SERPENT
USER GROUP MEETING

FRM II
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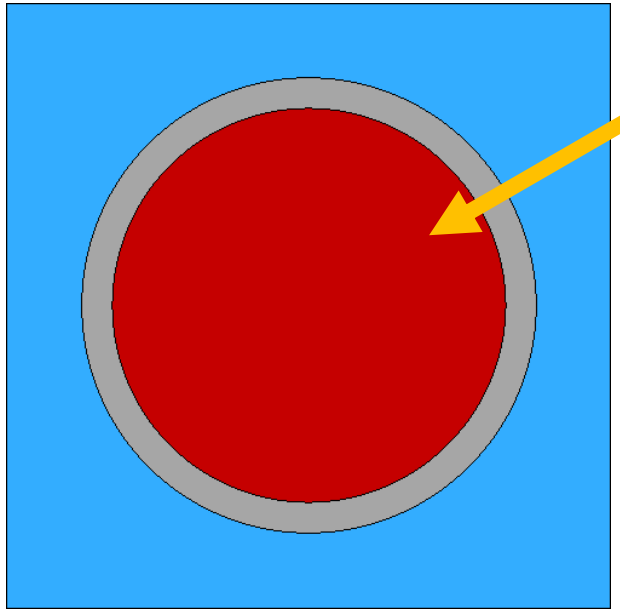
Code-to-code depletion benchmark to test the novel SERPENT2 capabilities while utilizing different energy deposition models

Background

- In the past, it was customary to assume local energy deposition in the fuel
  - ✓ Or, perhaps many models still assume this?



ALL energy is there! → *A unique Q-value to account for all possible terms!*

Fortunately….

SERPENT 2.1.31 comes with new models for energy deposition!

Background

- SERPENT2 energy deposition (edep) models have been described before

Tuominen R. et. al. ***"New energy deposition treatment in the SERPENT2 Monte Carlo trasnport code",*** Annals of Nuclear Energy (129), 2019.

A quick glance…

- ***EDEP MODE 0 → Original (and default) model***
  - ✓ So-called "local energy deposition" treatment
    - One lumped recoverable energy Q-value
- ***EDEP MODE 1 → Similar to EDEPMODE 0***
  - ✓ Local energy deposition treatment but with Q-values taken by MF=1 MT=458 contained in NDL's (it is encouraged to add a capture contribution)
- ***EDEP MODE 2 → Based on pre-computed NJOY KERMA factors***
  - ✓ Photon energy is deposited locally at reaction sites
- ***EDEP MODE 3 → Coupled neutron-photon transport calculation***
  - ✓ Best estimate way of calculating energy deposition

Background

- ***EDEP MODE 2 → Based on pre-computed NJOY KERMA factors***
  - ✓ They subtract from the NJOY total reaction KERMA the correspondent fission factor, and calculate this last one separately

$$M901_i(E) \equiv N901_i(E) - N918_i(E) + [E_{i,fr} + E_{i,\beta} + E_{i,\gamma,p} + E_{i,\gamma,d}]\,\sigma_{i,f}(E)$$

- E_{fr} - kinetic energy of fission fragments
- $E_{n,p}$ - energy of prompt fission neutrons
- $E_{n,d}$ - energy of delayed fission neutrons
- $E_{\gamma,p}$ - energy of prompt fission photons
- $E_{\gamma,d}$ - energy of delayed fission photons
- E_{β} - energy of released β particles

  - ✓ NJOY KERMA fission do not account for delayed fission gammas and betas
    - ✓ Which seems to be a significant contribution of fission energy release
  - ✓ Need to correct criticality source simulations and energy distribution of delayed gamma

Background

- EDEP models are very important while depleting at constant power
  - ✓ The power of the depleting material dictates the real flux level at which the RR's will take place to solve Bateman

If pure energy local deposition is assumed

↓

Then power is overestimated in the material → ***Overestimated normalization factor***

↓

Overestimated fission RR

Background

- There are other codes that nowadays treat as well different EDEP models
  - ✓ OpenMC!
    - Monte Carlo based code
      - Open source
      - Offers different models (like SERPENT) (besides just doing criticality calculations)
        - Cross-section homogenization
        - Depletion (e.g. CRAM)
        - Multi-group Monte Carlo
    - Neutron and photon transport are programmed in C++
      - Pre- and post-processing are carried out by a PYTHON wrapper
        - As well as the depletion module!

Objectives

- The work presented here has two main objectives:

1. To evaluate the differences that arise during a depletion calculation (at constant power) while employing the SERPENT2 edep models 0, 2 and 3 for a single pin
   - In other words, how do the eigenvalue and isotopic inventory behave, as a function of burnup, using different edep models

2. To benchmark SERPENT2 and OpenMC while depleting using different edep models
   - This type of exersices are fundamental to validate codes while using same data, same models and same type of solution

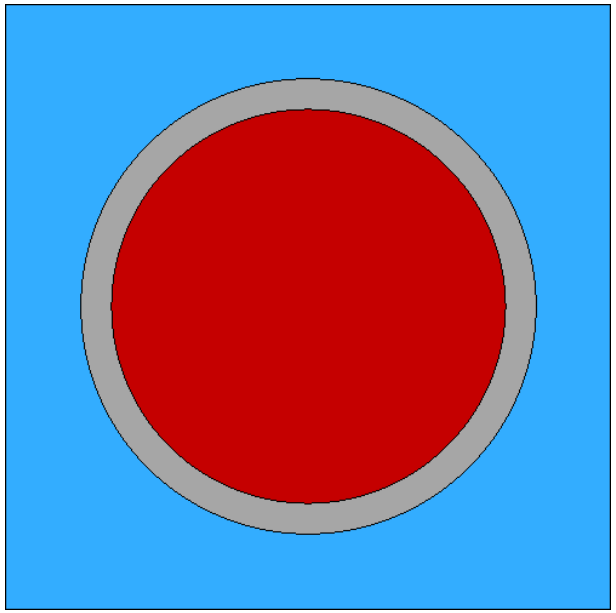
Test case

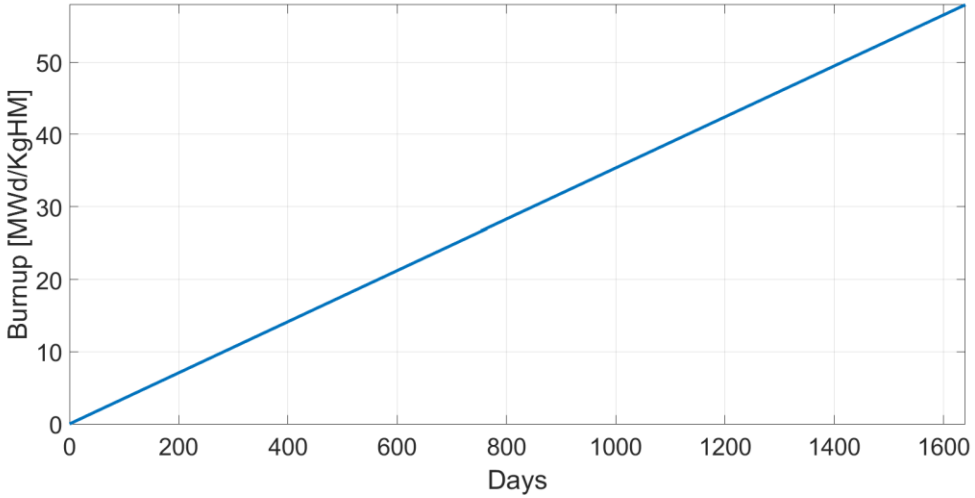
Simple pin! → PWR case

- Let's start simple! (fully reflective boundary conditions!)

UO_2 rods

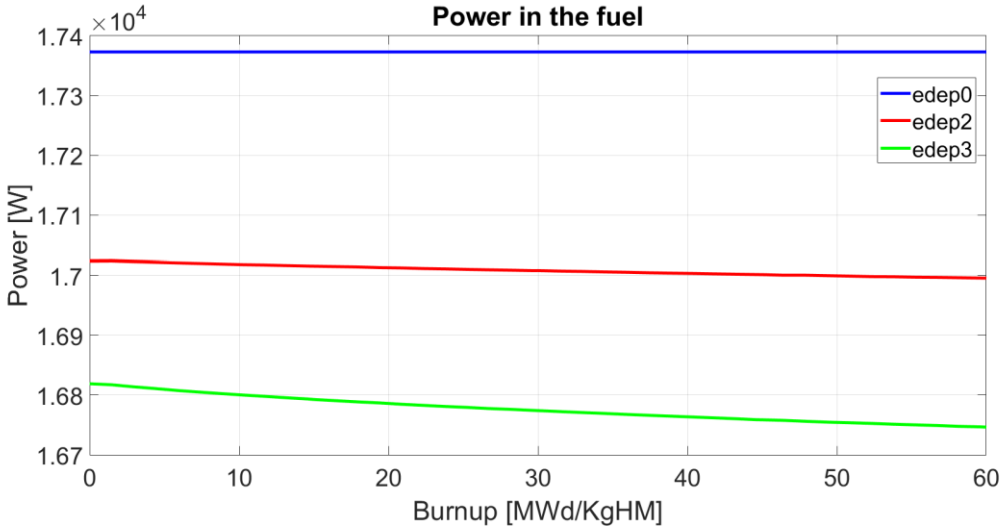
4.95% wt

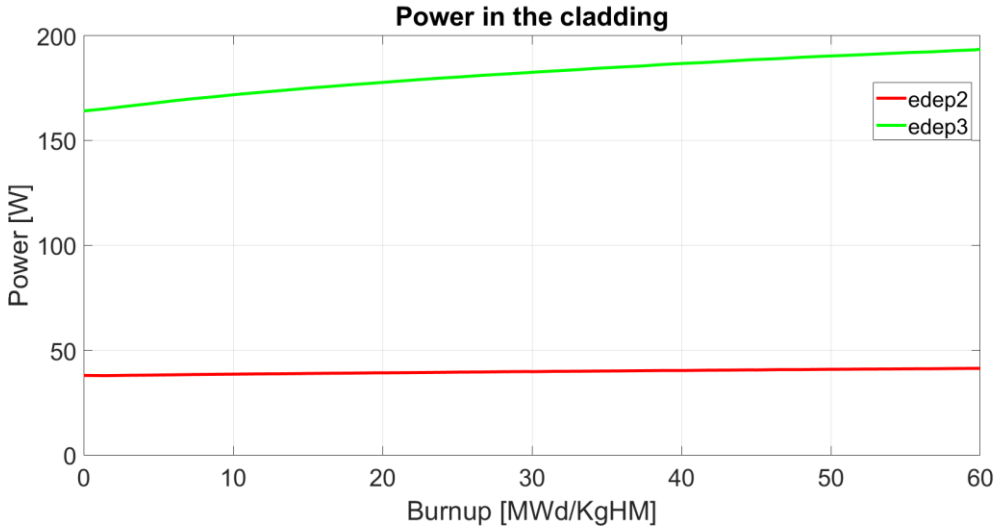


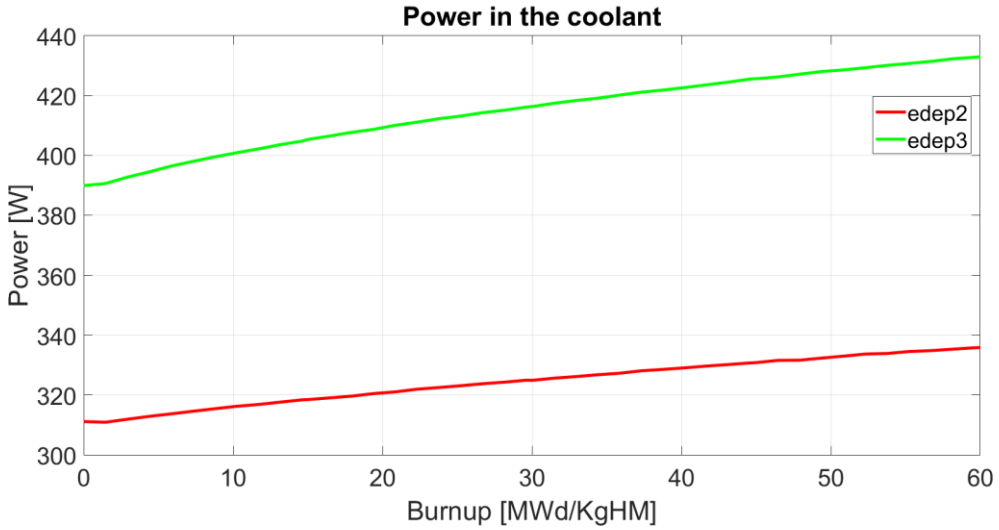


- 100,000 particle/cycle
  - ✓ 250 active cycles
  - ✓ 50 discarded cycles
- Card pcc set to zero (e.g. no P/C)
- Depletion performed in steps of 40 days
- Discharged BU of 58 MWd/kgU @ 1640 days

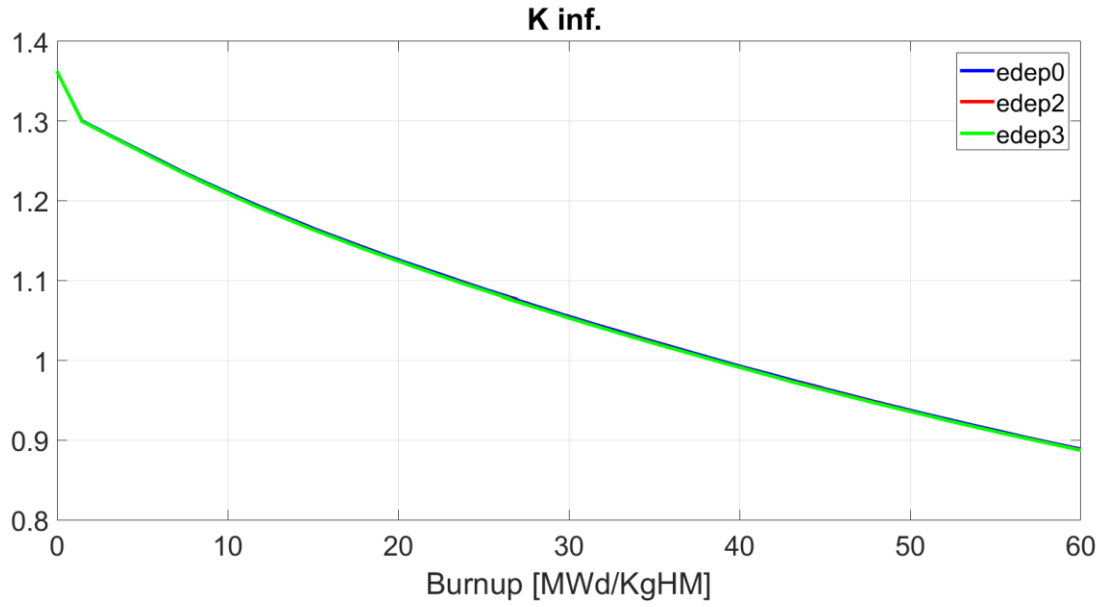
SERPENT2 – Material power distribution during depletion EDEP modes



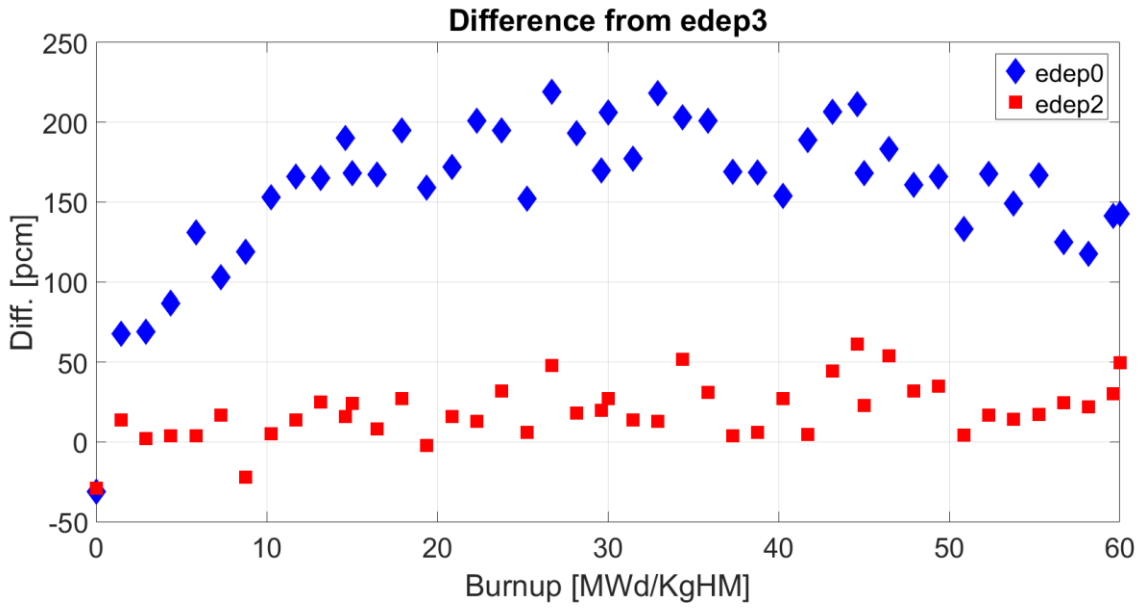




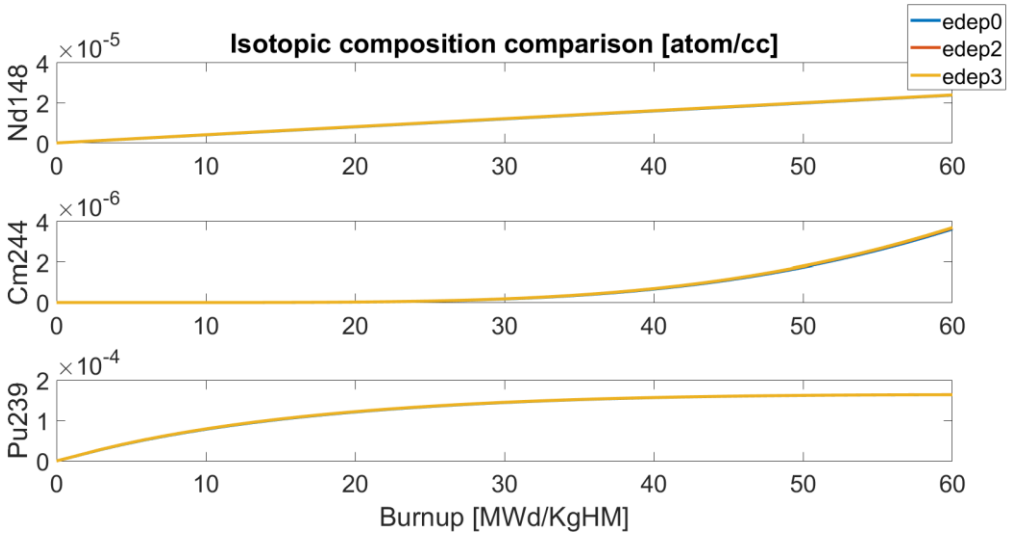
SERPENT2 – Eigenvalue comparison during depletion EDEP modes

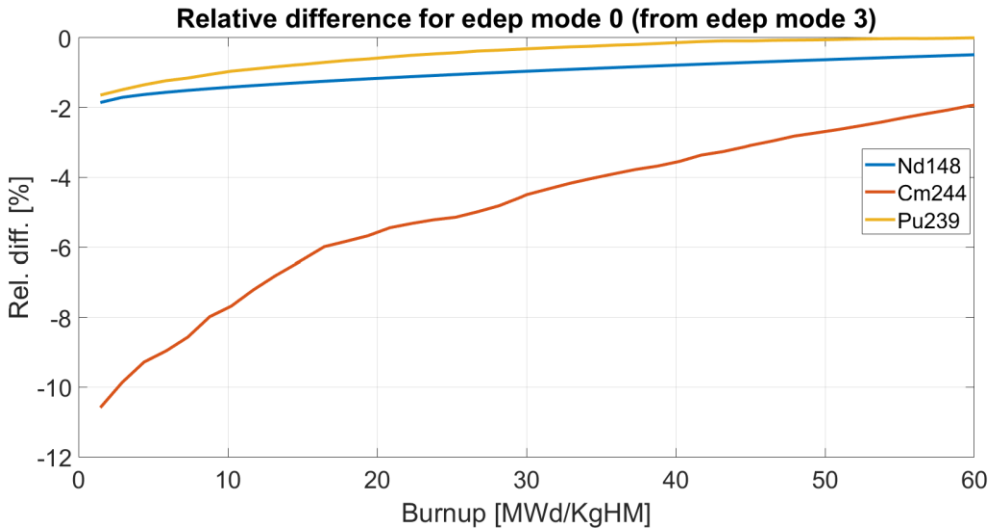


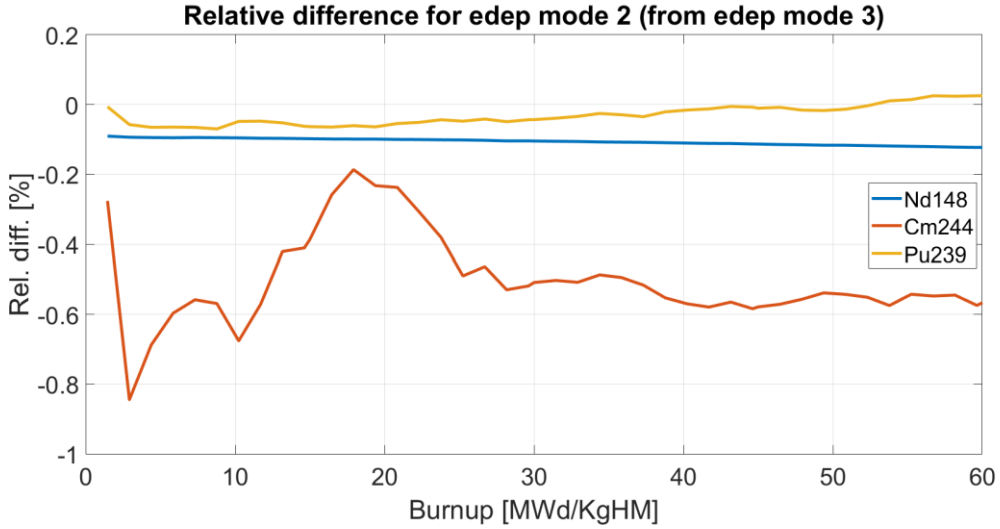
Max. statistical uncertainty during the burnup cycle of *K*-inf: 11 [pcm]



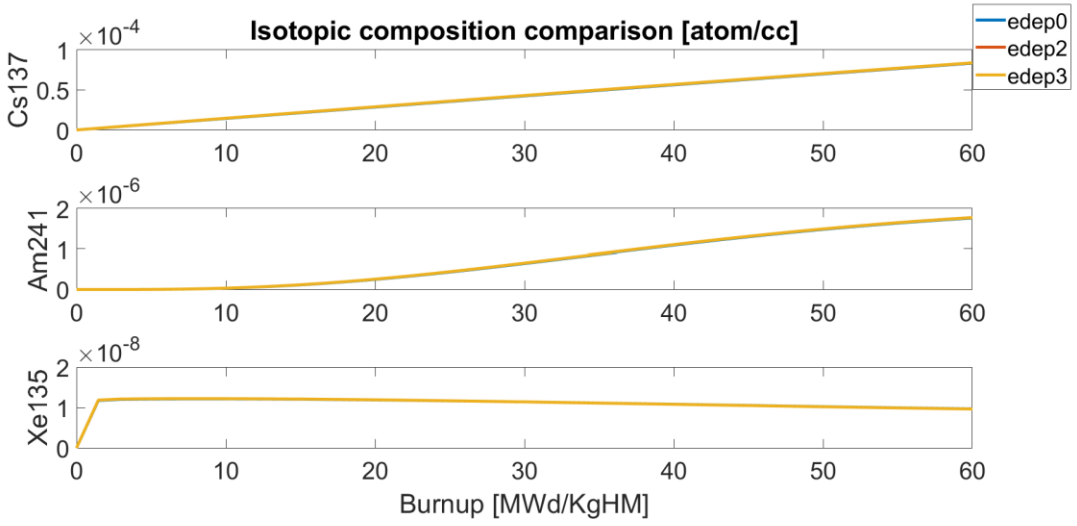
SERPENT2 – Inventory comparison during depletion EDEP modes

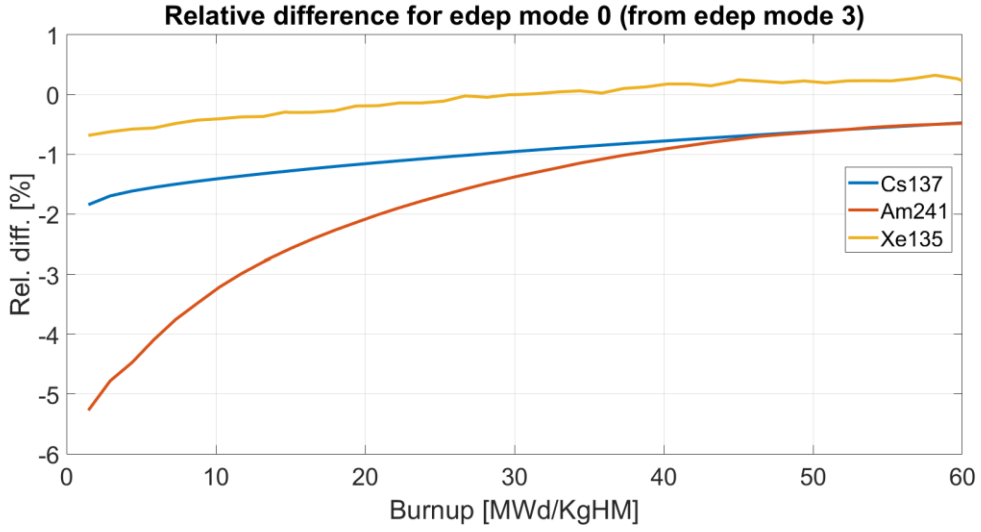


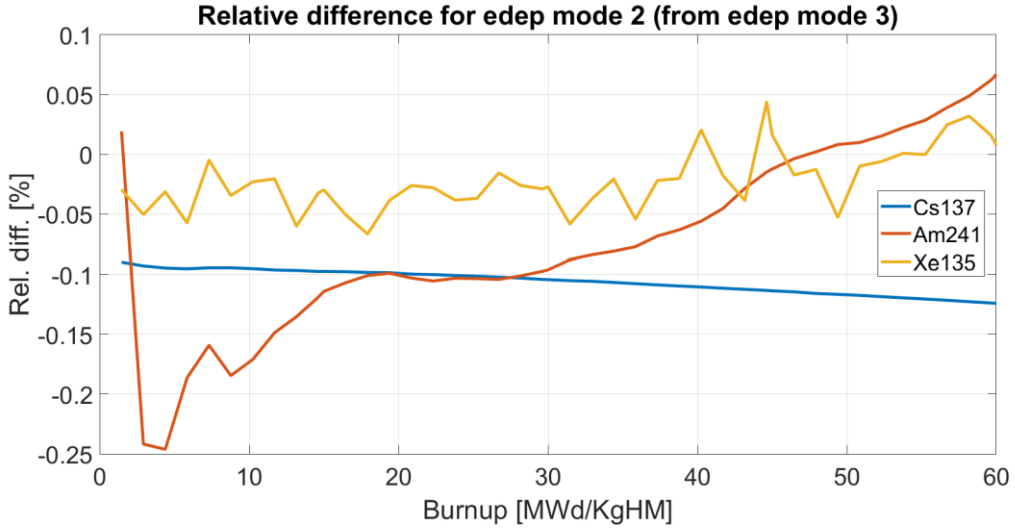




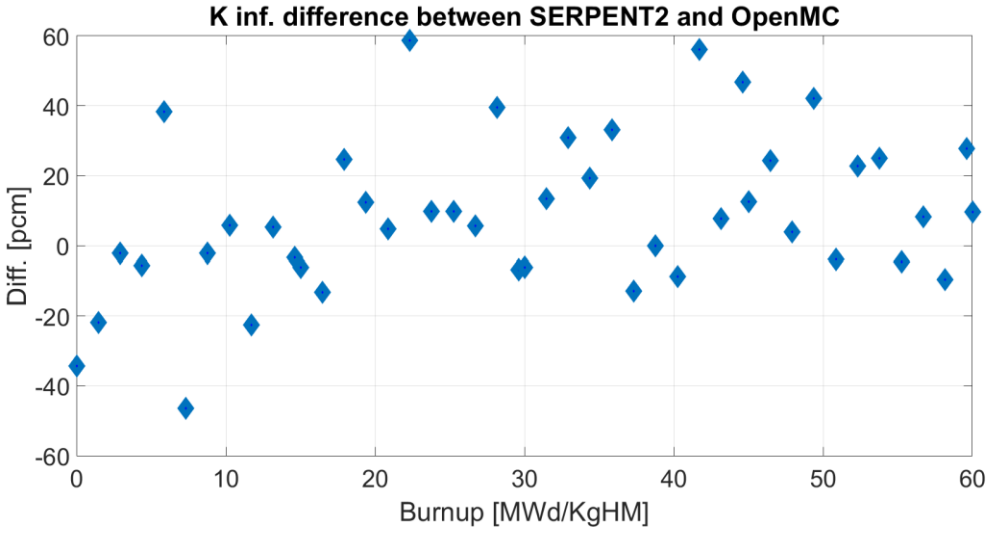
SERPENT2 – Inventory comparison during depletion (2) EDEP modes

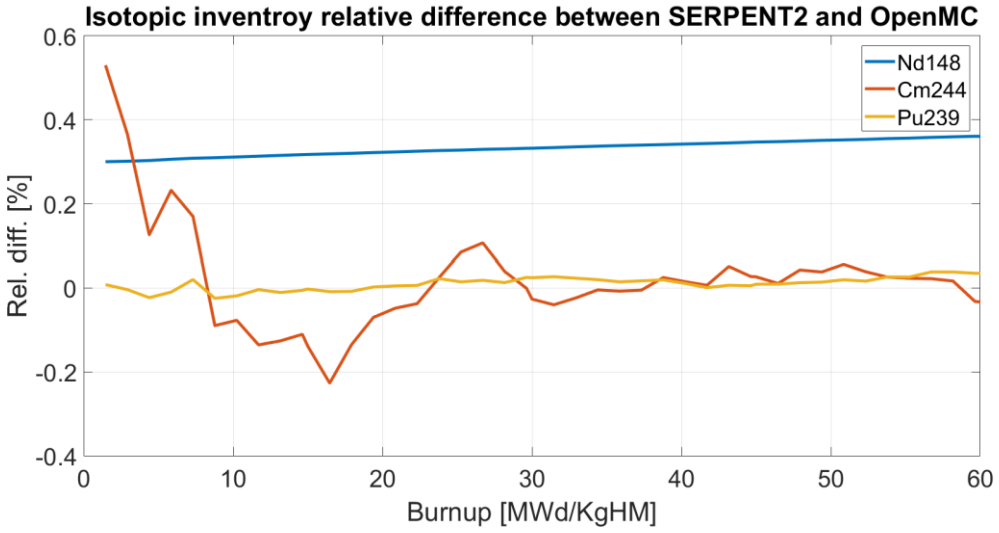


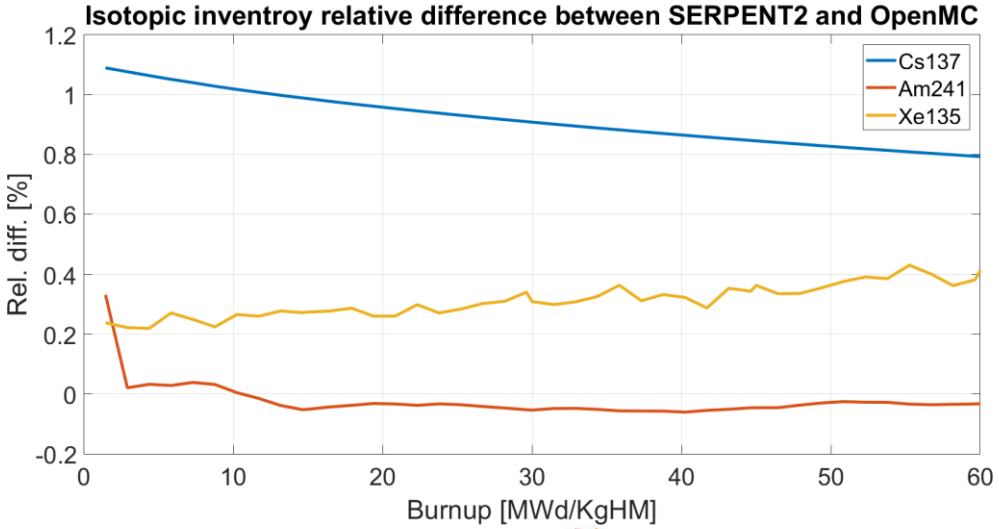




SERPENT2 & OpenMC – Comparison
EDEP mode 0

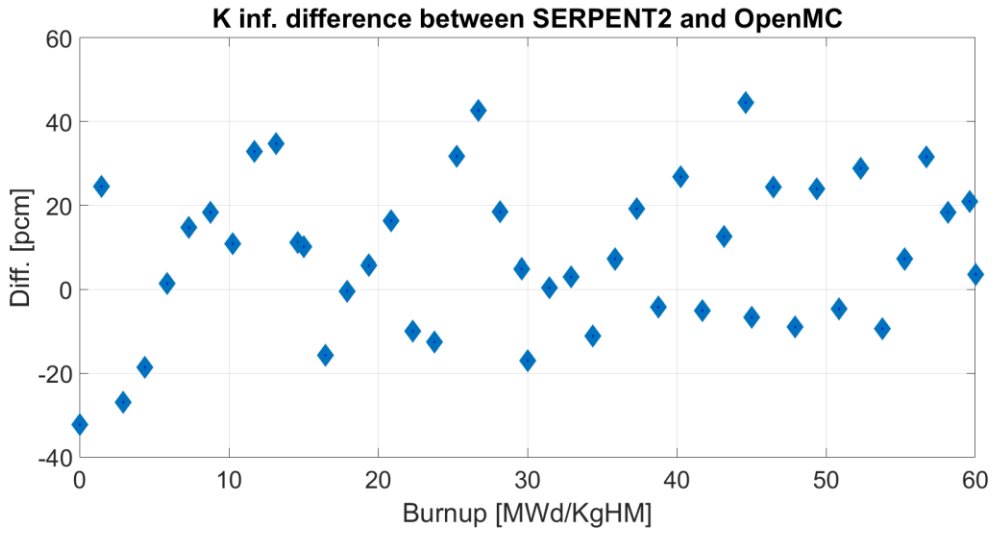


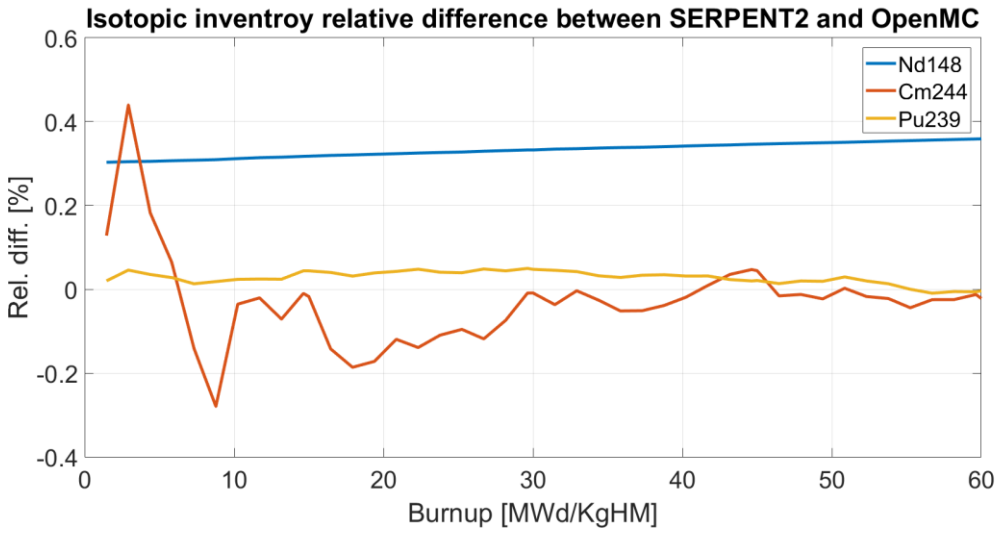


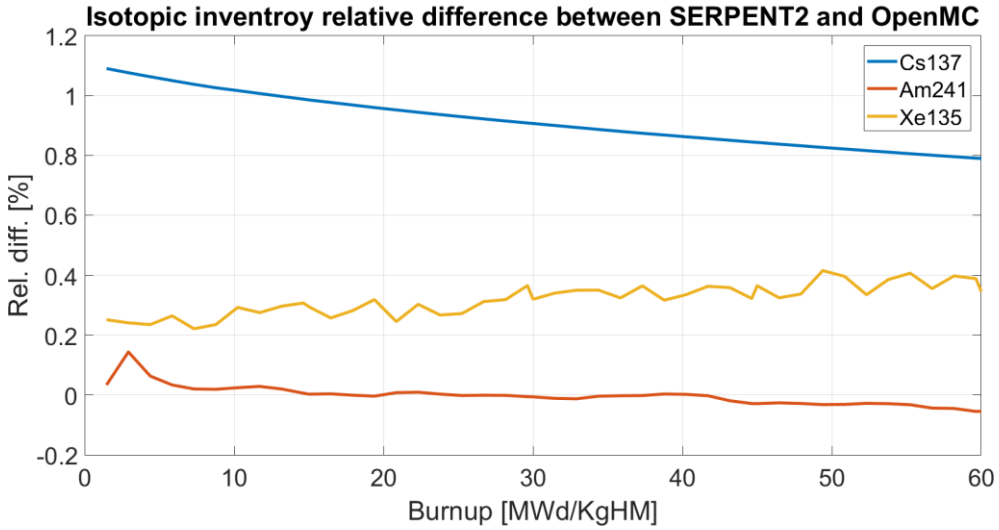


Code	Max. statistical uncertainty (during burnup cycle) [pcm]
SERPENT2	11
OpenMC	18

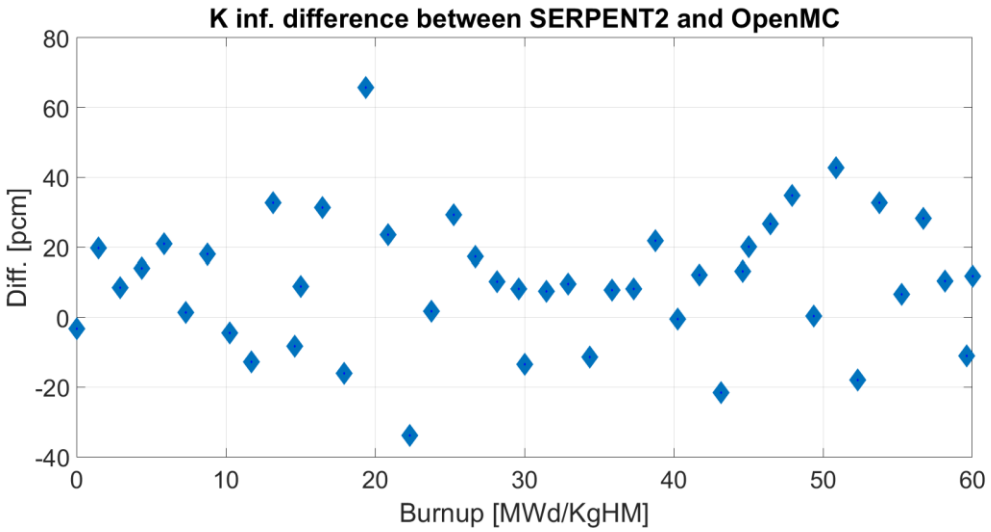
SERPENT2 & OpenMC – Comparison EDEP mode 2

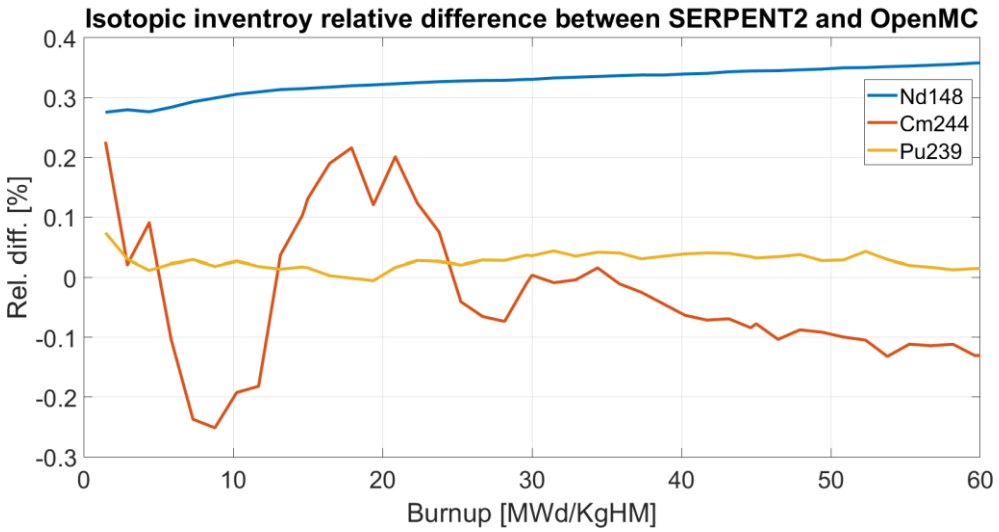


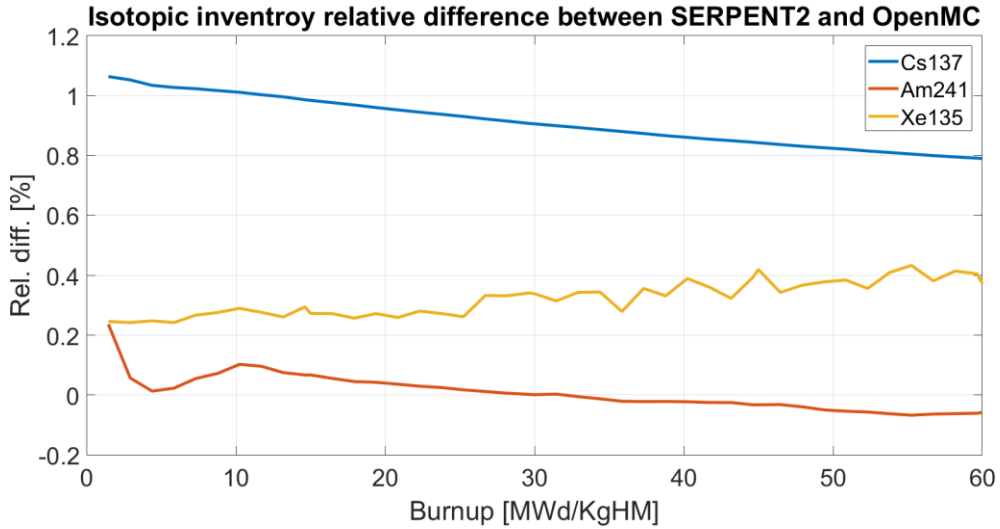




SERPENT2 & OpenMC – Comparison
EDEP mode 3







Conclusions

I think the EDEP mode chosen type has definetely an effect while depleting!

- Checking and trying such models in different test cases for depletion is fundamental to trust more and more these codes

- This work was inspired by all the previous nice (and long!) talks about predictions of decay heat (both at SCK•CEN and outside)
  - ✓ How can we actually make a fair benchmark for code V&V?
    - Input parameters (XS's, energy factors, geometry….)
    - Transport solvers
    - Depletion solvers (i.e. solving Bateman)
    - Nuclear data (i.e. branching ratios, *Q*-values, decay chains, neutron and photo induced reactions, etc.)

From this tiny point in the world,

Thank you for listening!!!

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