Impact of Fuel Type and Discharge Burnup on Spent Fuel Properties

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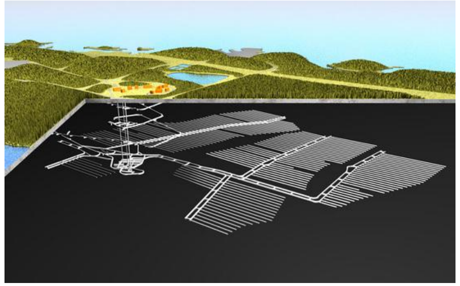
Motivation and context 1/2

- Knowledge of spent nuclear fuel (SNF) properties is important in SNF management, e.g.:
  - Decay heat and reactivity determine the repository space needed for SNF disposal.
  - Nuclide inventories are needed for safe handling of SNF and estimates of dose released to the biosphere.
- Accurate knowledge of SNF properties (source term) and associated uncertainties yield savings in repository space and enhanced safety.



Source: Posiva Oy

Motivation and context 2/2

- This work is part of a larger effort to establish methods to computationally determine the SNF source term by studying
  - computational uncertainties related to the determination of the spent fuel source term and
  - **effect of different fuel types and burnups on the source term.**
- Calculations are done with the Monte Carlo code Serpent 2 [1].
- The work is carried out in the KYT2022 project KÄRÄHDE.

Source: Posiva Oy

[1] Leppänen, J., et al. (2015) "The Serpent Monte Carlo code: Status, development and applications in 2013," Ann. Nucl. Energy, 82 (2015) 142-150.

Background

- Similar calculations performed at VTT in 2005 [2] with SCALE-5 package
    - VVER-440: 3.7 and 4.0 wt-% U-235 enrichment
    - BWR: 3.8 and 4.2 wt-% U-235 (0, 40 and 80 % void fraction)
    - EPR: 3.6 and 4.0 wt-% U-235
- Decay heat, activity, photon source strength, etc. for 40, 50 and 60 MWd/kgU discharge burnup
- Decay heat production for 20, 30, 40, 50 and 60 MWd/kgU discharge burnup

[2] Anttila, M. “Radioactive Characteristics of the Spent Fuel of the Finnish Nuclear Power Plants”, Posiva Working Report 2005-71

New round of calculations in KYT2022/KÄRÄHDE

- New codes (Serpent) & nuclear data
- Additional fuel types

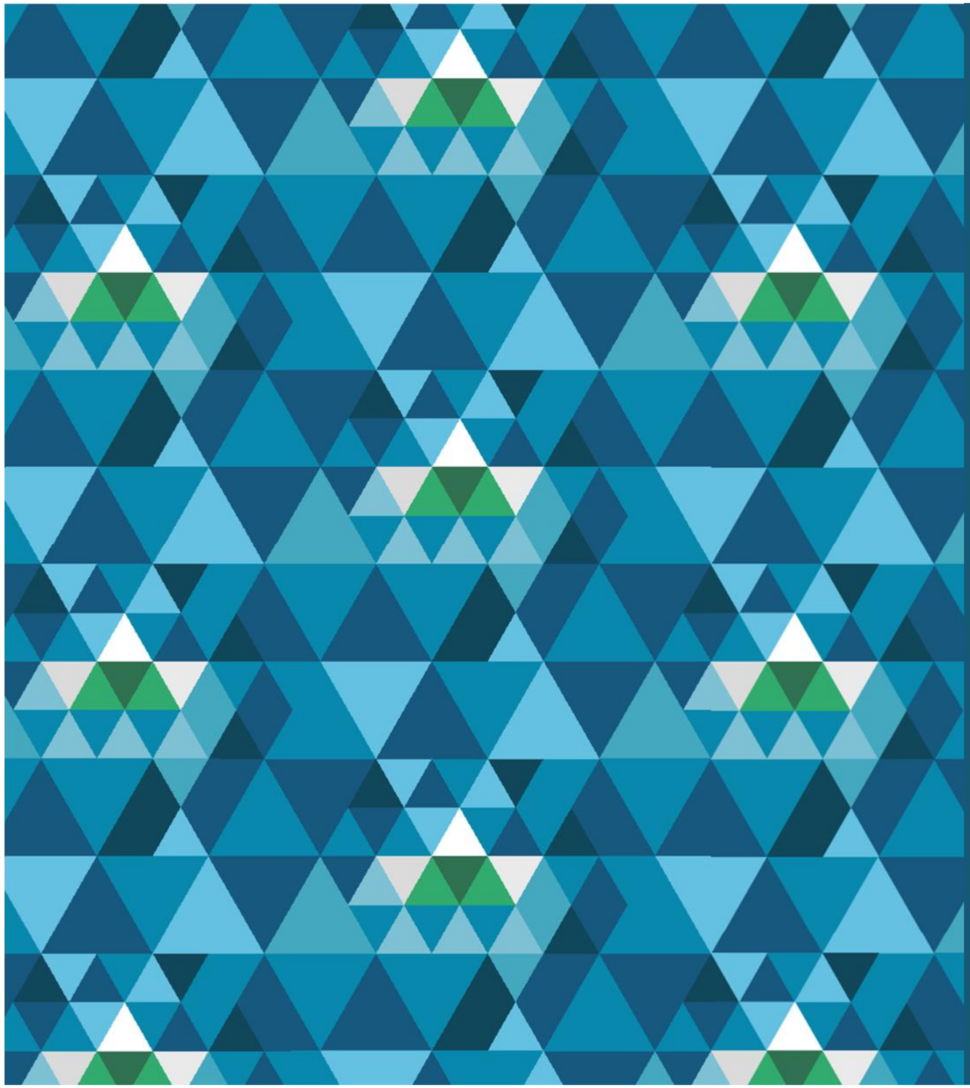
Phase 1:

Parameter	BWR GE14 (10 x 10)	VVER-440 TVEL 2^{nd} gen	EPR (17 x 17)	VVER-1200
U-235 Enr. (%)	4.23	4.37	3.60	4.92 (*)
Normal rods	74	120	253	306
Gd rods	18	6	12	6
Gd_2O_3 (wt-%)	3 or 8	3.35	9	5
Boron (ppm)	0	500	600	600

(*) 0.7 % U-236 included

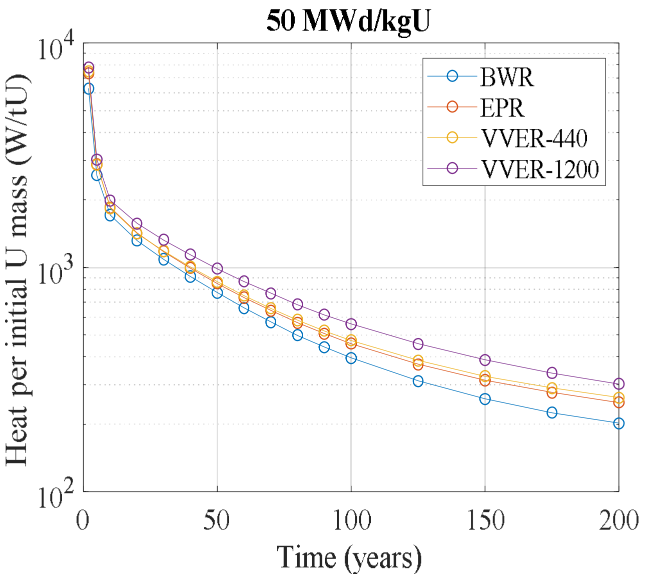
Computational model

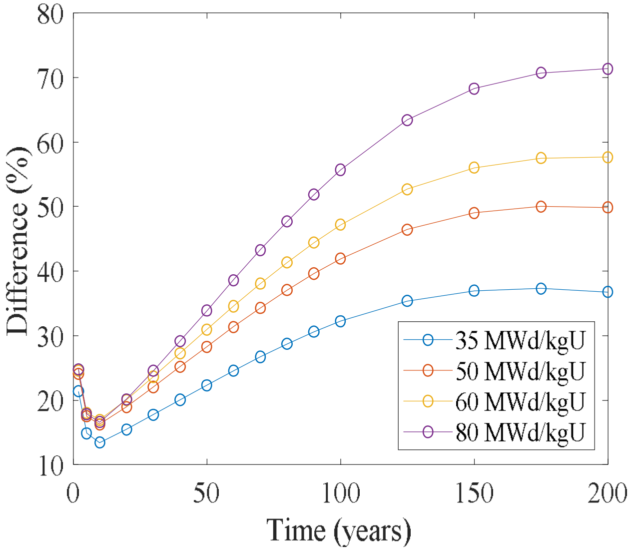
- Serpent 2.1.31 with JEFF-3.2 cross-section and JEFF-3.1.1 fission yield & decay data
- 2D Monte Carlo burnup calculation, reflective or periodic boundary conditions
- All models up to 80 MWd/kgU, intermediate burnup data written to restart file at several burnup points
- Short burnup steps
  - 0.1 – 0.3 MWd/kgU to Xe-equilibrum
  - 0.5 MWd/kgU to peak reactivity (full depletion of Gd)
  - 2.5 MWd/kgU later
- For several discharge burnup, decay calculations to 10^7 years after discharge



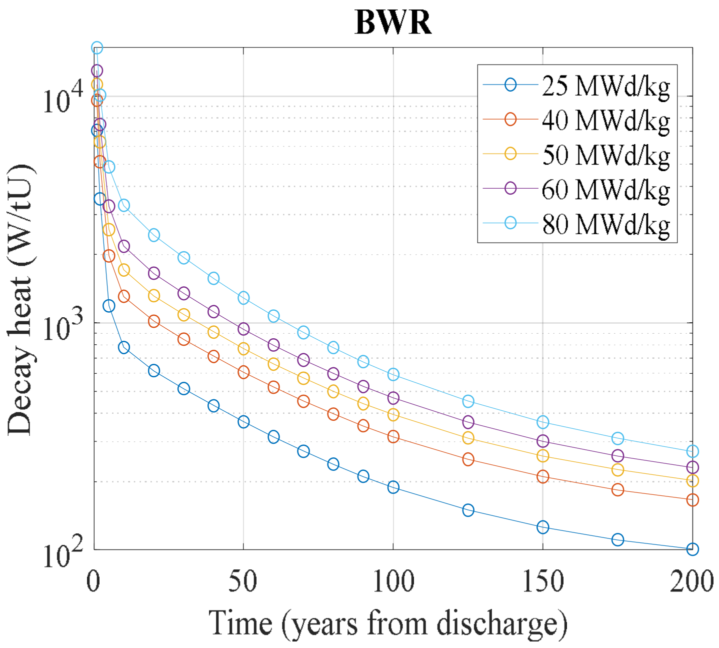
Results

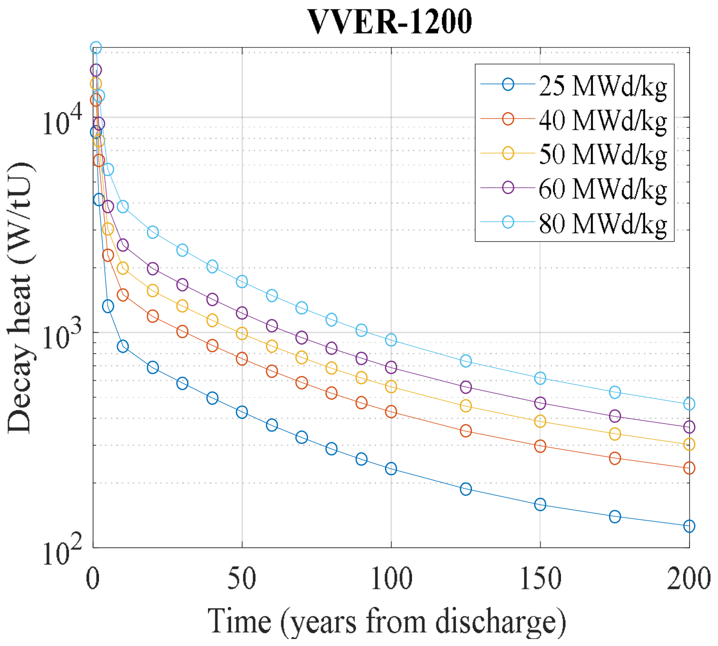
Decay heat – fuel type comparison





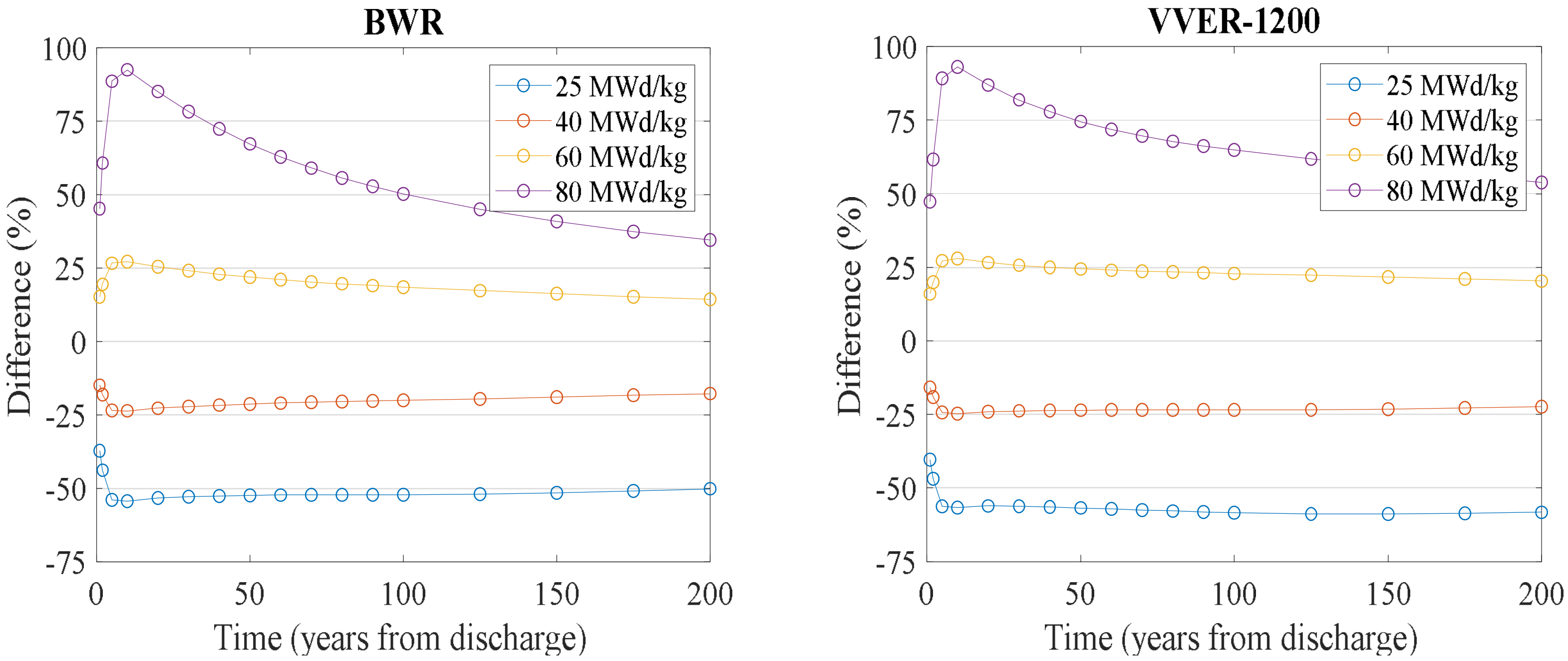
Decay heat – burnup comparison





Decay heat – burnup comparison (rel.)

Reference 50 MWd/kgU

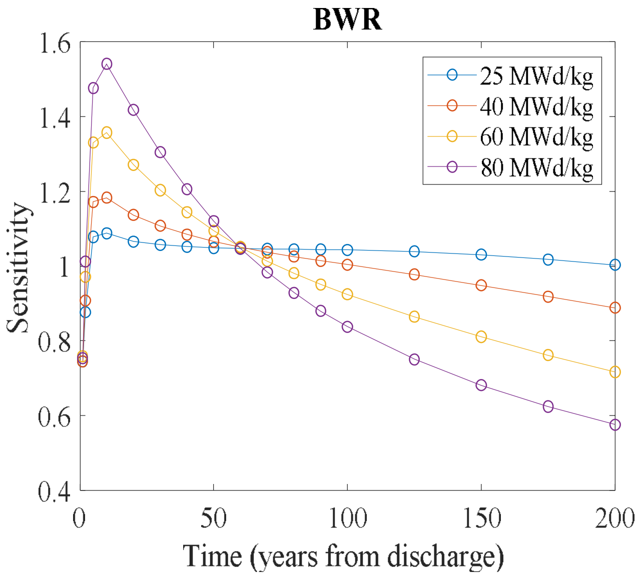


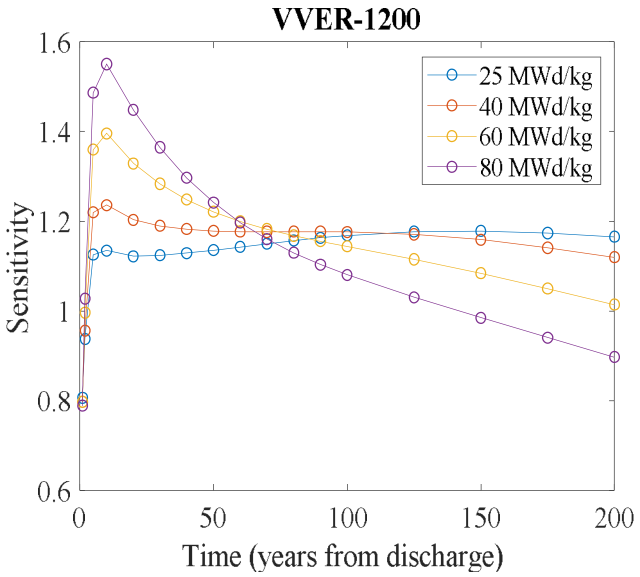
Decay heat – sensitivity to discharge burnup

$$S = \frac{\frac{H_i - H_{\mathrm{BU\_ref}}}{H_{\mathrm{BU\_ref}}}}{\frac{BU_i - BU_{\mathrm{ref}}}{BU_{\mathrm{ref}}}}$$

BU_{ref} = 50 MWd/kgU

H = decay heat





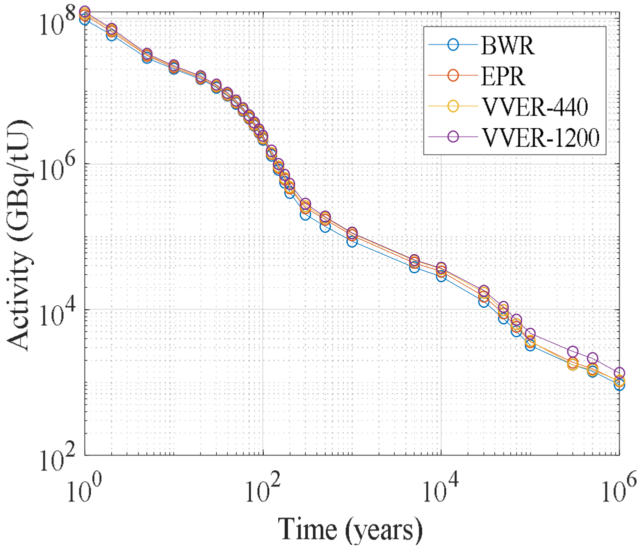
Top decay heat contributors 5 years after discharge

BWR	%	EPR	%	VVER-440	%	VVER-1200	%
Y90	27.7	Cs134	27.2	Cs134	27.9	Cs134	25.4
Ba137m	27.2	Ba137m	24.5	Y90	25.2	Y90	24.2
Cs134	24.9	Y90	23.2	Ba137m	25.1	Ba137m	23.2
Cm244	10.2	Cm244	13.7	Rh106	11.4	Pu238	16.9
Rh106	10.0	Rh106	11.4	Cm244	10.3	Rh106	10.4

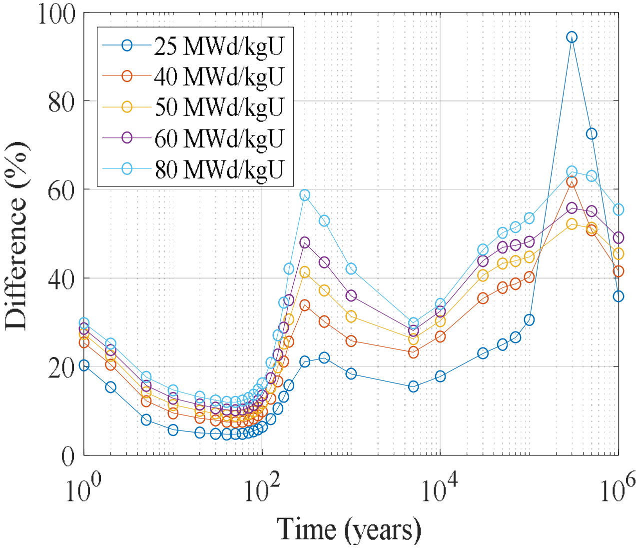
Top decay heat contributors 100 years after discharge

Nuclides	% (BWR)	% (EPR)	% (VVER-440)	% (VVER-1200)
Am241	40.0	44.8	46.4	39.1
Pu238	22.8	23.6	22.6	34.8
Ba137m	16.3	14.1	13.6	11.4
Y90	15.0	12.1	12.4	10.7
Pu240	5.9	5.4	5.0	4.0

Total activity

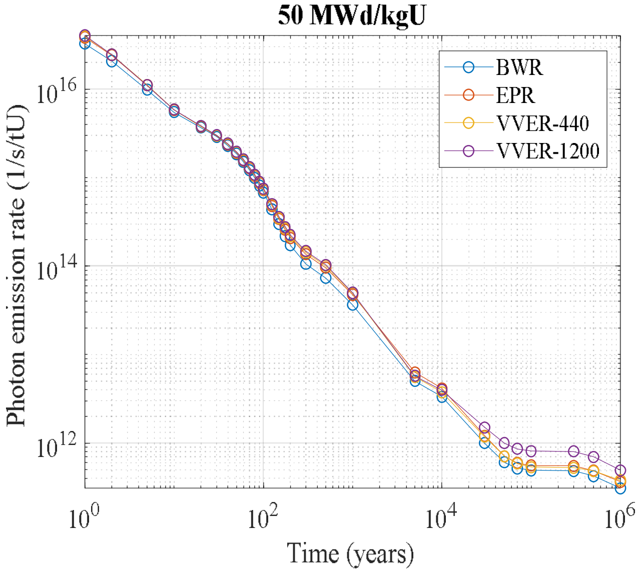


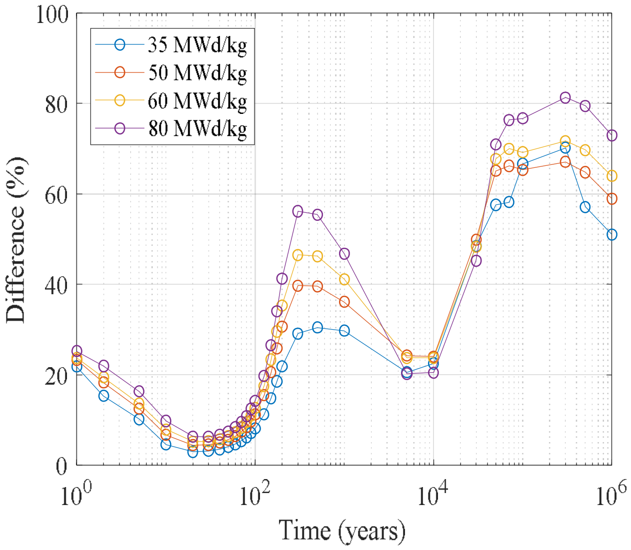
Discharge burnup 50 MWd/kgU



Relative difference between the most and least active assembly

Photon emission rate

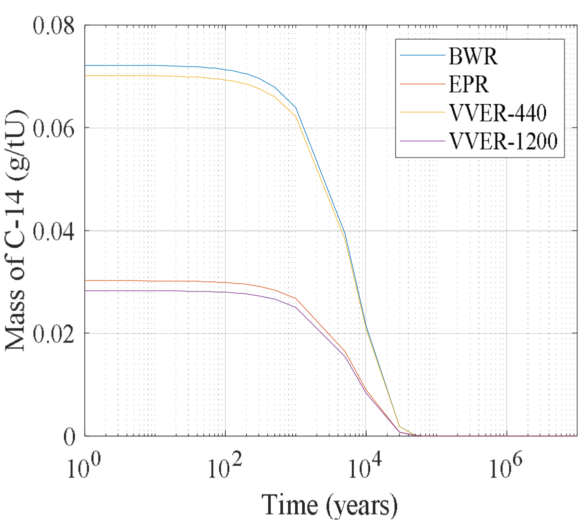


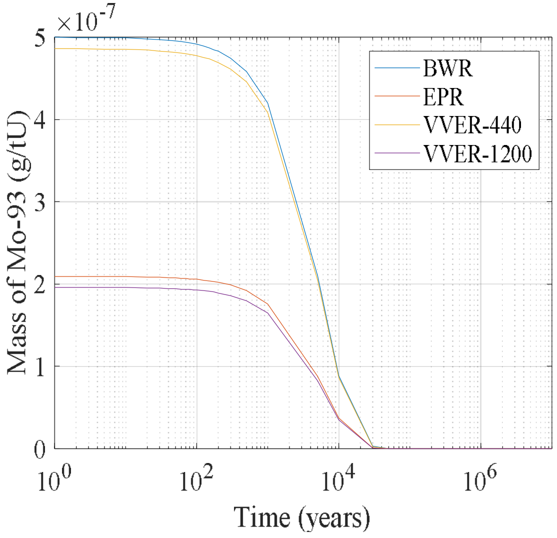


Relative difference between the most and least active assembly

Migrating nuclides

C-14, Cl-36, Mo-93, Ag-108m and I-129 determined to be the most likely to propagate to biosphere from repository





← 50 MWd/kgU discharge burnup

Summary, conclusions & future

- 2D Monte Carlo burnup calculation performed with Serpent for a fuel assembly representing BWR, EPR, VVER-440 and VVER-1200, approximated irradiation history
  - Differences identified, significance for each application to be determined in separate analyses
- More fuel types to be calculated in 2020-
  - E.g. other types of BWR assemblies with various void fractions
  - Effect of burnup, enrichment, amount of burnable absorbers, etc. on larger variety of source term components (such as spontaneous fission, plutonium mass,…)