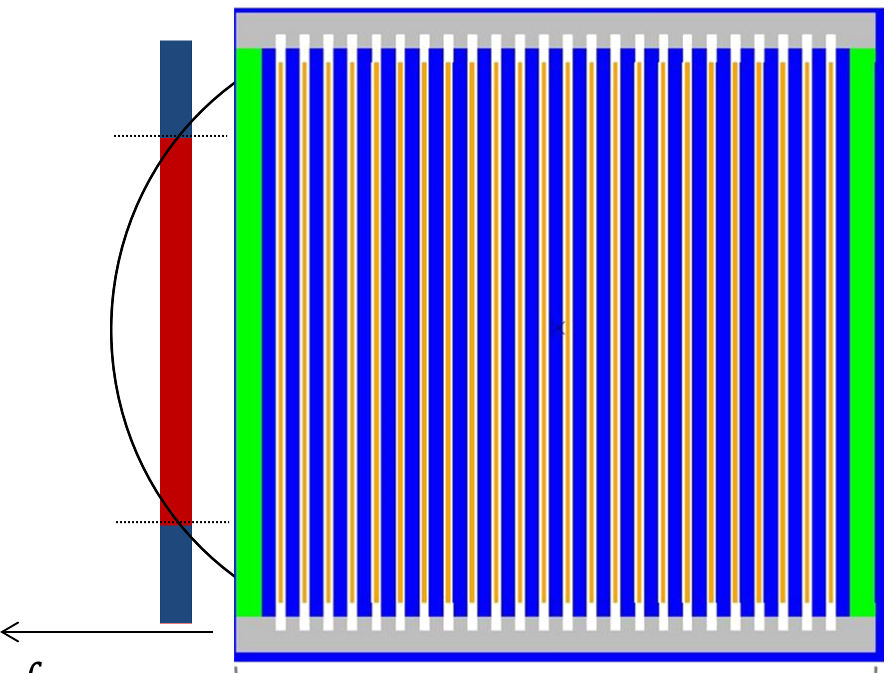
Results and analysis: Standard FA (1/3)



Benchmark considerations

- **The same consistent parameters are taken into account for each code and simulation**
  - Reflecting surface are defined as boundary conditions
  - **50 burnup steps** with a maximum value of **100 GWd/tU**
  - Assembly power of: **1.5625 MW_{th}**
  - **Depletion** in fuel and boron plates
  - Temperature: **300 K**
  - **JEFF-3.1.1** nuclear data library



$$\int_E \varphi_E \, dE$$

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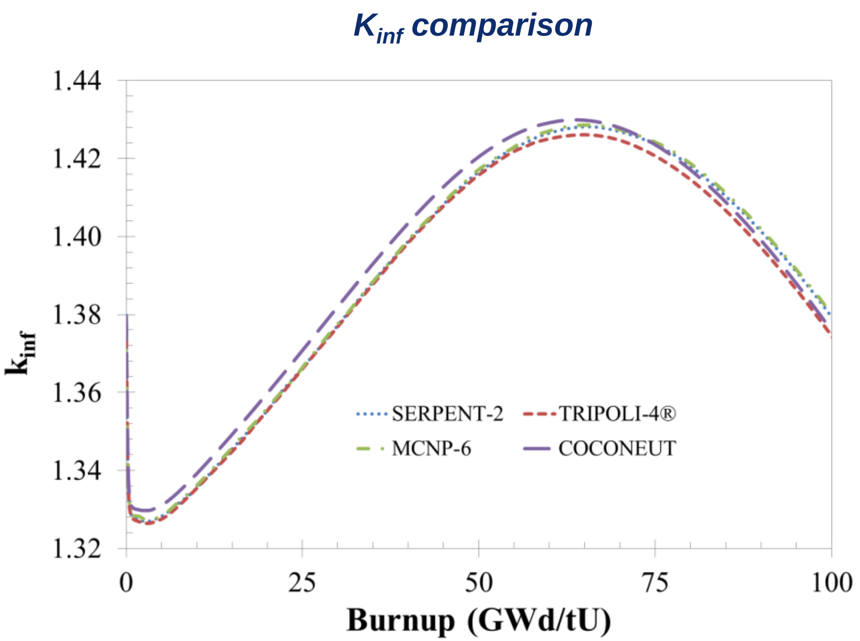
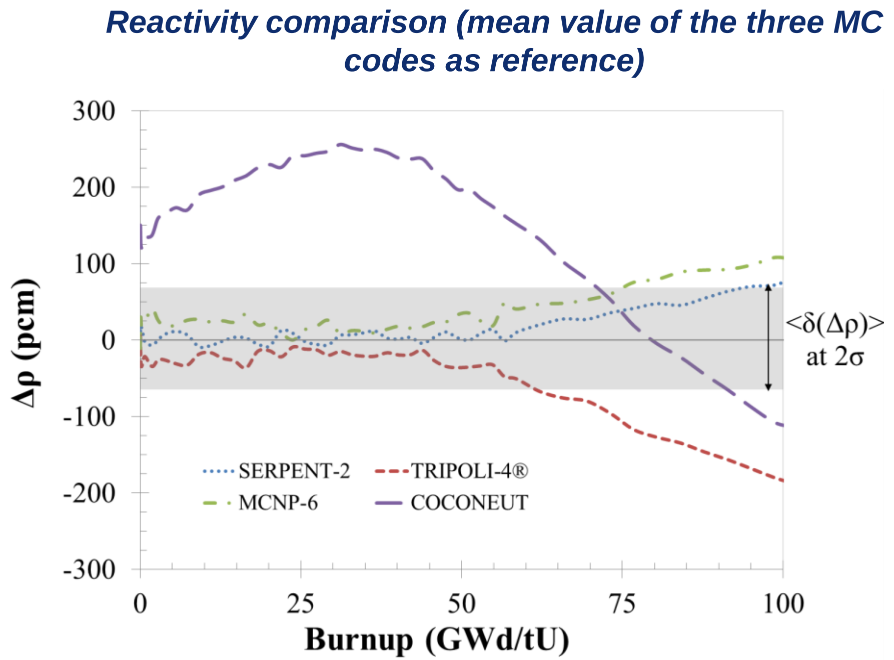
Results and analysis: Standard FA (2/3)

- **Standard FA:** multiplication factor comparison





- **Initial k_{inf}**
  - Monte Carlo codes are all the same within the 1σ range / **+150 pcm** bias for COCONEUT

- **Depletion**:
  - Maximum reactivity peak at ~64 GWd/tU (less than **10%** of [^{10}B] remains)
  - **COCONEUT**: Maximum reactivity discrepancy is found when ^{10}B is half consumed **(+280 pcm)**
  - Bias **relatively constant** between **MCNP and Serpent** even after **60 GWd/tU**
  - Discrepancies become visible after 60 GWd/tU between TRIPOLI4® and other MC codes

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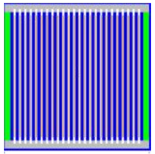
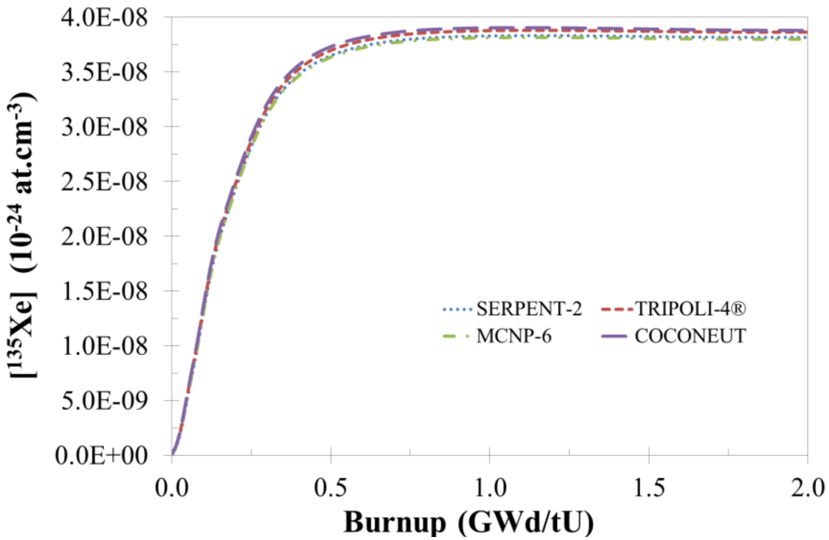
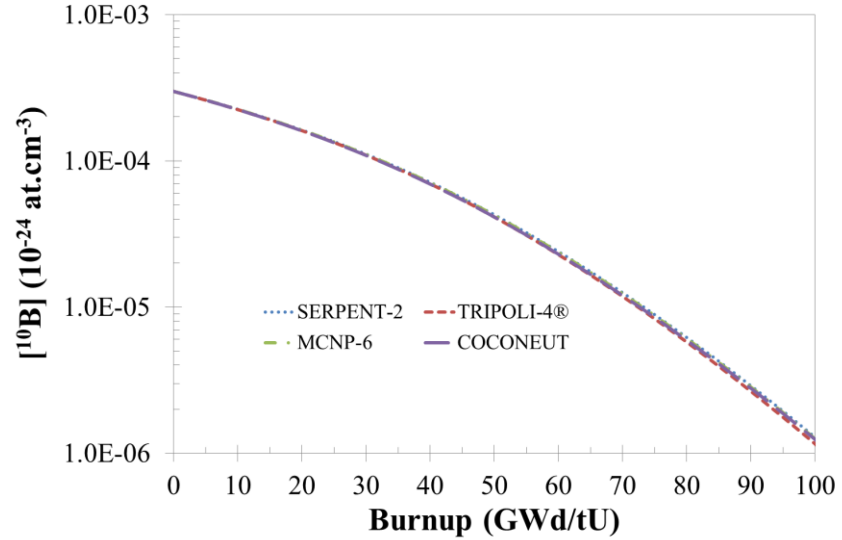
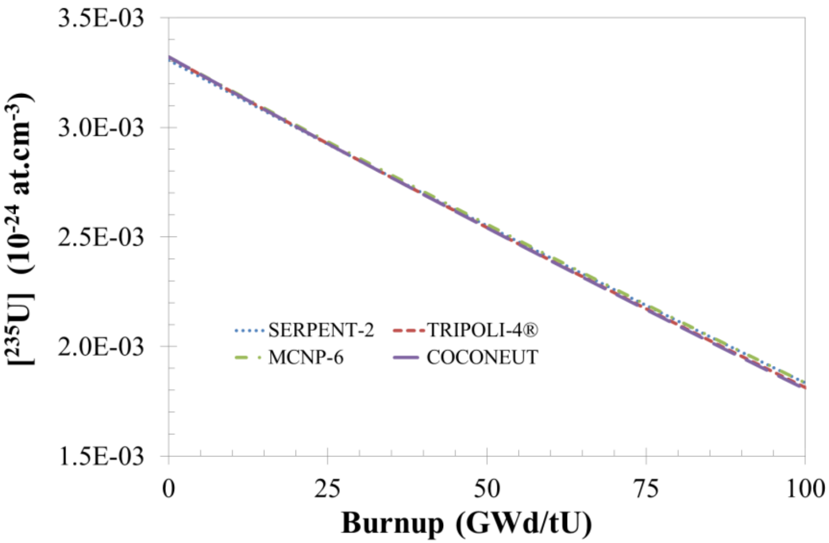


Results and analysis: Standard FA (3/3)

Whole concentrations comparison: MCNP as reference







- **[^{135}Xe]:** Less than **2.5 % (all codes)**
- **[^{10}B]:** at 60GWd/tU (10% ^{10}B remains)
  - MC codes: until **5.0 %**
  - COCONEUT: until **5.5 %**
- **[^{235}U]:** at the end of depletion
  - Serpent : **0.5 %**
  - TRIPOLI4®: **1.0 %**
  - COCONEUT: **1.5 %**

» **Good agreement between the codes**

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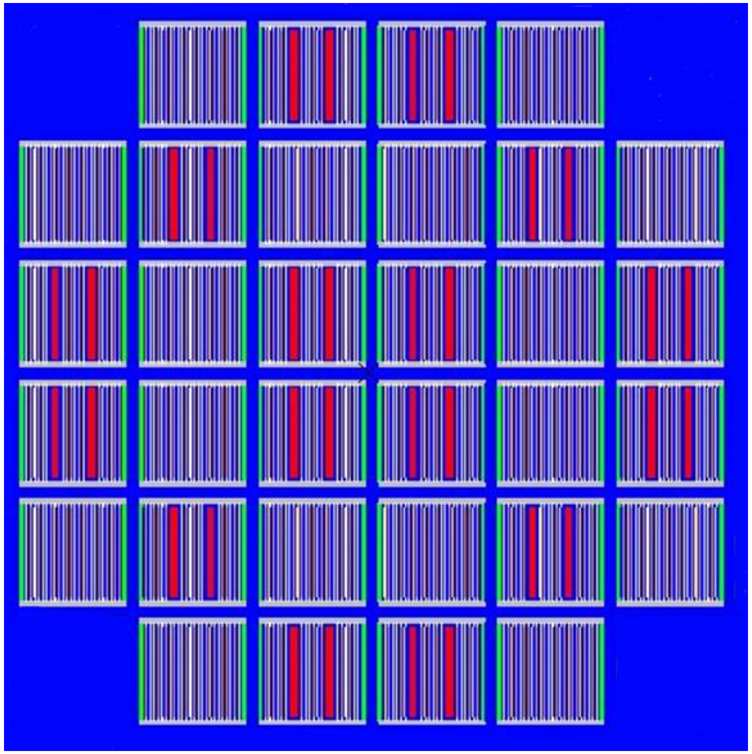
Results and analysis: 2D full core (1/3)



Benchmark considerations

- **The same consistent parameters are taken into account for each code and simulation**
  - Reflecting surface on Z axis
  - **50 burnup steps** with a maximum value of **80 GWd/tU**
  - Core power of: **50 MW_{th}**
  - Temperature: **300 K**
  - **JEFF-3.1.1** nuclear data library

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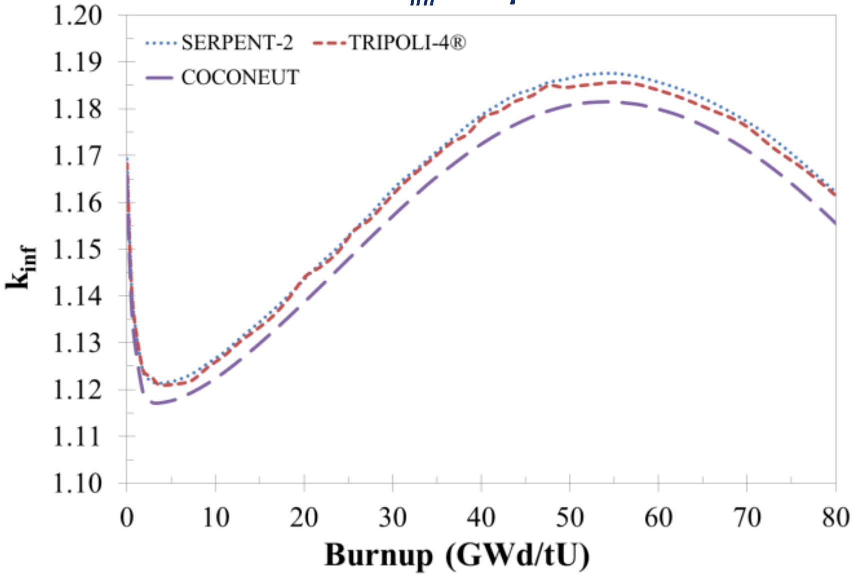
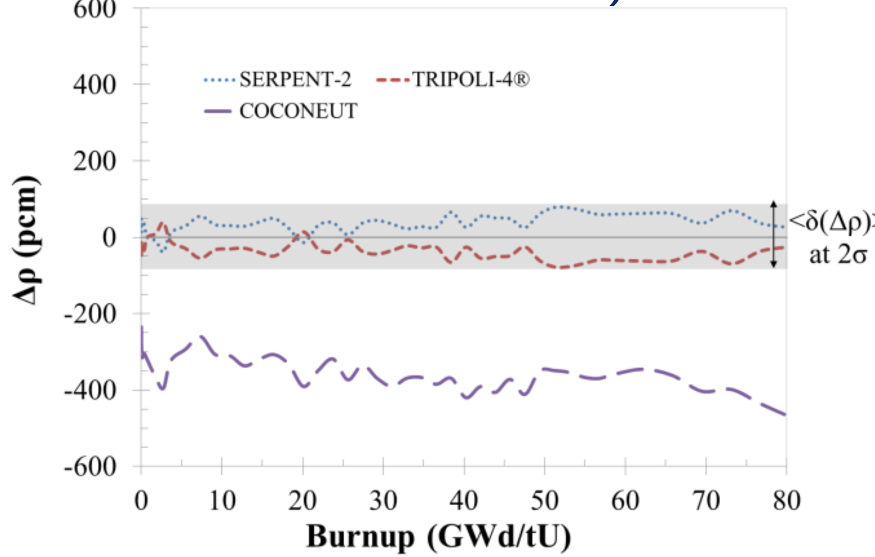
Results and analysis: 2D full core (2/3)

- **Core calculation:** multiplication factor comparison

K_{inf} comparison



Reactivity comparison (mean value of MC codes as reference)



- **MC codes**
  - Discrepancy between **-110 pcm** and **+78 pcm**
  - Simulation time: Serpent faster than TRIPOLI4®

- **COCONEUT vs mean of MC codes**
  - Fresh fuel **: -235 pcm**
  - **Constant bias** during the depletion: (between **-395 pcm** and **-235 pcm**)
  - **6 factor formula** has to be calculated during the depletion to determine compensations

Slight discrepancy between the codes.

Next step:

3D core calculation and critical configurations research during the depletion.

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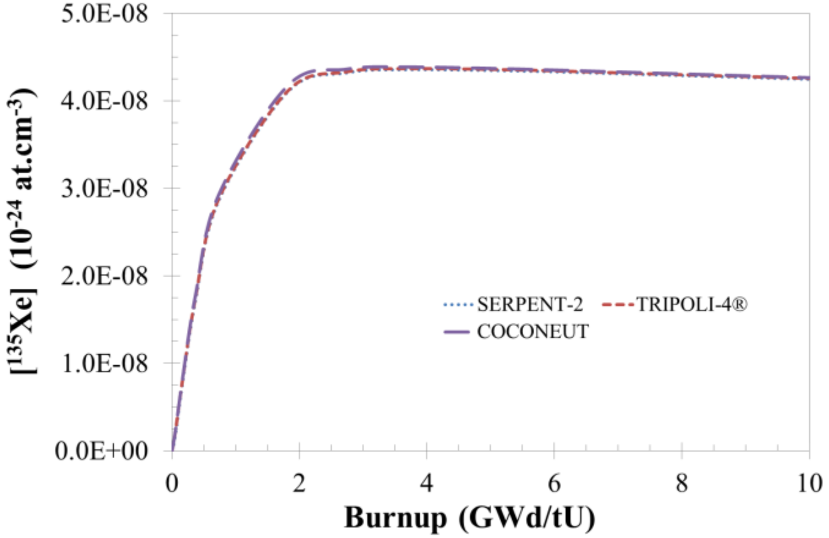
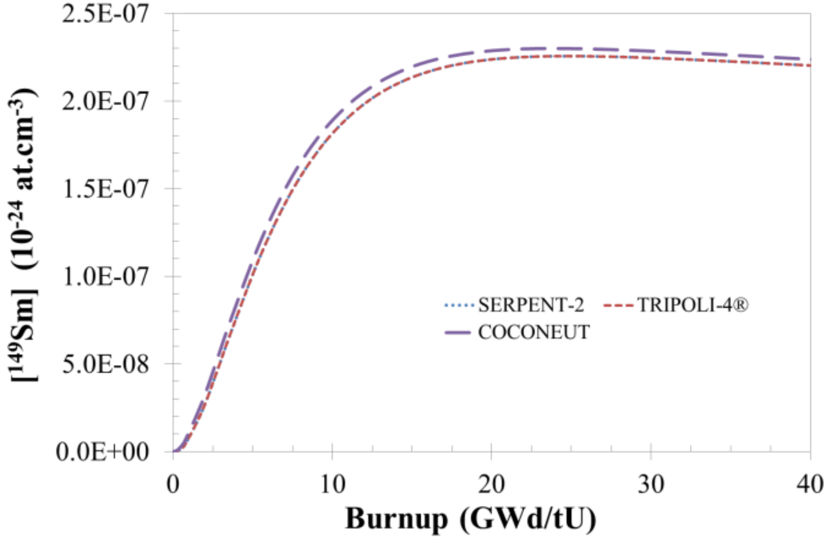
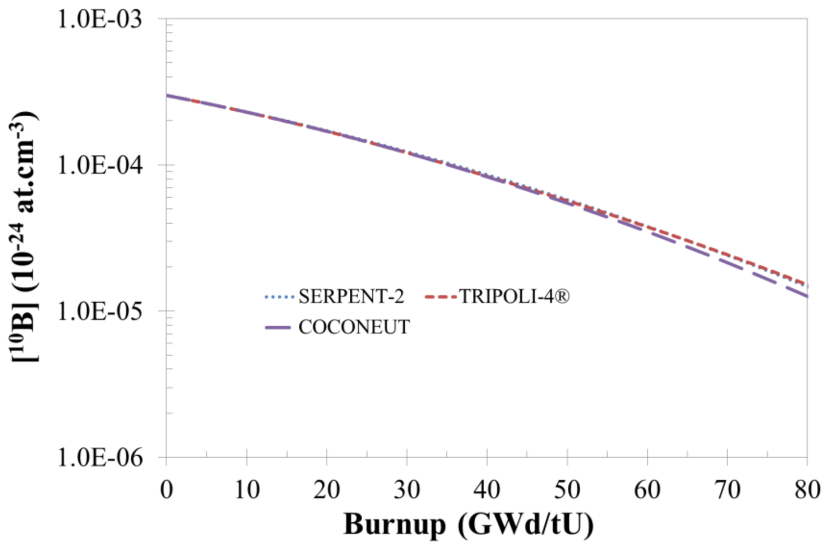
Results and analysis: 2D full core (3/3)

Whole concentrations comparison







- **[^{135}Xe] discrepancies**
  - MC codes: less **0.6 %**
  - COCONEUT vs MC: Maximum of **1.6 %**
- **[^{149}Sm]**
  - MC codes: less **0.5 %**
  - COCONEUT vs MC: **4.0 %** during the first steps
- **[^{10}B]**
  - MC codes: Maximum of **2.5 %**
  - COCONEUT vs MC: Close to **4.5 %**

Good agreement between the codes

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Conclusions

- **Good agreements** between MC codes for 2D assembly and 2D full core
  - Serpent faster than other MC codes
  - Quantify the differences between normalization methods
- **Small discrepancy** between COCONEUT and MC codes
  - **Constant bias around -300 pcm** during the entire depletion for 2D full core
- **Dummy core is well suitable for core calculation studies and gives a better understanding of design purpose**

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Outlooks

- **Optimize MC coupled depletion codes**
  - Adapt time mesh with the flux gradient
  - Test of refueling algorithm proposed by Serpent and TRIPOLI4®
  - Changing depletion mesh step by step during the depletion (3D calculation)
  - Perform uncertainties propagation (compositions / flux)
  - Comparison with experimental core data

- **COCONEUT**
  - Estimate compensations with 6 factors formula
  - 281 groups calculation
  - Perform self shielding during the depletion

- **Dummy core:** future works on new methods for neutron propagation from core to ex-core system

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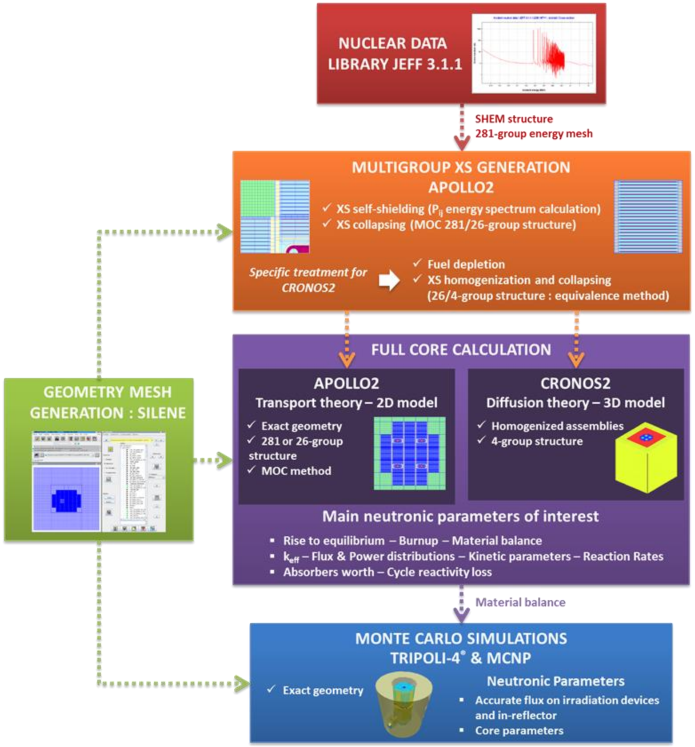
Depletion calculation codes and benchmark considerations (1/2)



- **Neutronic analysis :**
  - Rise to equilibrium / Material balance
  - Flux / power distribution, Absorbers worth

- **Mainly used for export fuel assembly burnup compositions to MC codes**

- **Principal model consideration**
  - 1) XS calculation
    - XS collapsing: MOC calculation 281 → 26 groups
    - Self-shielding performed at the initial step
    - AFA is treated as a supecritical pattern representative of neutronic spectrum in the AFA.
  - 2) Core calculation
    - Transport theory (26-group) - 2D exact → APOLLO2
    - Diffusion theory (4-group) - 3D model → CRONOS2

- **Currently undergoing a large V&V process**
  - Part of this process: estimate the impact of main assumptions on depleted composition with MC codes

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Results and analysis: Standard FA (3/4)

COCONEUT : discrepancy analysis

Relative concentration comparison (%) between COCONEUT and mean value of MC codes

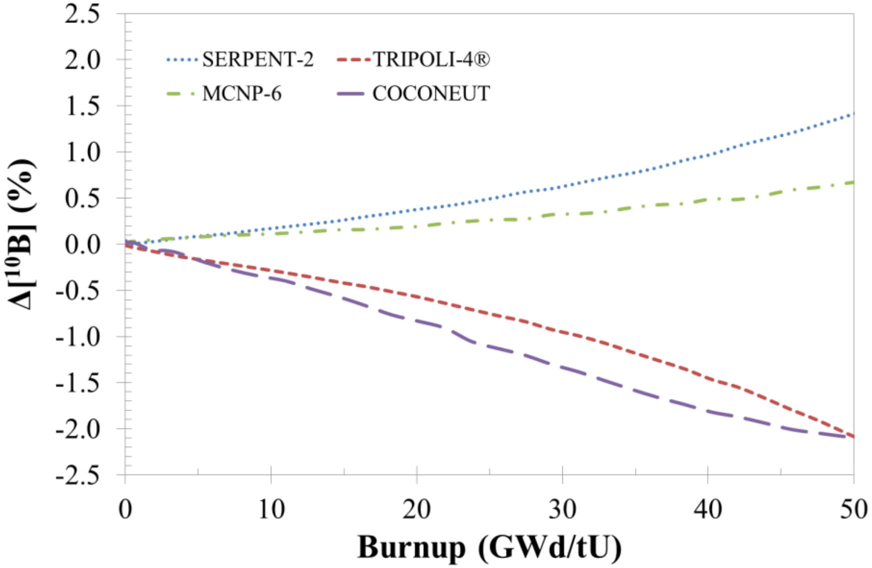
Burnup (GWd/tU)	20	40	60	80	100
$\Delta[^{235}U]$	-0.12	-0.27	-0.46	-0.69	-1.03
$\Delta[^{239}Pu]$	2.42	1.89	1.33	0.82	0.21
$\Delta[^{148}Nd]$	1.95	2.07	2.12	2.14	2.15
$\Delta[^{149}Sm]$	1.36	1.13	1.59	2.03	2.48

Main concentrations

- Less than 3% discrepancy
- Constant bias on ^{148}Nd (burnup indicator)

[^{10}B]

- Burned faster with TRIPOLI4® and COCONEUT
- » depletion chain / power normalization ?



COCONEUT Outlook

- Depletion with 281 group
- Self shielding during depletion (several steps)

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