”Fast Total Monte Carlo” applied to Phase II-2: PWR assembly depletion

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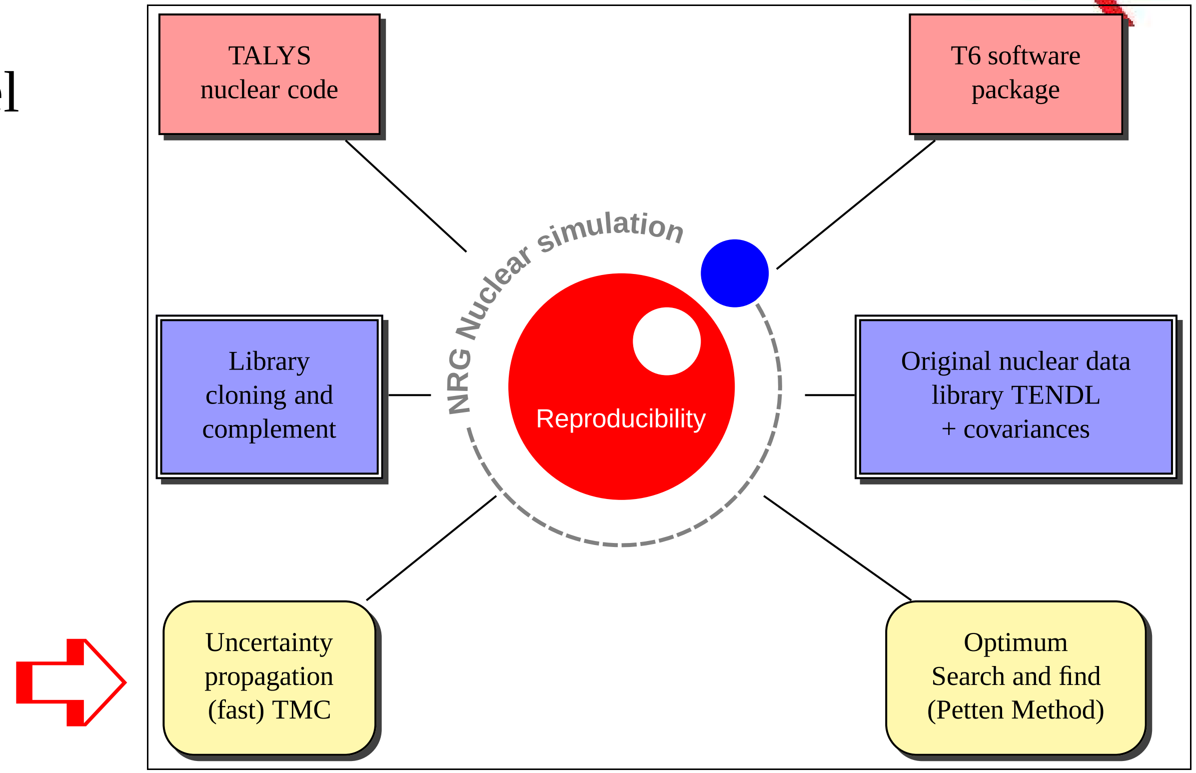
Overview

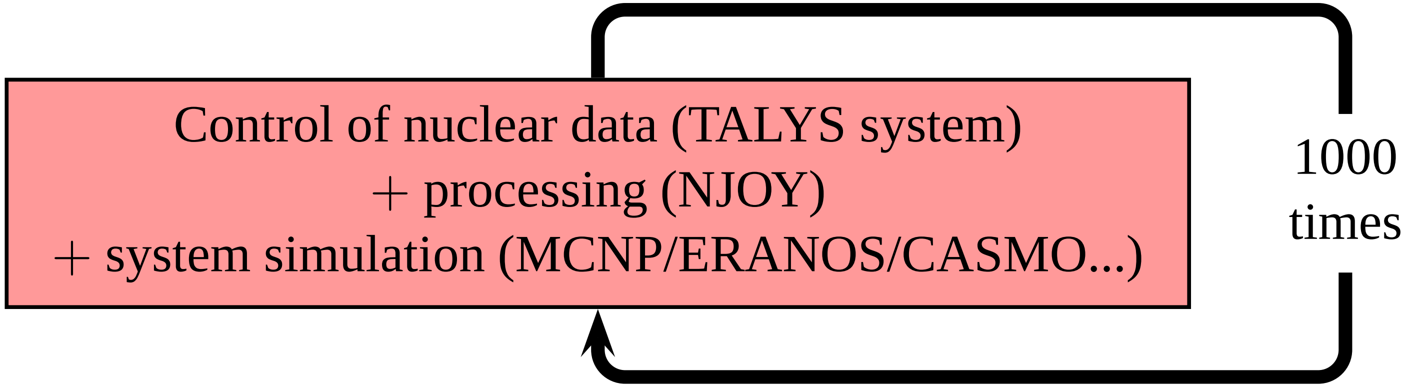
- Method: Fast Total Monte Carlo
- Description of the SERPENT model (assembly)
- Considered data in fast TMC
- Results



The preliminary report can be found at

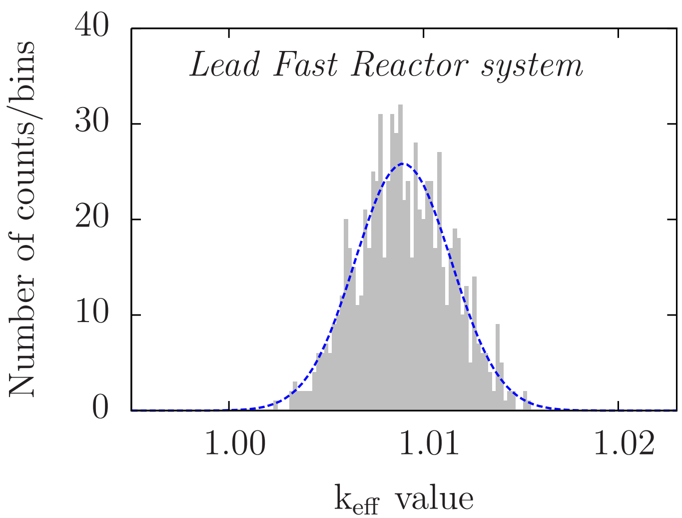
ftp://ftp.nrg.eu/pub/www/talys/bib_rochman/uam-phase2.pdf

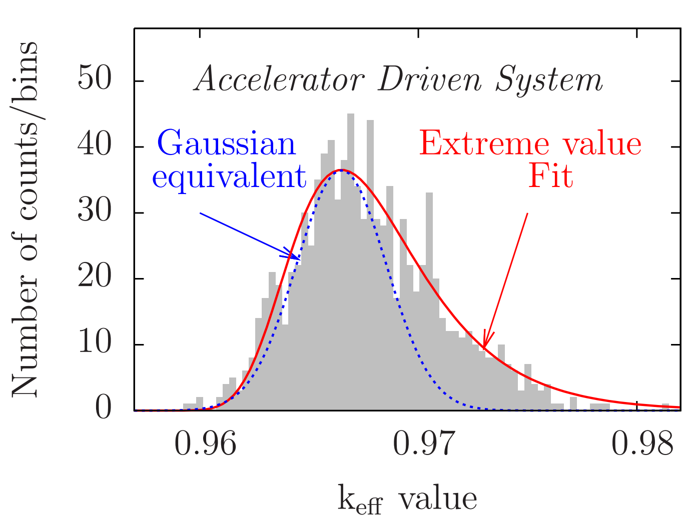
Previous method: Total Monte Carlo (TMC)



For each random ENDF file, the benchmark calculation is performed with MCNP. At the end of the *n* calculations, *n* different k_{eff} values are obtained.

$$\sigma^2_{total} = \sigma^2_{statistics} + \sigma^2_{nuclear\ data}$$





Advantages & drawbacksof the TMC method

- computer time (not human time),
- Successfully applied (criticality, shielding, reactor, burn-up...)
- Most simple path (no additional processing, no covariance required),
- Many spin-offs (TENDL covariances, sensitivity, adjustment...)
- also applicable to fission yields, thermal scattering, pseudo-fission products, all isotopes (...just everything),

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If we can do a calculation once, we can also do it a 1000 times, each time with a varying data library.

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Well, then uncertainty propagation with TMC takes 1000$\times$ longer than a single calculation... (*Each* $\sigma_{\text{statistics}}$ *needs to be small*)
There is at least one solution with Monte Carlo codes: the fast TMC method

New method: fast TMC

If a single calculation takes m histories (σ_{stat} small enough),
then repeat it n times with m/n histories,
random nuclear data and random seeds.

$$\sigma^2_{\text{total}} = \sigma^2_{\text{statistics}} + \sigma^2_{\text{nuclear data}}$$ still holds.

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$\vdots$		$\vdots$			$\vdots$
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⋮		⋮			⋮
run *n*	nuclear data *n*	seed s_n	m/n hist.	T/n sec.	$k_n \pm \sigma_n$
n runs				T sec.	

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$$\sigma^2_{total} = \frac{1}{n-1}\sum_{i=1}^{n}\left(k_i - \overline{k}\right)^2$$

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n runs				T sec.	

$$\begin{cases} \sigma^2_{total} = \frac{1}{n-1}\sum_{i=1}^{n}\left(k_i - \bar{k}\right)^2 \\ \sigma^2_{statistics} = \frac{1}{n}\sum_{i=1}^{n}\sigma^2_i \end{cases}$$

Description of the SERPENT model (assembly)

The fuel test is a typical fuel rod from TMI-1 PWR, 15x15 assembly design, see complete description in K. Ivanov (March 2013).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	g	-	-	-	-	-	-	-	-	-	-	-	g	-
3	-	-	-	-	-	G	-	-	-	G	-	-	-	-	-
4	-	-	-	G	-	-	-	-	-	-	-	G	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	G	-	-	G	-	-	-	G	-	-	G	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	I	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	G	-	-	G	-	-	-	G	-	-	G	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	G	-	-	-	-	-	-	-	G	-	-	-
13	-	-	-	-	-	G	-	-	-	G	-	-	-	-	-
14	-	g	-	-	-	-	-	-	-	-	-	-	-	g	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 19: TMI-1 FA Pin Layout

Table 47: TMI-1 FA Pin Descriptions

Marker	Rod Type
g	2.0 w/o Gd 4.12% 235U pin
G	Guide Tube
I	Instrumentation Tube
-	4.12% 235U fuel pin

Considered data in fast TMC

Several hundreds of random ENDF files for transport + depletion

- 3 Major actinides: ^{235}U, ^{238}U, ^{239}Pu,
- 1 Thermal scattering data: H in H_2O,

- 12 Fission yields: ^{234,235,236,238}U, ^{239,240,241}Pu, ^{237}Np, ^{241,243}Am, ^{243,244}Cm,
- 13 Minor actinides: ^{234,236,237}U, ^{237}Np, ^{238,240,241,242}Pu, ^{241,242g,243}Am, ^{242,245}Cm
- 138 fission products: $^{72-74,76}$Ge, ^{75}As, $^{76-80,82}$Se, ^{79,81}Br, $^{80-84,86}$Kr, ^{85,87}Rb, $^{86-88,92}$Sr, ^{89}Y, ^{93,95}Zr, ^{94,95}Nb, $^{95-97}$Mo, ^{99}Tc, $^{99-104,106}$Ru, ^{103,105,106}Rh, $^{104-108,110}$Pd, ^{109}Ag, $^{111-114,116}$Cd, ^{113,115}In, $^{115,117-119,126}$Sn, ^{121,123,125}Sb, $^{122-128,130}$Te, ^{127,129,135}I, $^{128,130-132,134-136}$Xe, $^{133-137}$Cs, $^{134-138}$Ba, ^{140}La, ^{140,142}Ce, ^{141,144}Pr, $^{142-146,148,150}$Nd, $^{147-149}$Pm, $^{147,149-152,154}$Sm, $^{151-156}$Eu, $^{152,154-158,160}$Gd, ^{159,160}Tb, $^{160-164}$Dy, ^{165}Ho, ^{166,167}Er.

Calculated quantities: k_∞, rr, macroscopic cross sections (2 groups), ADF, Number densities, relative power pin distribution

Results on k_∞

	Burn-up (GWd/MTU)					
	0	0.2	10	20	30	40
k_∞	1.39	1.35	1.26	1.17	1.09	1.02
Order						
1.	^{235}U	^{235}U	^{235}U	^{238}U	^{235}U	^{239}Pu
2.	^{238}U	^{238}U	^{238}U	^{235}U	^{238}U	^{235}U
3.	H in H_2O	H in H_2O	H in H_2O	H in H_2O	^{239}Pu	^{238}U
Uncertainties (in %) coming from						
^{235}U	0.56	0.53	0.44	0.40	0.37	0.34
^{238}U	0.41	0.42	0.42	0.42	0.35	0.31
^{239}Pu	-	-	0.15	0.25	0.32	0.38
H in H_2O	0.14	0.12	0.24	0.30	0.30	0.28
Minor Act.	-	-	0.03	0.03	0.06	0.07
Fiss. Yiel.	-	0.11	0.17	0.22	0.26	0.31
Lumped F.P.	-	0.05	0.07	0.10	0.14	0.14
Total	0.71	0.70	0.70	0.74	0.74	0.75

Results on reaction rates

	Burn-up (GWd/MTU) (main contributor)					
	0	0.2	10	20	30	40
^{235}U(n,γ)	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U
^{238}U(n,γ)	^{238}U	^{238}	^{238}U	^{238}U	^{238}U	^{238}U
^{239}Pu(n,γ)	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O	^{239}Pu
^{240}Pu(n,γ)	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O
^{241}Pu(n,γ)	^{235}U	^{235}U	^{235}U	Minor Act.	^{238}U	^{238}U
^{235}U(n,f)	^{235}U	^{235}U	^{235}U	^{238}U	^{238}U	^{238}U
^{238}U(n,f)	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U
^{239}Pu(n,f)	H in H_2O	H in H_2O	H in H_2O	H in H_2O	^{239}Pu	^{239}Pu
^{240}Pu(n,f)	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U
^{241}Pu(n,f)	^{235}U	^{235}U	^{235}U	^{235}U	^{238}U	^{238}U
	Total uncertainties (due to transport data and fission yields, in %) for					
$^{235}U_{n,\gamma}$	2.06	2.04	2.03	2.14	2.30	2.56
$^{238}U_{n,\gamma}$	1.82	1.81	1.72	1.70	1.49	1.31
$^{239}Pu_{n,\gamma}$	2.68	2.64	2.13	1.96	1.95	2.04
$^{240}Pu_{n,\gamma}$	4.89	5.11	4.93	4.55	4.54	4.66
$^{241}Pu_{n,\gamma}$	1.80	2.07	1.70	1.67	1.85	2.13
$^{235}U_{n,f}$	0.57	0.59	0.79	1.17	1.58	2.10
$^{238}U_{n,f}$	7.38	7.41	5.78	4.94	4.41	4.10
$^{239}Pu_{n,f}$	2.24	2.21	2.22	2.12	2.17	2.36
$^{240}Pu_{n,f}$	3.08	3.11	2.53	2.20	2.02	1.81
$^{241}Pu_{n,f}$	1.60	1.59	1.32	1.33	1.56	1.93

Results on macroscopic cross sections

	Burn-up (GWd/MTU) (main contributor)					
	0	0.2	10	20	30	40
Σ_{abs1}	^{235}U	^{235}U	^{235}U	^{238}U	^{238}U	^{238}U
Σ_{abs2}	H in H_2O	H in H_2O	H in H_2O	^{238}U	^{238}U	^{238}U
Σ_{fiss1}	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U
Σ_{fiss2}	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{238}U
$\nu\Sigma_{fiss1}$	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{238}U
$\nu\Sigma_{fiss2}$	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{238}U
D_{iff1}	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U
D_{iff2}	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O
Σ_{trn1}	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U	^{235}U
Σ_{trn2}	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O
$InvVel_1$	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O
$InvVel_2$	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O

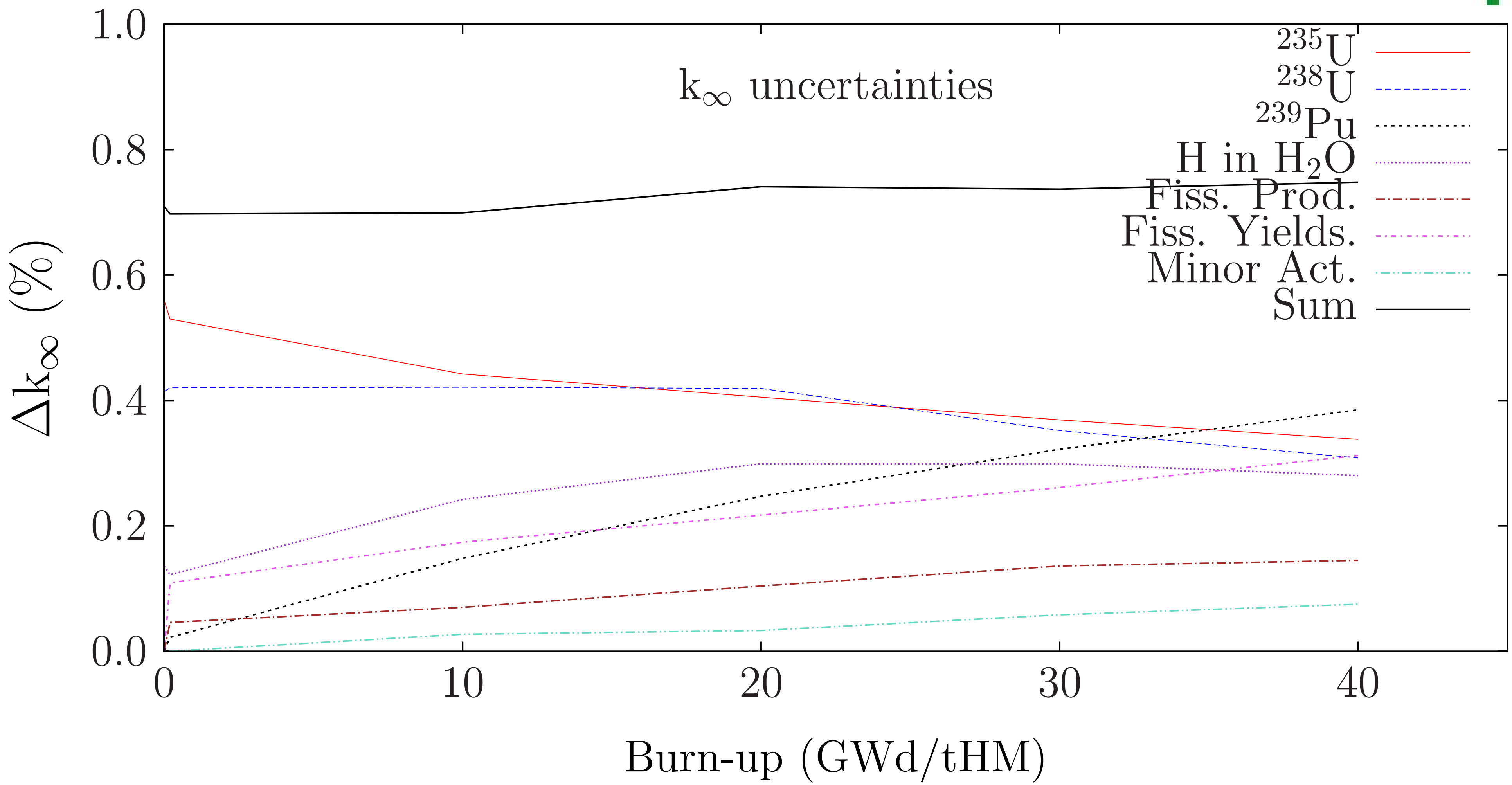
Results on number densities for actinides

	Burn-up (GWd/MTU) (main contributor)					
	0	0.2	10	20	30	40
^{234}U	-	Minor Act.	Minor Act.	Minor Act.	Minor Act.	Minor Act.
^{235}U	-	^{235}U	^{235}U	^{235}U	235	^{238}U
^{236}U	-	^{235}U	^{235}U	^{235}U	235	^{235}U
^{238}U	-	-	^{238}U	^{238}U	^{238}U	^{238}U
^{237}Np	-	^{235}U	^{235}U	^{235}U	235	^{238}U
^{238}Pu	-	^{235}U	^{235}U	^{235}U	Minor Act.	Minor Act.
^{239}Pu	-	^{238}U	^{238}U	^{238}U	^{238}U	^{238}U
^{240}Pu	-	Minor Act.	^{238}U	^{238}U	H in H_2O	H in H_2O
^{241}Pu	-	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O
^{242}Pu	-	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O
^{241}Am	-	H in H_2O	H in H_2O	H in H_2O	Minor Act.	Minor Act.
^{243}Am	-	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O
^{242}Cm	-	H in H_2O	H in H_2O	H in H_2O	Minor Act.	Minor Act.
^{244}Cm	-	H in H_2O	H in H_2O	H in H_2O	H in H_2O	H in H_2O

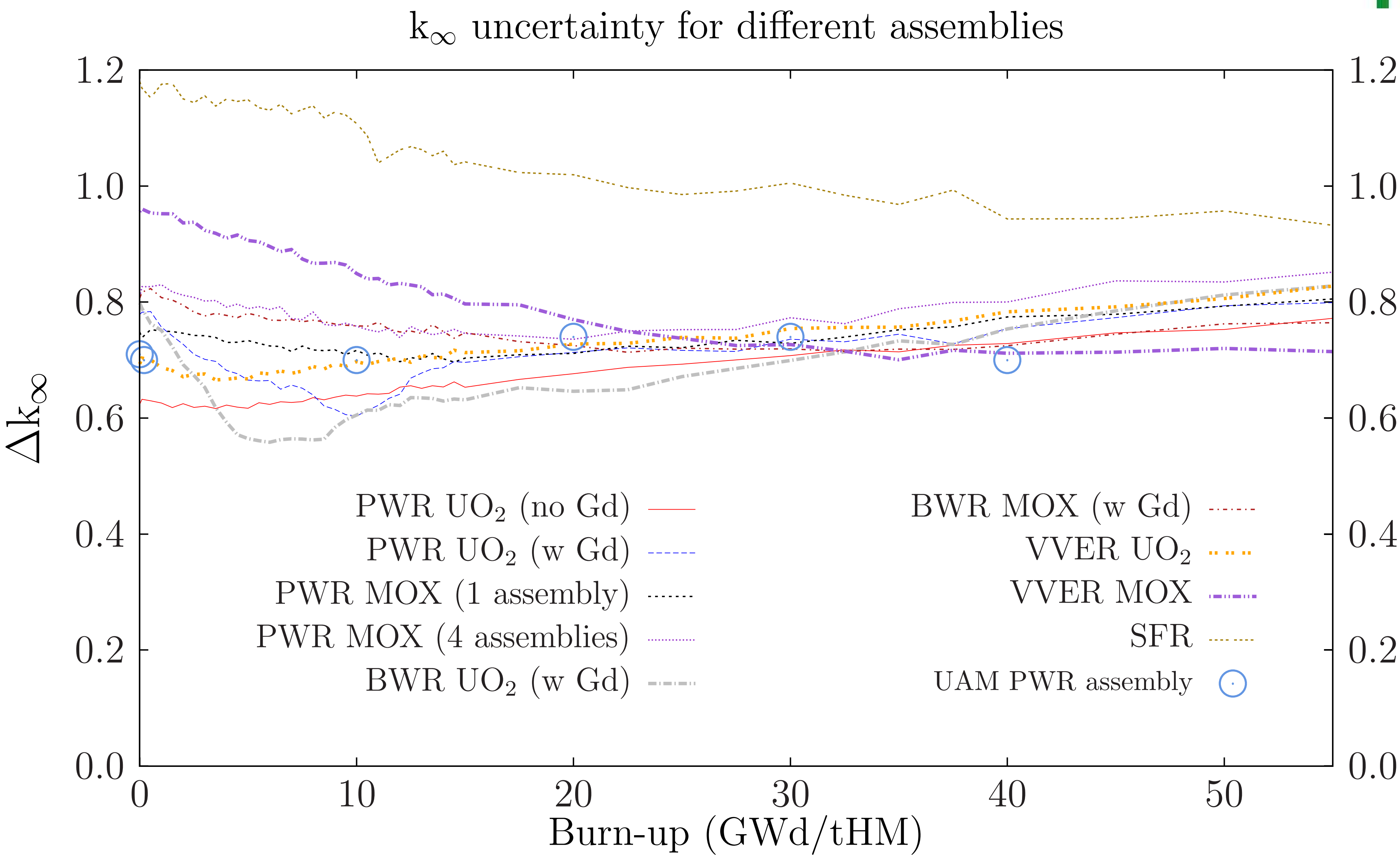
Results on number densities for fission products

	Burn-up (GWd/MTU) (main contributor)					
	0	0.2	10	20	30	40
^{90}Sr	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{95}Mo	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{99}Tc	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{101}Ru	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{103}Rh	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{109}Ag	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{129}I	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{133}Xe	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{135}Xe	-	Minor Act.	Minor Act.	Minor Act.	Minor Act.	Minor Act.
^{133}Cs	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{134}Cs	-	Minor Act.	Minor Act.	Minor Act.	Minor Act.	Minor Act.
^{137}Cs	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{144}Ce	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
^{142}Nd	-	Minor Act.	Minor Act.	Minor Act.	Minor Act.	Minor Act.
$^{143-148}Nd$	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
$^{147-152}Sm$	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
$^{153-155}Eu$	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields
$^{155-158}Gd$	-	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields	Fiss. Yields

Example for k_∞



Comparison of Δk_∞



Local power density

The pin power distribution and burnup of each fuel pin (in GWd/t) as well as the associated uncertainties is requested with one unique material definition for all pins.

Is that the best ?

We varied all nuclear data separately $\Longrightarrow$ no visible effect

Better to vary all of them together (to be done).

Conclusions

- fast TMC successfully applied for this PWR assembly benchmark,
- Transport nuclear data, fission yields and thermal scattering were considered,
- Importance of $^{235,238}U$, ^{239}Pu and thermal scattering (H in H_2O),
- (and fission yields for number densities),
- Minor actinides and fission products are of less importance.

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fast TMC:

If we can do a calculation once, we can also get nuclear data uncertainties in the same time