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Bowing effects on power and burn-up distributions for simplified full PWR and BWR cores

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- CASMO Models for PWR and BWR
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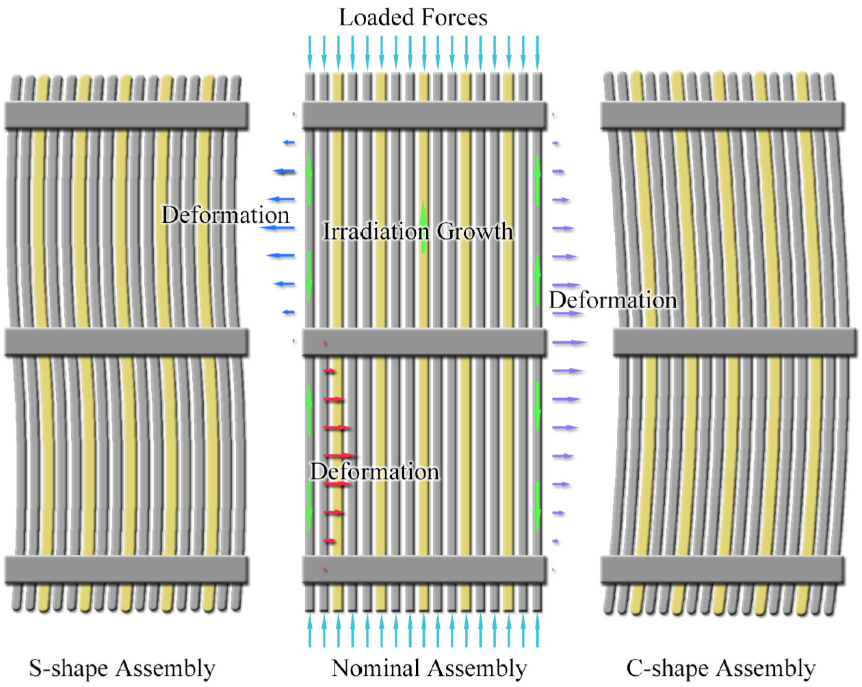
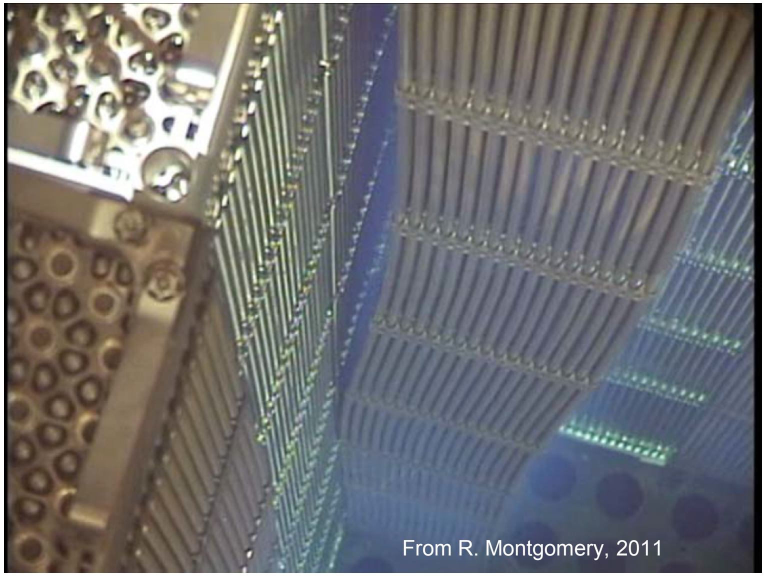
Introduction

- Bowing effect: deformation of the fuel assemblies observed in PWR and BWR,

- Impact on the motion of control rods,
- Impact on isotopic content, power map…

- And impact on the safe operation of the reactor



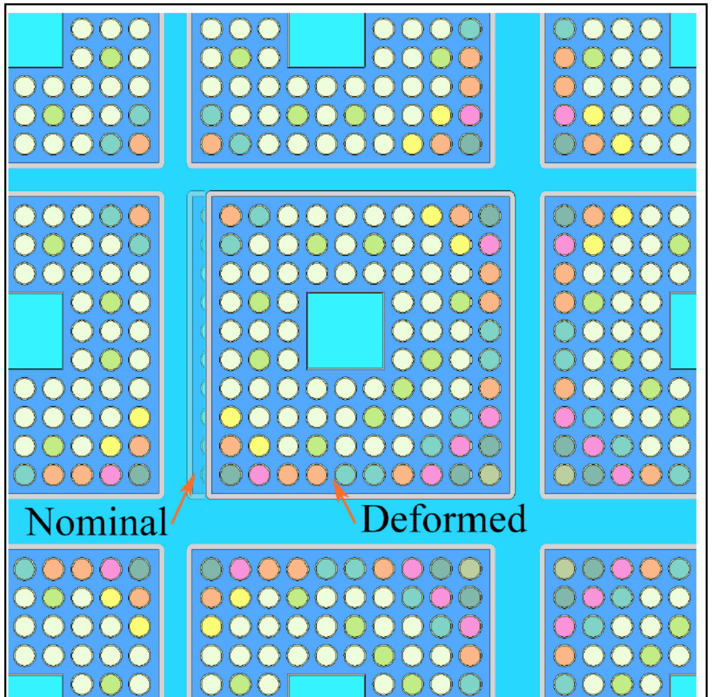


Description of the simplified models

- Full core simulation with CASMO-5 (MxN model), up to 30 MWd/kgU
- Assemblies are modelled with X and Y displacements
  - „*LDX/LDY*“ cards for the PWR
  - „*GAP*“ card for the BWR
- One type of fresh fuel (UO_2)

Assembly			
Geometry	17×17	Fuel pin R	0.4095
Fuel type	UO_2	Air gap R	0.4177
Rods	289	Clad R	0.475
Pitch (cm)	1.254	Clad	Zircaloy
Water channels	25	Clad ρ (g/cm^3)	6.56
Enrichment ^{235}U	4.11 %	Inner water R	0.57
Fuel ρ (g/cm^3)	10.07	Outer water R	0.615
Power dens. (W/gU)	25		
Core			
Assemblies	193	Geometry	17×17
Fuel T	900 K	Moderator T	600 K

TABLE I. Main characteristics of the PWR assemblies and core considered in this work. “R” means *radius*, given in cm.



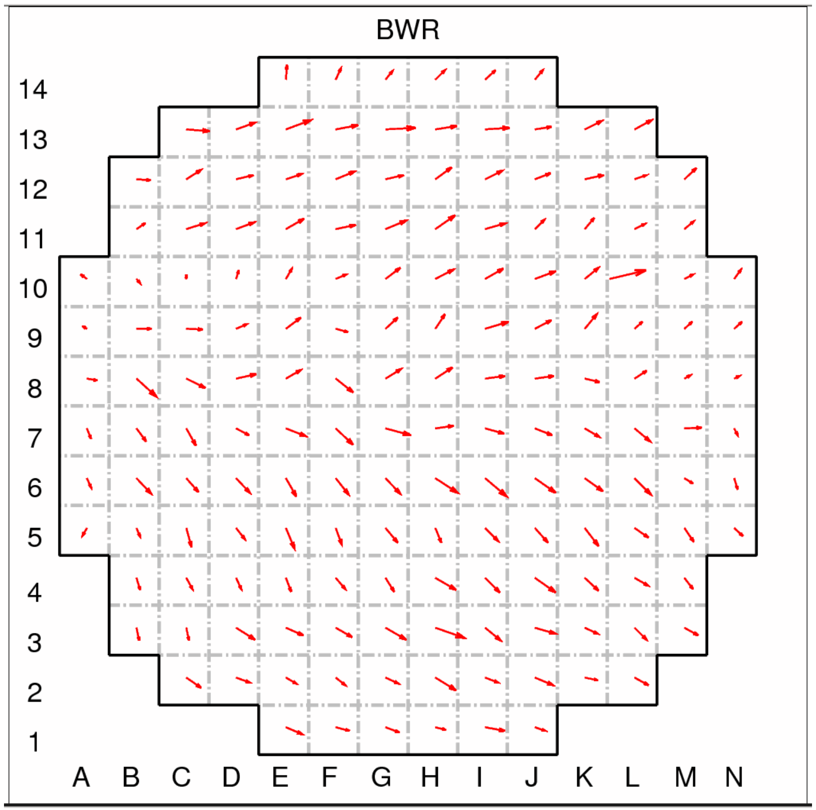
(b) BWR channel bowing with UO_2

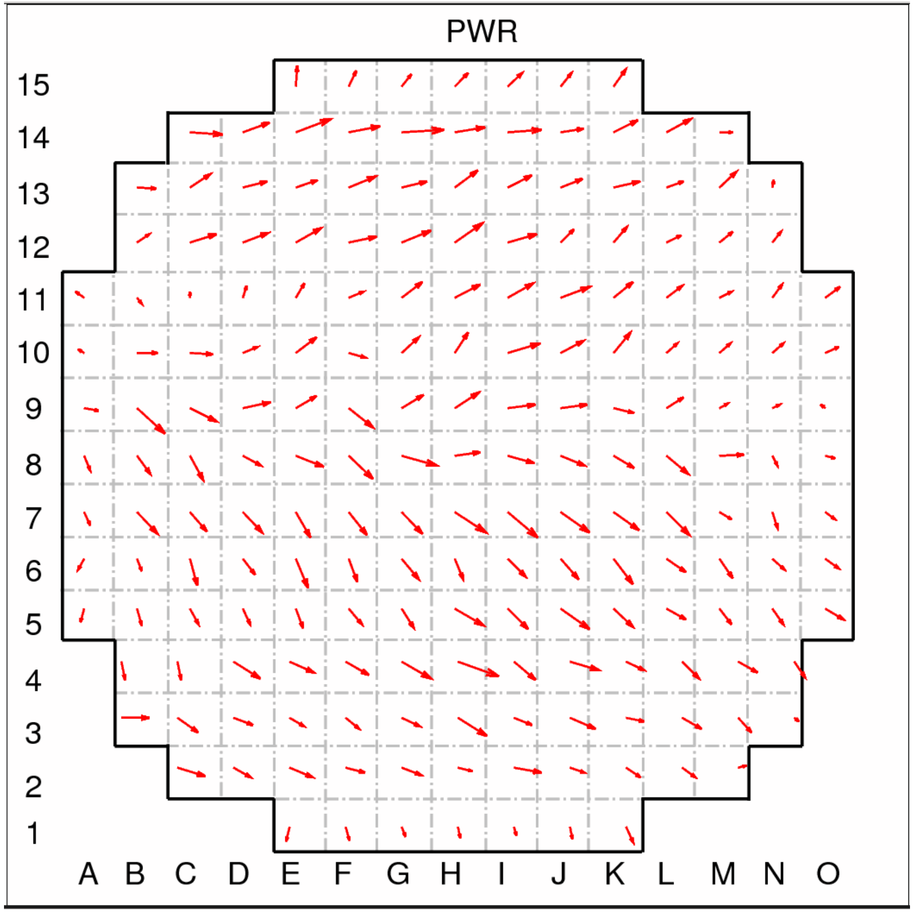
Bundle			
Geometry	10×10	Fuel pin R	0.442
Fuel type	UO_2	Air gap R	0.452
Rods	91	Clad R	0.502
Pitch (cm)	1.295	Clad	Zircaloy
Water Channel	9	Clad ρ (g/cm^3)	6.55
Wall dist. (cm)	13.4	Box Wall tick.	25 mm
Wide Water gap	2 cm	Narrow Water gap	1 cm
Fuel ρ (g/cm^3)	10.31	Power dens. (W/gU)	25
Core			
Assemblies	164	Geometry	16×16
Fuel T	900 K	Moderator T	559 K
Void coolant	41 %	Pressure	70 bar

TABLE II. Main characteristics of the BWR bundles and core considered in this work. “R” means *radius*, given in cm.

Bowing map

- The bowing map is from a typical assembly bow in PWR EDF 1300 MW(e) reactors,
- Assumed constant for the whole cycle,
- Same map applied to the PWR and BWR,





Results: general comments

- The results for presented in the form of

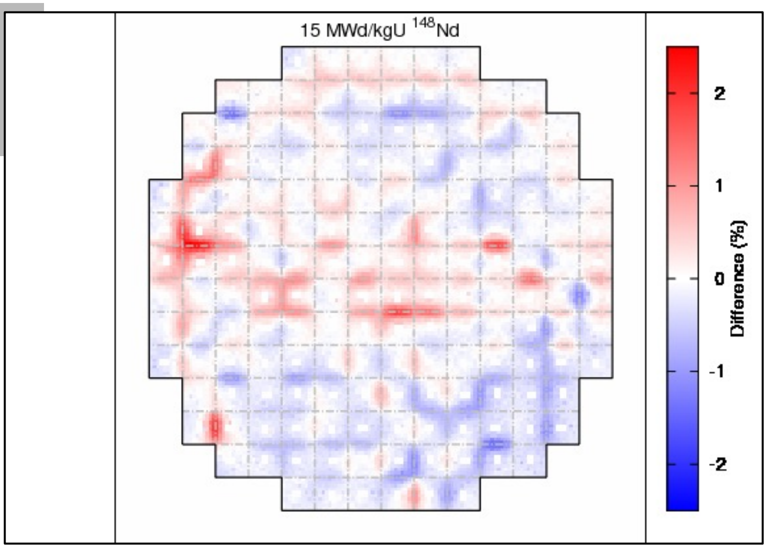
$$\Delta = (C^D - C^N)/C^N,$$

With C^D: quantity of interest for the deformed core,
And C^N: quantity of interest for the nominal core,

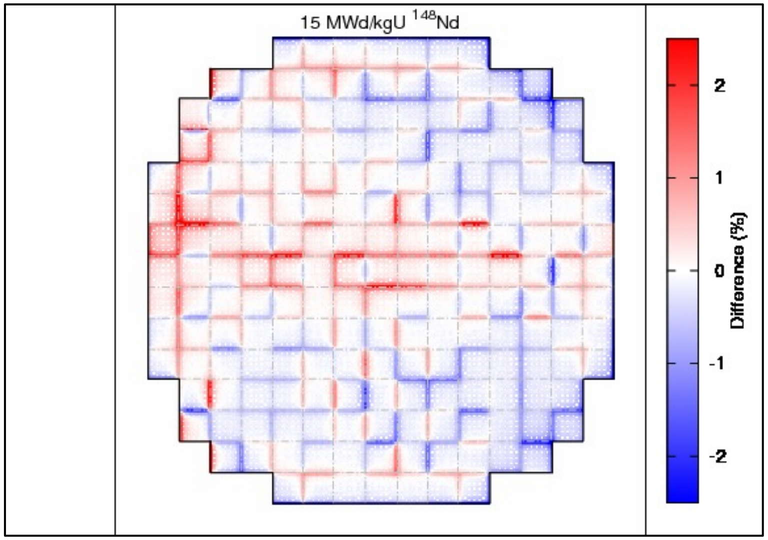
- In general, the following observations are true:

- gap increase $\Longleftrightarrow$ higher thermal neutron population
- gap increase $\Longleftrightarrow$ higher local power
- gap increase $\Longleftrightarrow \Delta(^{235}U) < 0$ $\longleftarrow$ Higher consumption of ^{235}U
- gap increase $\Longleftrightarrow \Delta(^{148}Nd) > 0$ $\longleftarrow$ Higher fission products production
- gap increase $\Longleftrightarrow \Delta(^{239}Pu) < 0$ $\longleftarrow$ Higher consumption of ^{239}Pu
- gap increase $\Longleftrightarrow \Delta(^{244}Cm) > 0$ $\longleftarrow$ Higher heavy actinide production

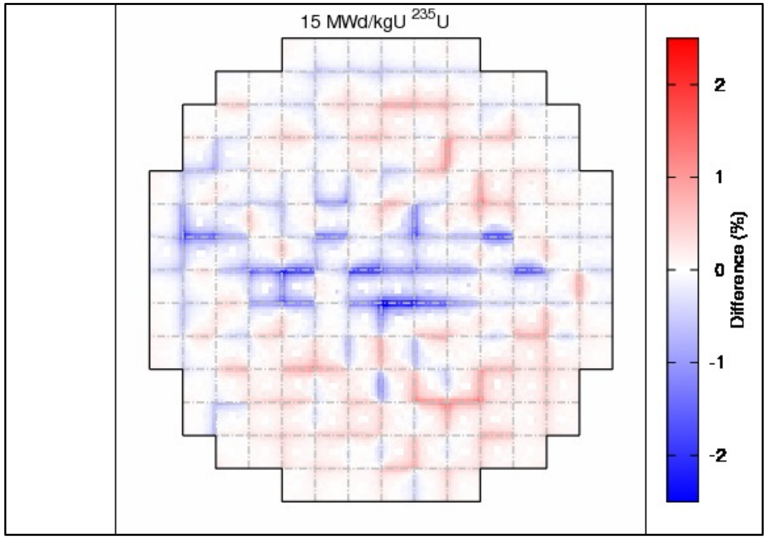
Results: isotopic content for ^{148}Nd and ^{235}U

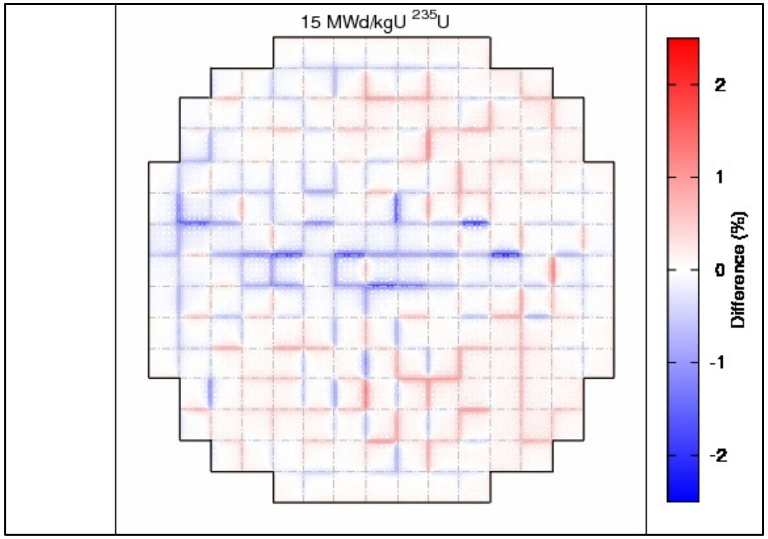


BWR

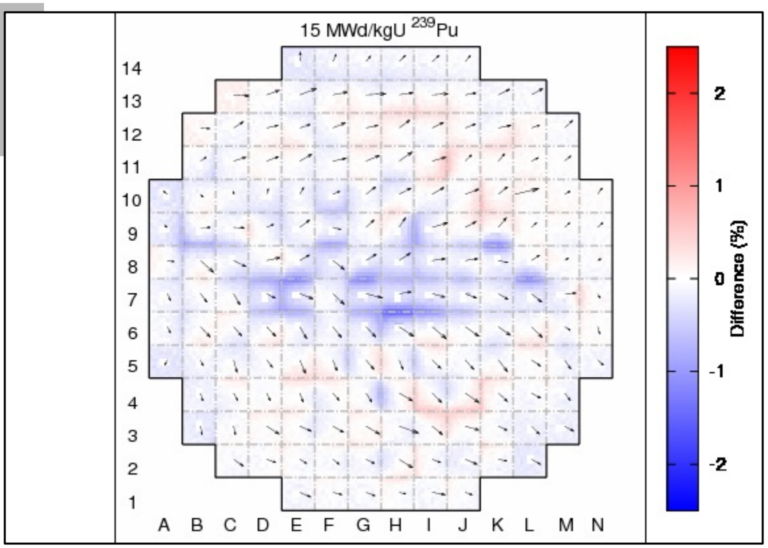


PWR

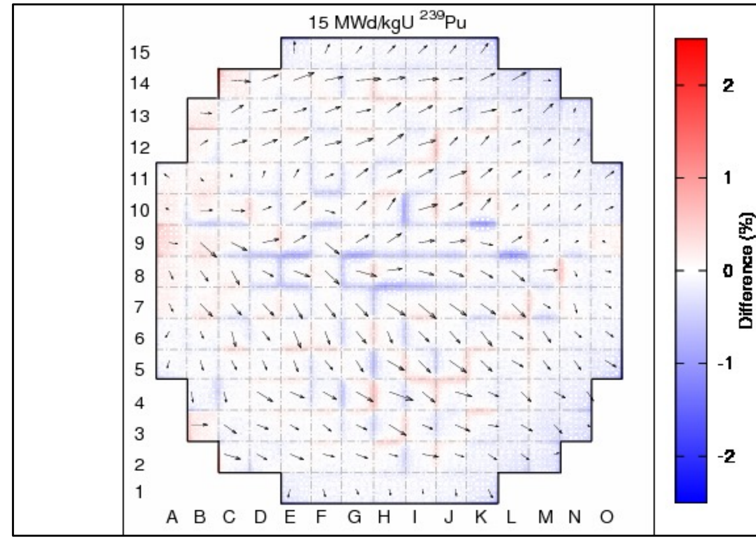




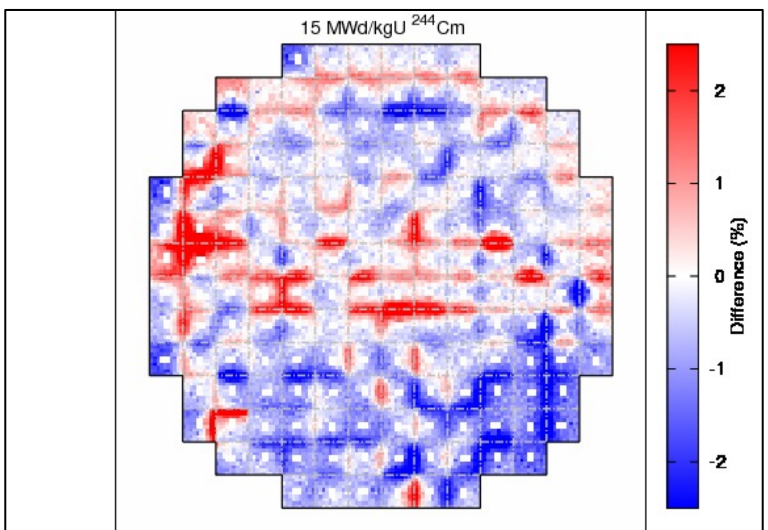
Results: isotopic content for ^{239}Pu and ^{244}Cm

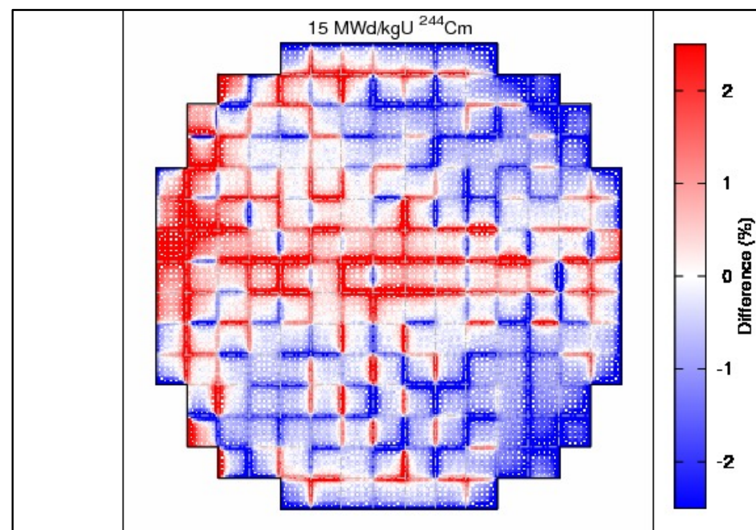


BWR



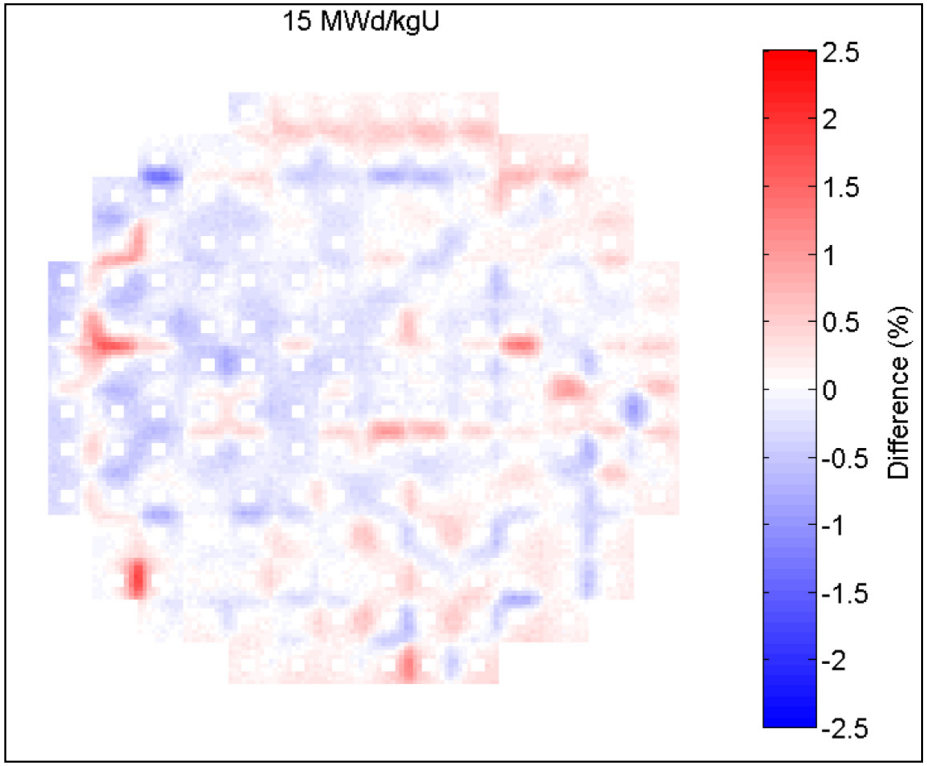
PWR



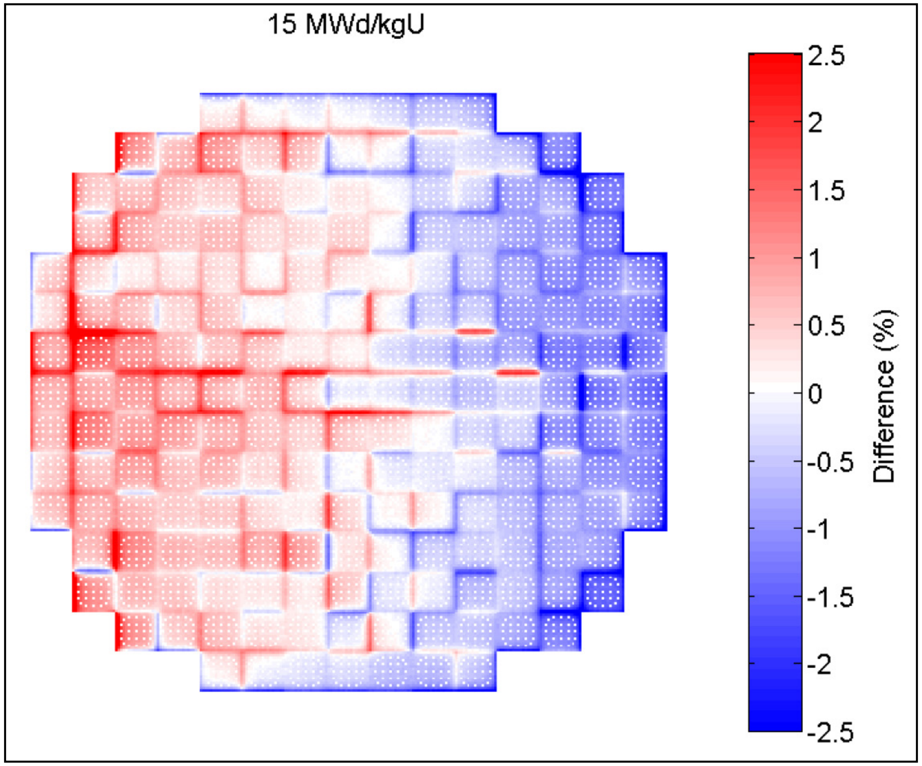


Results: Assembly power

BWR



PWR



- Stronger effect for the PWR (3 times higher compared to the BWR), following the ^{148}Nd map.

Conclusions and perspective

- Same constant bowing map implemented for PWR and BWR cores
- CASMO-5 simulation for the full cores up to 30 MWd/kgU:
  - Local pin number densities: effect stronger for the PWR
  - Local pin average power: effect stronger for the PWR

	Extreme		Average	
	PWR	BWR	PWR	BWR
Pin ^{148}Nd	5.1	2.5	0.0	0.0
Pin ^{235}U	2.0	2.9	0.0	0.0
Pin ^{239}Pu	1.8	1.4	0.0	-0.1
Pin ^{244}Cm	21	8.0	-0.2	-0.3
Pin Power	5.5	1.8	0.0	0.0

TABLE III. Absolute values of Δ in % for the extreme variations of number densities, and average Δ, at 15 MWd/kgU.

- These results depend on the selected assumption (bowing map, fuel…)

- Many improvements are possible:
  - UO_2/MOX fuel,
  - Variable bowing amplitude in cycle and for more than 1 cycle,
  - Realistic BWR bowing map