

IRSN

INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

An alternative simple approach for the modelling of fuel assemblies with missing fuel rods

Track n°6 - Operational practices and safety cases



Thomas ALBERT
Aurélié BARDELAY
Luis AGUIAR
Ludylvine JUTIER
Véronique DUMONT

September 16th, 2019

MEMBRE DE

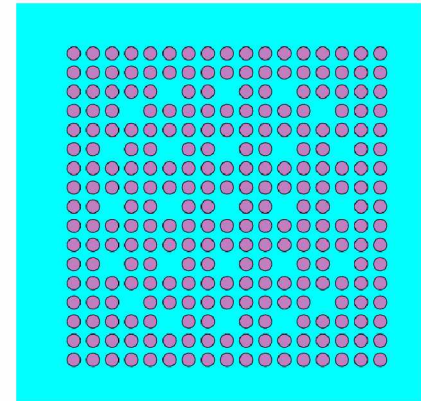
ETSON

EUROPEAN
TECHNICAL SAFETY
ORGANISATIONS
NETWORK

© IRSN

Introduction (1/2)

- The criticality assessment of fuel assemblies is needed for fuel pools (fresh and used fuel), fuel assemblies fabrication, recycling facilities and transports.
- These assemblies may have empty rod slots whose positions are known, corresponding to the positions of control rods and guide tubes within the reactor core.
- They also may have empty rod slots whose positions are unknown, corresponding to damaged fuel rods which have been removed: these are difficult to take into account in continuous energy Monte Carlo codes (or « reference » codes), because of a huge number of possible assembly configurations.



Introduction (2/2)

■ Need to find a simple calculation scheme which:

- doesn't have to take into account real rod positions within the array ;
- remains bounding.

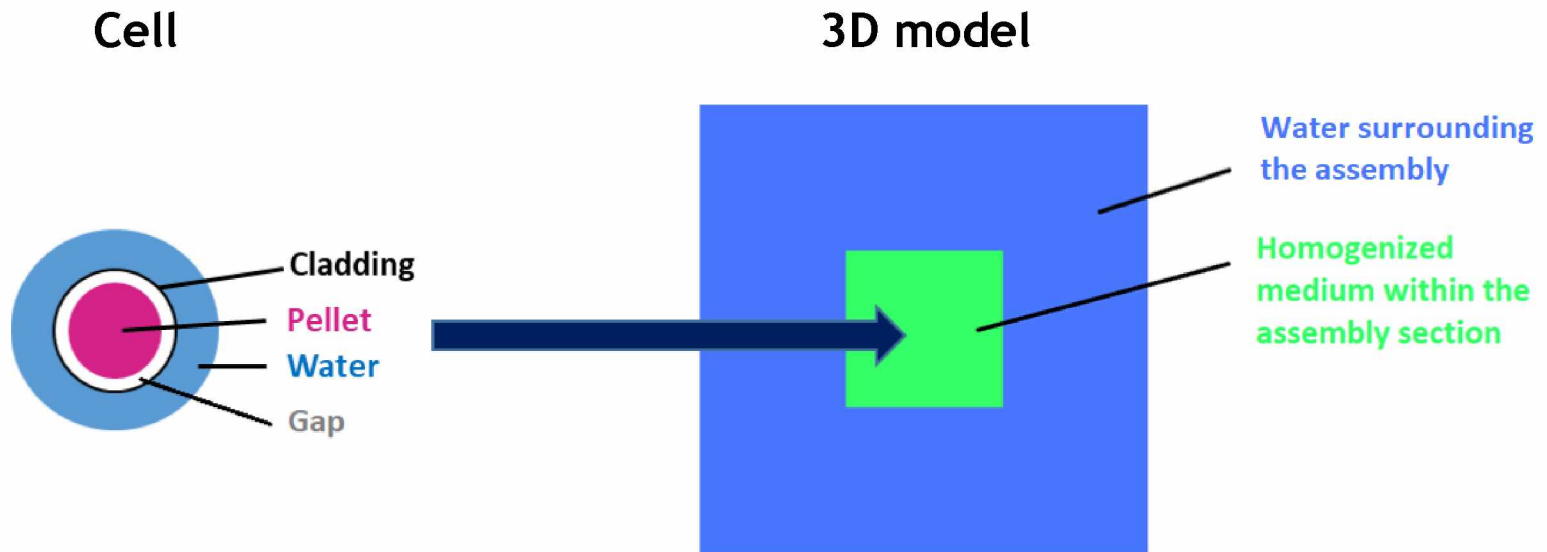
This is the purpose of this work!

One zone homogenized modelling

One zone homogenized modelling (1/9)

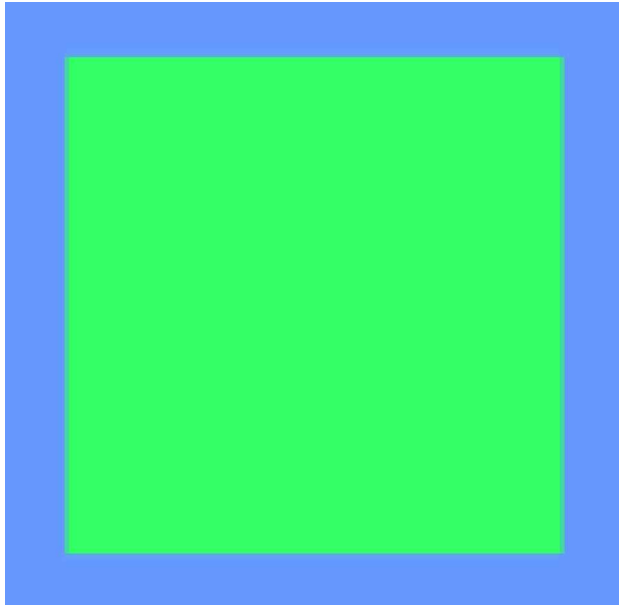
- The « homogenized » modelling is the approach that is usually considered in French criticality assessment of fuel assemblies.
- This approach is easier to implement than an array of rods which position can vary in the reference modellings.
- Rod arrays are represented by a unique fully reflected cell, in which moderation brought by missing rods is accounted for by tuning the water quantity around the rod in the modelled cell: no need to know missing rods positions.
- A homogeneous medium whose nuclear cross sections are equivalent to those of the cell is computed and then used in the 3D modelling.

One zone homogenized modelling (2/9)



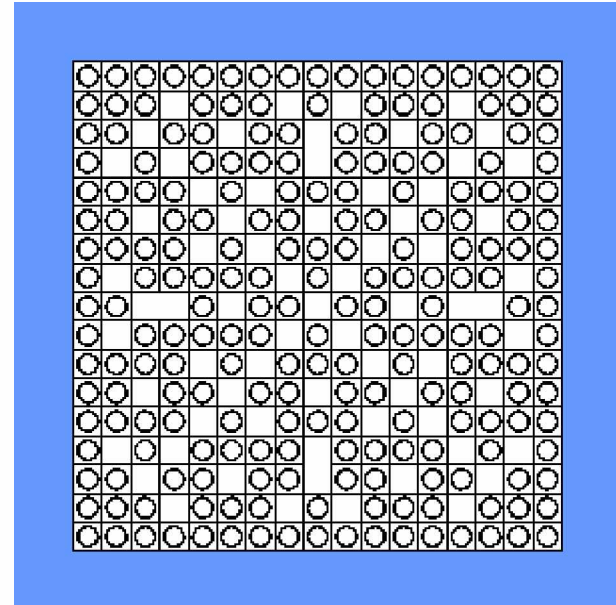
One zone homogenized modelling (3/9)

One zone



Variable: moderation ratio of the cell

Reference



Variables: number of missing rods and their location

Calculation codes and nuclear data used

- The MORET 5 3D continuous energy code was used as the reference code.
- The APOLLO2-MORET route of the CRISTAL V2.0.2 package was used for the homogenized modellings of fuel assemblies in one or two zones. The APOLLO cell code generates the multigroup cross-sections file that will then be used in the MORET 5 Monte Carlo transport calculation code.
- JEFF 3.1.1 nuclear data library were used for all calculations.

One zone homogenized modelling (4/9)

Let's challenge this calculation scheme for an infinite array of PWR type assemblies, for which two parameters can vary:

- The number of missing fuel rods per assembly ;
- The water gap between assemblies.

Fuel:

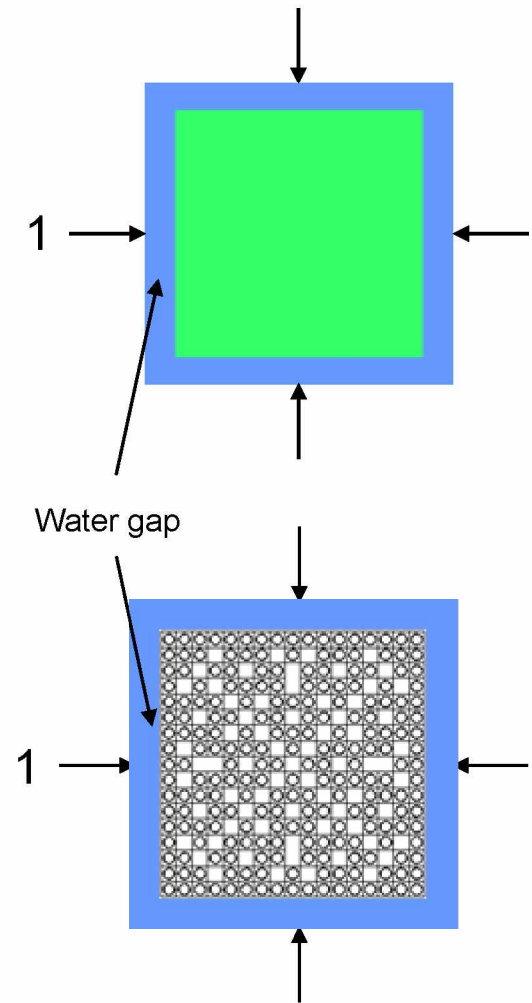
- Uranium oxide density of 10.96 ;
- 5% ^{235}U mass enrichment ;
- Pellet radius of 0.4102 cm ;
- No gap was considered between the pellet and its cladding

Cladding:

- Zirconium density of 6.506 ;
- Cladding thickness of 0.053 cm ;

PWR assembly design:

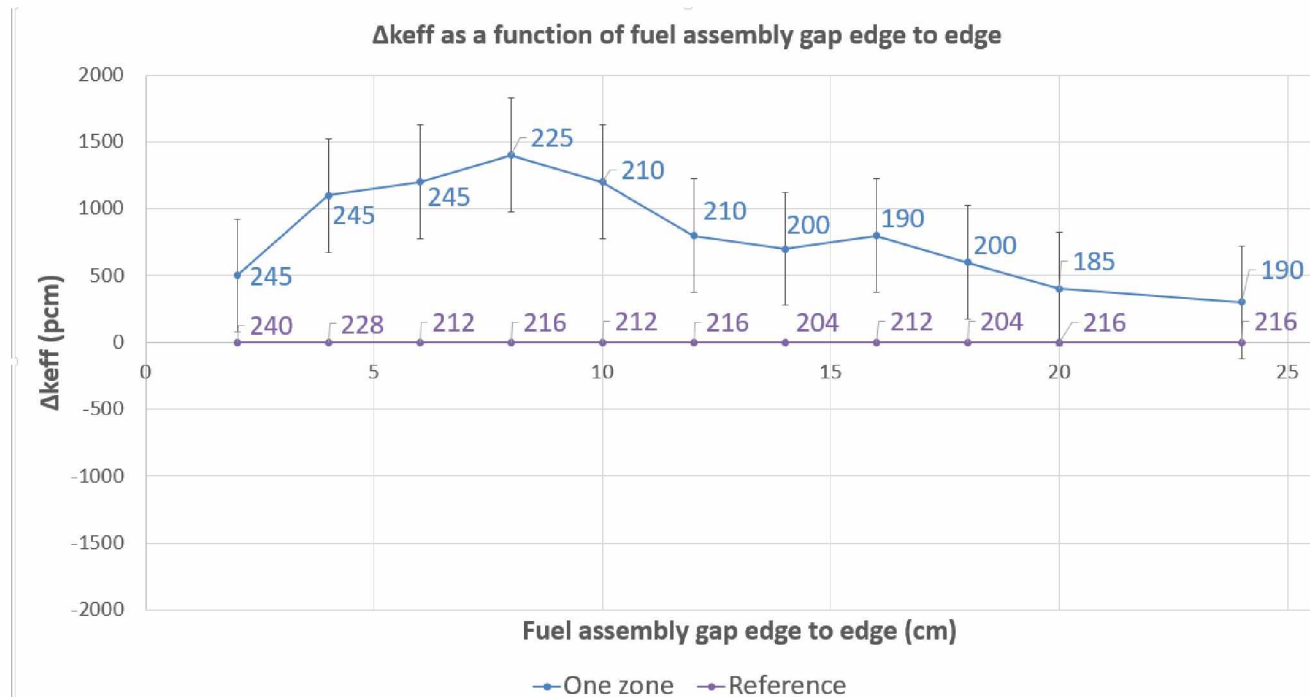
- 17x17 array (264 fuel rods and 25 water holes) ;
- Rods pitch of 1.262 cm ;
- Assembly section of 21.45 cm x 21.45 cm ;
- Infinite height modelled.



One zone homogenized modelling (5/9)

Comparison of reference Monte Carlo calculations with homogenized ones
Infinite array of 17x17 PWR assemblies

$$\Delta k_{\text{eff}} = k_{\text{eff}}(\text{reference}) - k_{\text{eff}}(\text{one zone})$$



Given numbers correspond to the number of rods needed for optimum moderation in fuel assembly

The one zone modelling isn't bounding for the studied configurations.

One zone homogenized modelling (6/9)

Let's challenge this calculation scheme for a **single BWR type assembly**, for which two parameters can vary:

- The number of missing fuel rods per assembly ;
- The pellet radius.

Fuel

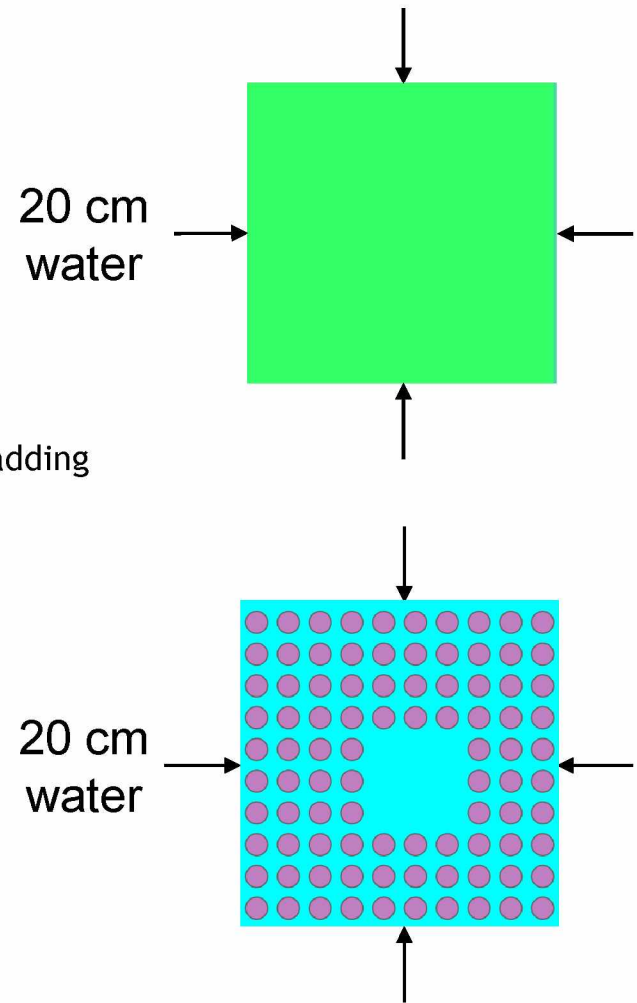
- Uranium oxide density of 10.5 ;
- 5% ^{235}U mass enrichment ;
- Variable pellet radius (from 0.4 to 0.6 cm) ;
- No gap was considered between the pellet and its cladding

Cladding

- Zirconium density of 6.506 ;
- Cladding thickness of 0.053 cm ;

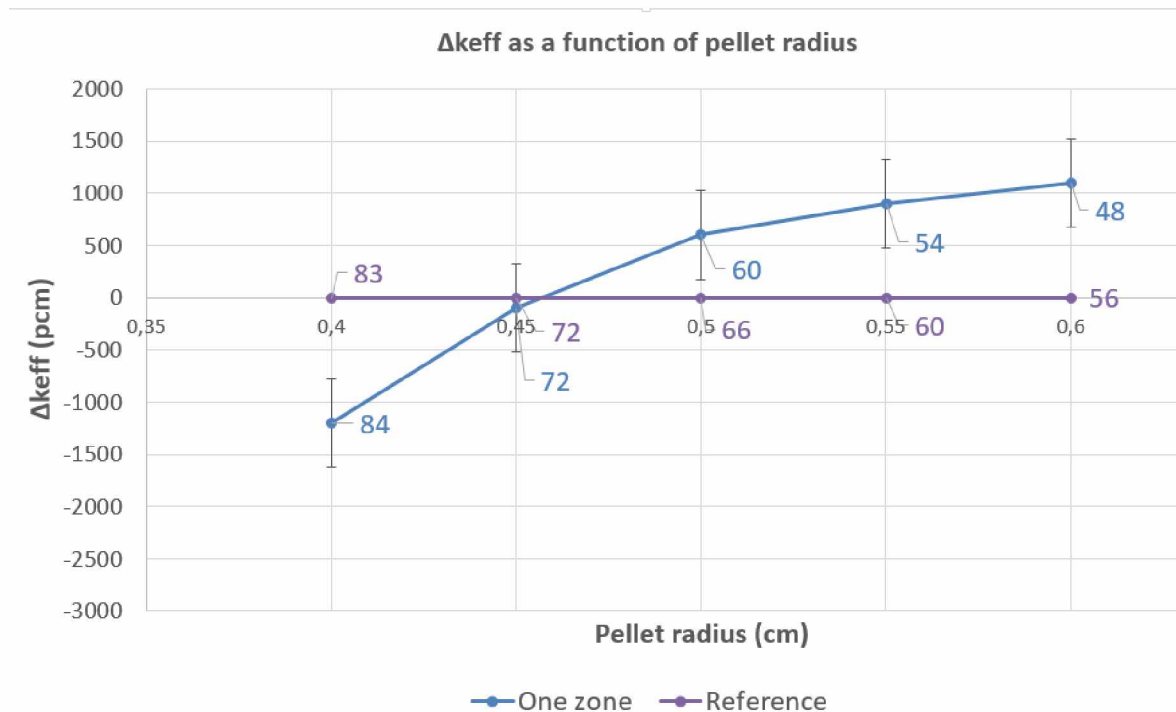
BWR assembly design

- 10x10 array (91 fuel rods and 9 water holes) ;
- Rods pitch of 1.345 cm ;
- Assembly section of 13.45 cm x 13.45 cm ;
- Infinite height modelled.



One zone homogenized modelling (7/9)

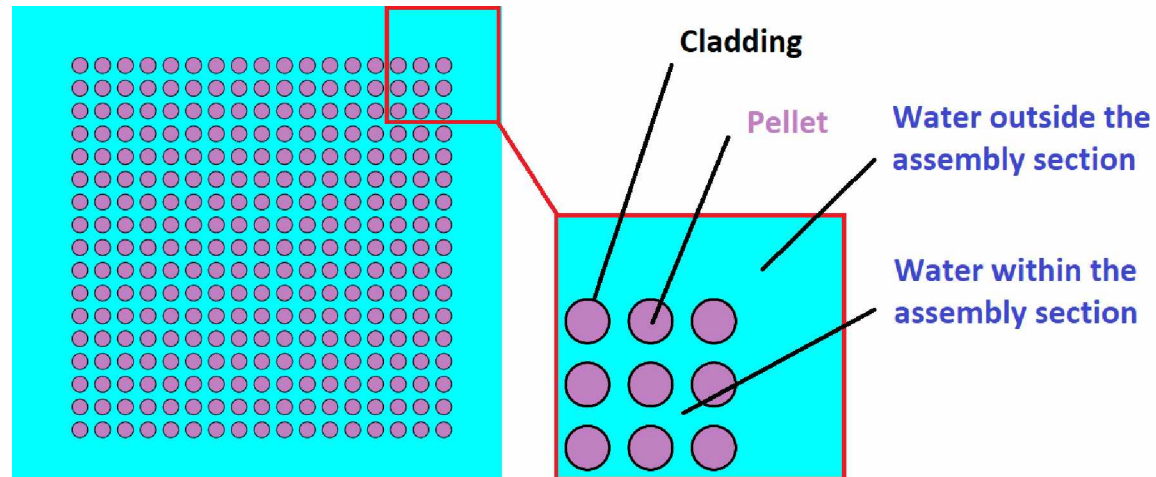
Comparison of reference Monte Carlo calculations with homogenized ones
Isolated 10x10 BWR assembly
 $\Delta k_{\text{eff}} = k_{\text{eff}}(\text{reference}) - k_{\text{eff}}(\text{one zone})$



The one zone modelling isn't bounding for high pellet radius.

One zone homogenized modelling (8/9)

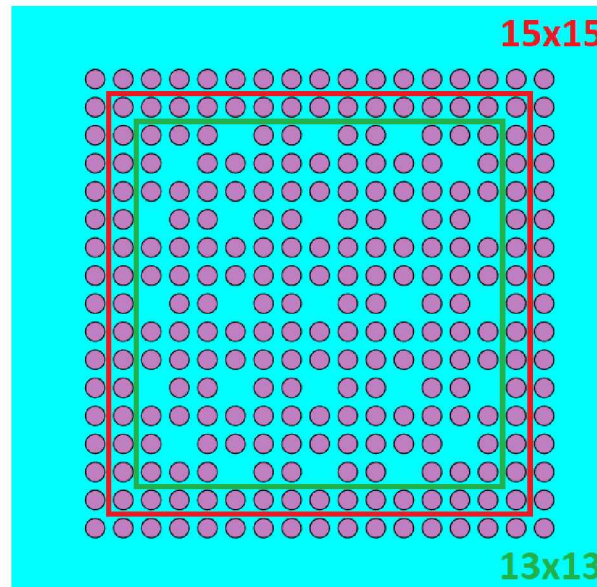
- How can these high discrepancies be explained?
- When applying the one zone homogenized modelling, the moderation ratio is **averaged for the whole assembly section**. But the generated cross sections do not take into account the spectrum shift due to the water located outside the assembly section.



- In the 3D model, rod rows on the border of the assembly is thus over-moderated and those in the inner part are under-moderated.

One zone homogenized modelling (9/9)

- Moreover, the missing rods distribution within the assembly section is not necessarily fully homogeneous.

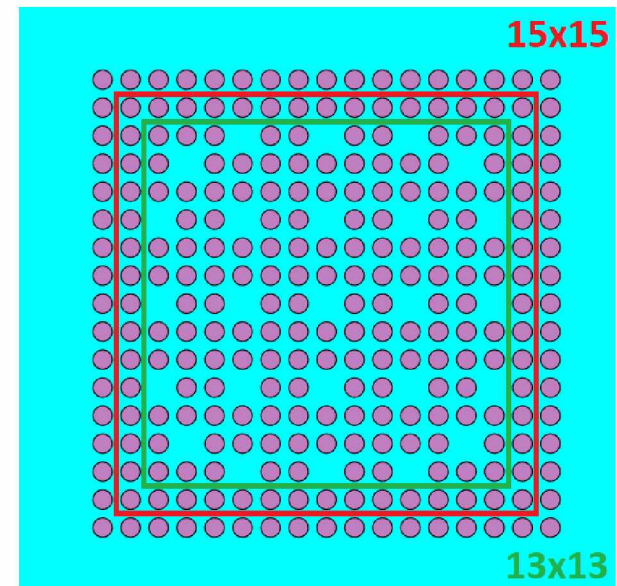
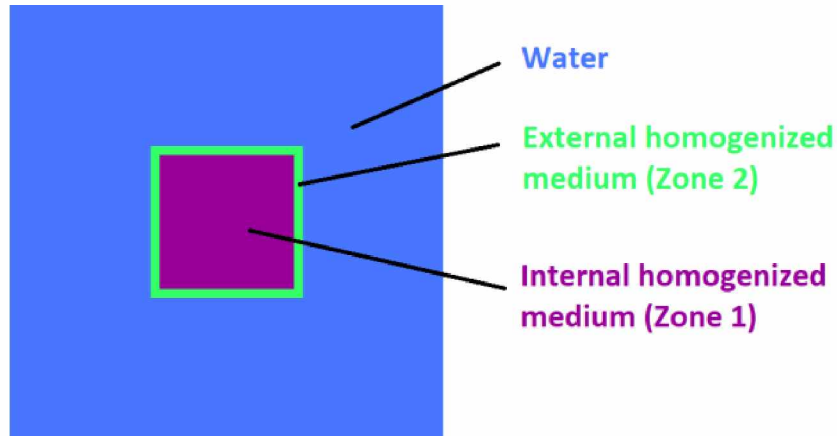


- The one zone modelling does not take into account potential moderation ratio discrepancies within the assembly section, which may influence the overall assembly reactivity.

Two zones homogenized modelling

Two zones homogenized modelling (1/6)

- Two distinct cells are modelled in order to differentiate the internal and external parts of the assembly section.



- The moderation ratios (i.e. the number of rods) in the external zone and in the internal zone vary independently.

Two zones homogenized modelling (2/6)

Let's challenge this calculation scheme for an infinite array of PWR type assemblies, for which two parameters can vary:

- The number of missing fuel rods per assembly ;
- The water gap between assemblies.

Fuel:

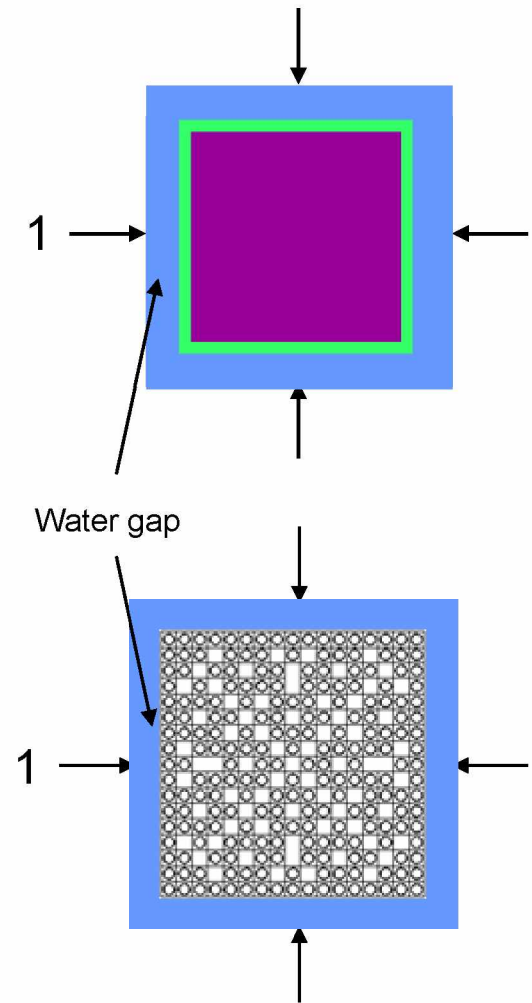
- Uranium oxide density of 10.96 ;
- 5% ^{235}U mass enrichment ;
- Pellet radius of 0.4102 cm ;
- No gap was considered between the pellet and its cladding

Cladding:

- Zirconium density of 6.506 ;
- Cladding thickness of 0.053 cm ;

PWR assembly design:

- 17x17 array (264 fuel rods and 25 water holes) ;
- Rods pitch of 1.262 cm ;
- Assembly section of 21.45 cm x 21.45 cm ;
- Infinite height modelled.

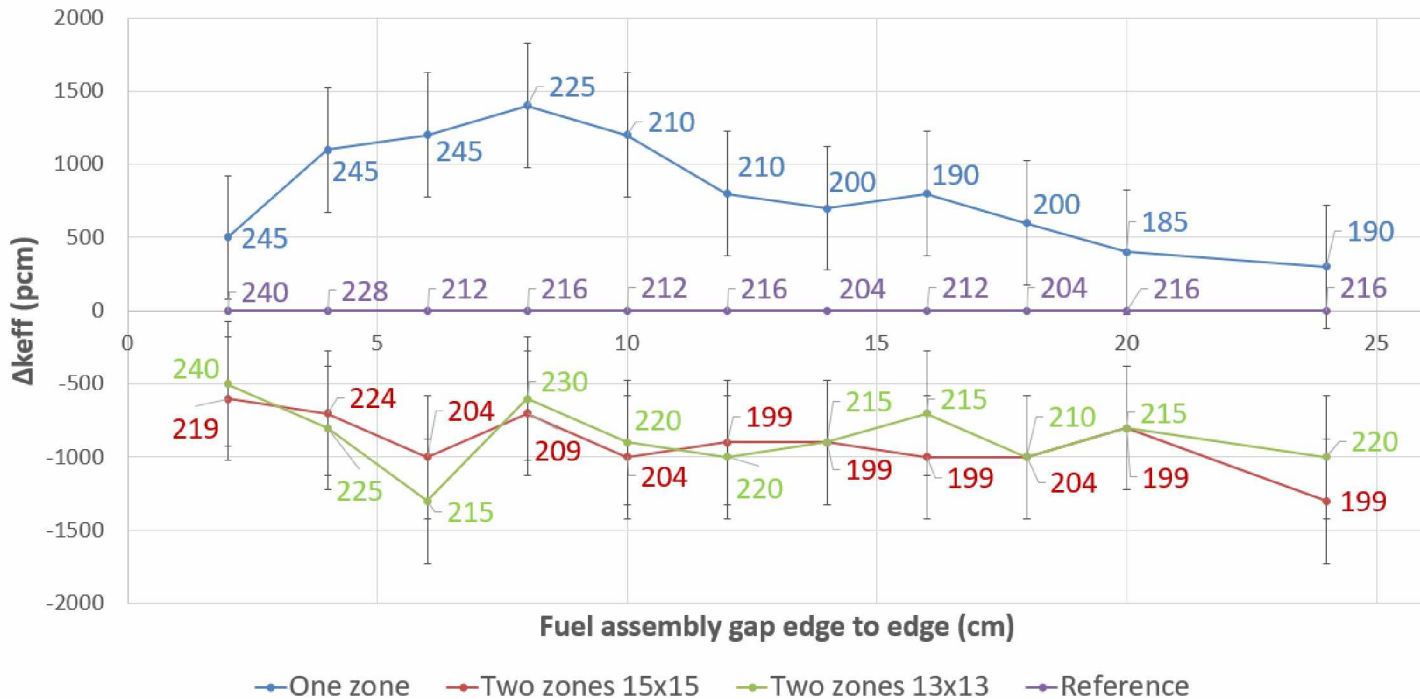


Two zones homogenized modelling (3/6)

Comparison of reference Monte Carlo calculations with homogenized ones
 Infinite array of 17x17 PWR assemblies

$$\Delta k_{\text{eff}} = k_{\text{eff}}(\text{reference}) - k_{\text{eff}}(\text{one zone})$$

Δk_{eff} as a function of fuel assembly gap edge to edge



The two zones modelling is bounding for the studied configurations.

Two zones homogenized modelling (4/6)

Let's challenge this calculation scheme for a **single BWR type assembly**, for which two parameters can vary:

- The number of missing fuel rods per assembly ;
- The pellet radius.

Fuel

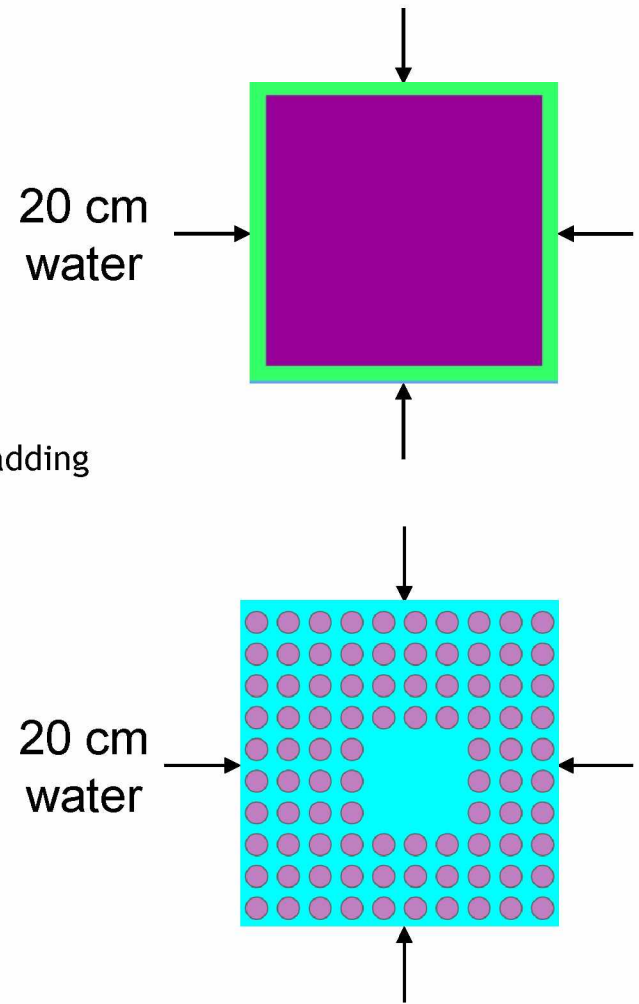
- Uranium oxide density of 10.5 ;
- 5% ^{235}U mass enrichment ;
- Variable pellet radius (from 0.4 to 0.6 cm) ;
- No gap was considered between the pellet and its cladding

Cladding

- Zirconium density of 6.506 ;
- Cladding thickness of 0.053 cm ;

BWR assembly design

- 10x10 array (91 fuel rods and 9 water holes) ;
- Rods pitch of 1.345 cm ;
- Assembly section of 13.45 cm x 13.45 cm ;
- Infinite height modelled.



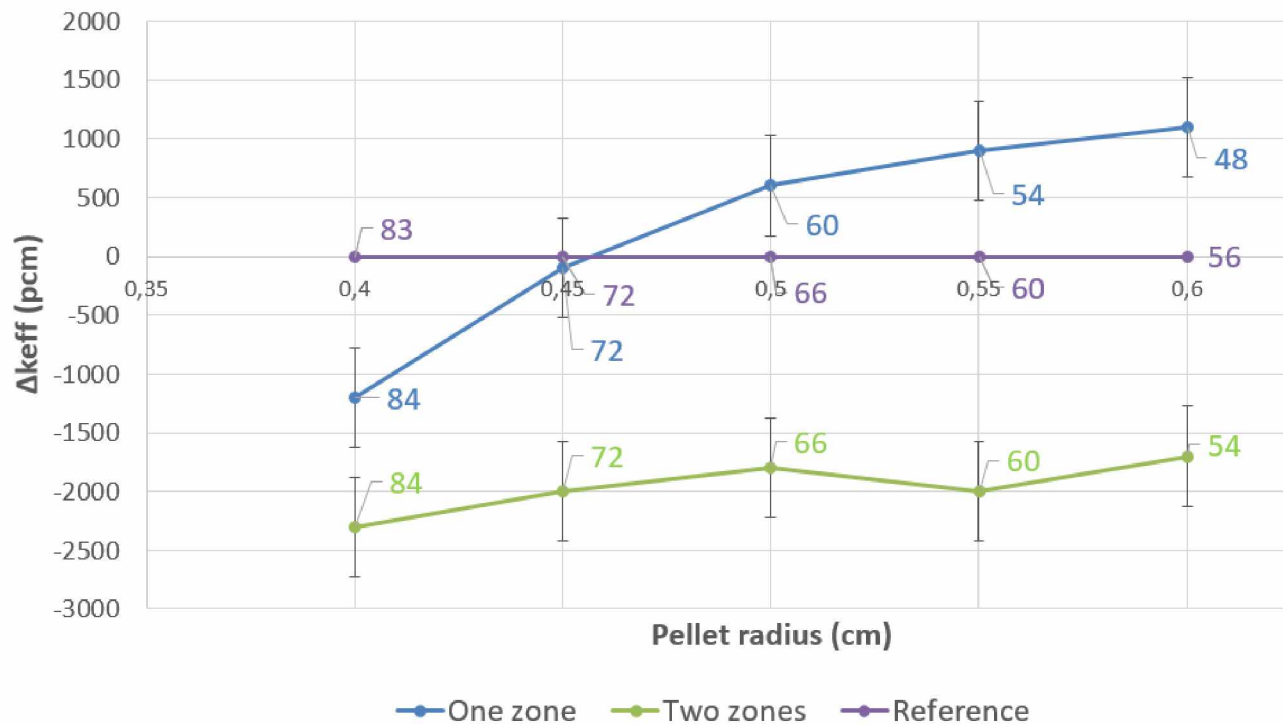
Two zones homogenized modelling (5/6)

Comparison of reference Monte Carlo calculations with homogenized ones

Isolated 10x10 BWR assembly

$$\Delta k_{\text{eff}} = k_{\text{eff}}(\text{reference}) - k_{\text{eff}}(\text{one zone})$$

Δk_{eff} as a function of pellet radius



The two zones modelling is bounding for all studied pellet radiuses.

Two zones homogenized modelling (6/6)

- The two zones homogenized scheme is relatively easy to implement: compared to the one zone scheme, it only needs an additional cell and some more calculation points.
- It leads to bounding results compared to reference calculations.
- For all pellet radiuses and fuel assemblies the maximal k_{eff} is obtained when the moderation ratio in the external zone is minimal (zone filled with rods at nominal pitch).
- However, for an industrial purpose, the two zones modelling can be too penalizing and can be difficult to use.

To go further...

- Keep on studying the two zones, particularly the influence of:
 - the nature of the fuel: this can influence the neutronic spectrum and the distribution of reaction rates within the internal and external zones defined ;
 - the pellet radius and rod pitch: they can lead to wider moderation ratio possibilities and wider discrepancies compared to the reference modelling ;
 - the size of the assembly array of rods: the proportion of “external” rods compared to “internal” rods may be a source of bias.
- Prevent assemblies from having too many missing rods, or have information regarding the assembly rods configuration to avoid k_{eff} under-estimation.
- Develop algorithms to « automatically » predict the most penalizing missing rods configuration with reference calculations and avoid tedious search for optimal positions.

Thank you for your attention 😊

Questions?