Karlsruhe Institute of Technology

Analyse von Kritikalitätsbedingungen im BE- Lagerbecken

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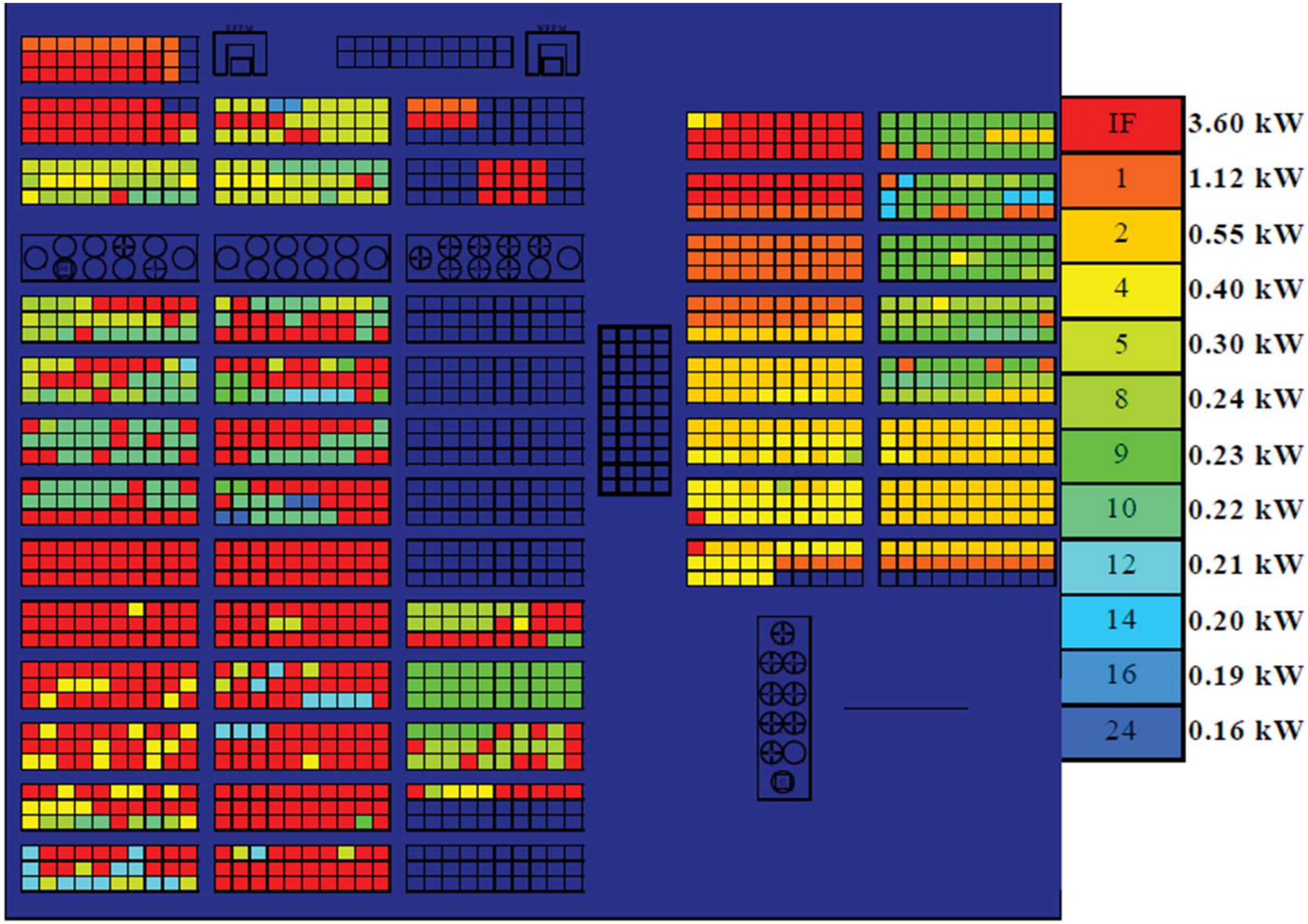
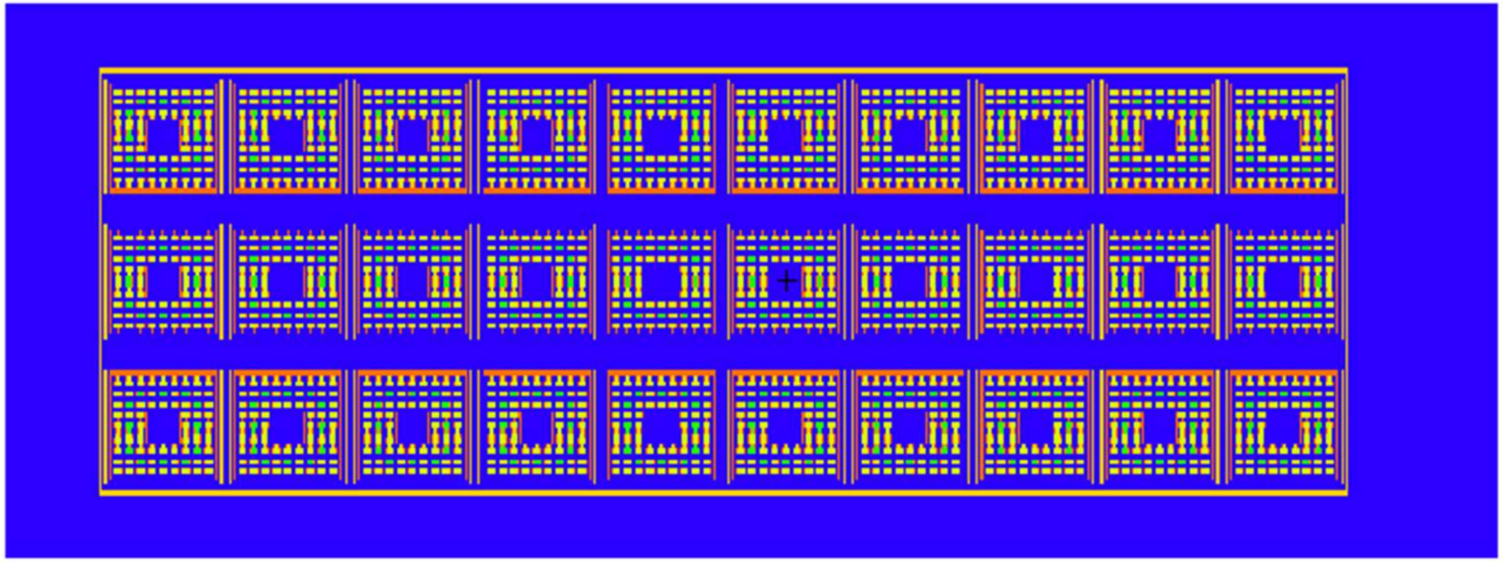
Layout of unit 4 SFP



Layout of representative Rack

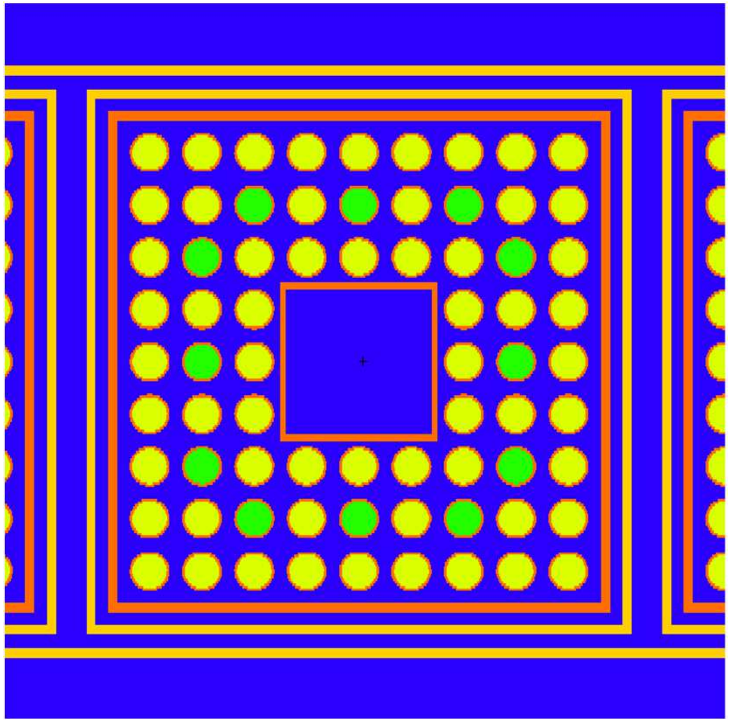
- Conservative approach:
  - reflective boundary conditions
  - water at bottom and top of the fuel pins
- Reference case: Fresh BWR fuel



Layout of fuel element

- 4wt % U235 enrichment (yellow pins)
- 3.4wt % U235 enrichment and 5 wt% in Gadolinium (green) pins
- Clad Zircaloy 4
- Stainless Steel type 1.4568

(Norm DIN EN10027-1/2 (X7 CrNIAl 17-7))



Cell pitch: 159.5 mm
Leg height: 184.2 mm
Leg weight (8 legs): 3 kg each, Stainless steel
Base plate thickness: 12.7 mm
Base plate weight of rack: 78 kg, Stainless steel
Rack height (above base plate): 4293 mm
Rack steel thickness: 2.5 mm
Rack Weight (above base plate): 2000 kg, Stainless steel
Radius of opening in base plate per FA: 48.26 mm (3.8 inch diameter)
Absorber material: none

Between the steel walls of the rack is empty space, which is filled with water (8.5 mm in outer walls (13.5 mm total wall thickness) and 35 mm in long inner walls (40 mm total wall thickness)).

Impact of Racks steel walls on criticality

- All calculations with reflective boundaries

- 4 longitudinal walls: Keff=0.7707

- 2 Longitudinal walls: Keff =0.78638

- No inner longitudinal walls:
  Keff =0.80234

$\sigma = 1\times10^{-4}$ for all calculations

Impact of void with reflection at the boundary (I)

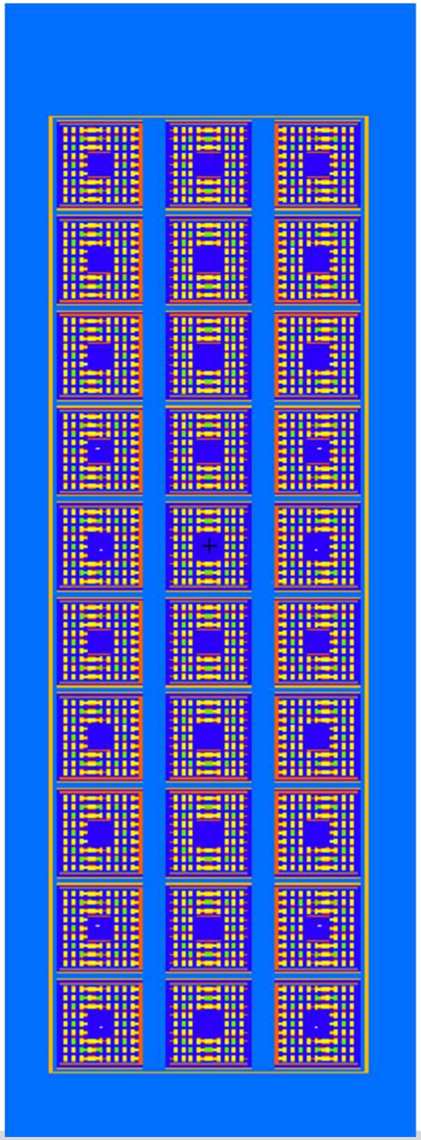
- Reference calculations with fresh fuel were done without inner longitudinal walls: Keff: 0.8023

- With 94% void in the spaces between the fuel pins and normal density within the pin:

  Keff=0.91107

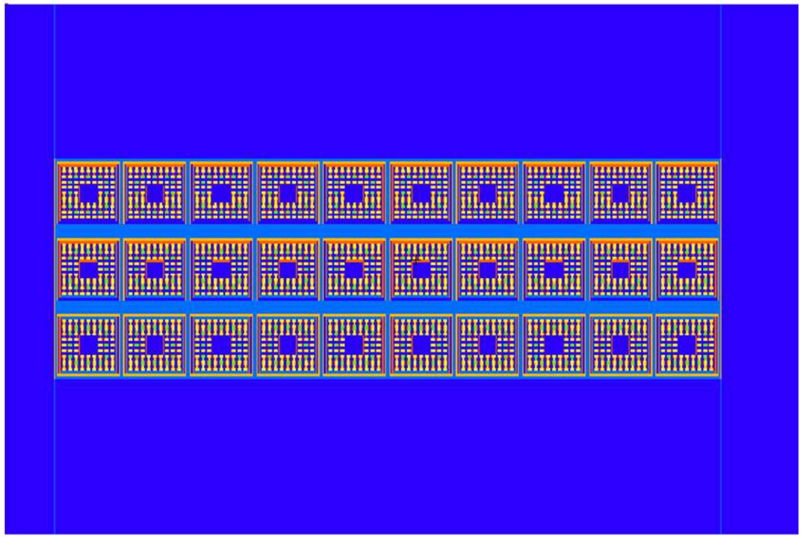
- 94% void over all the rack , including the fuel elements

  Keff : 0.5632

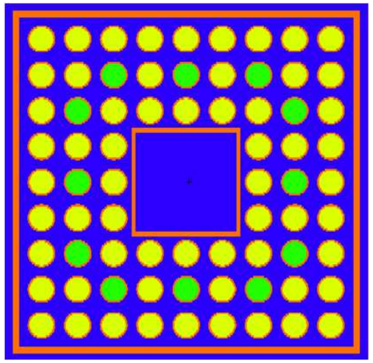


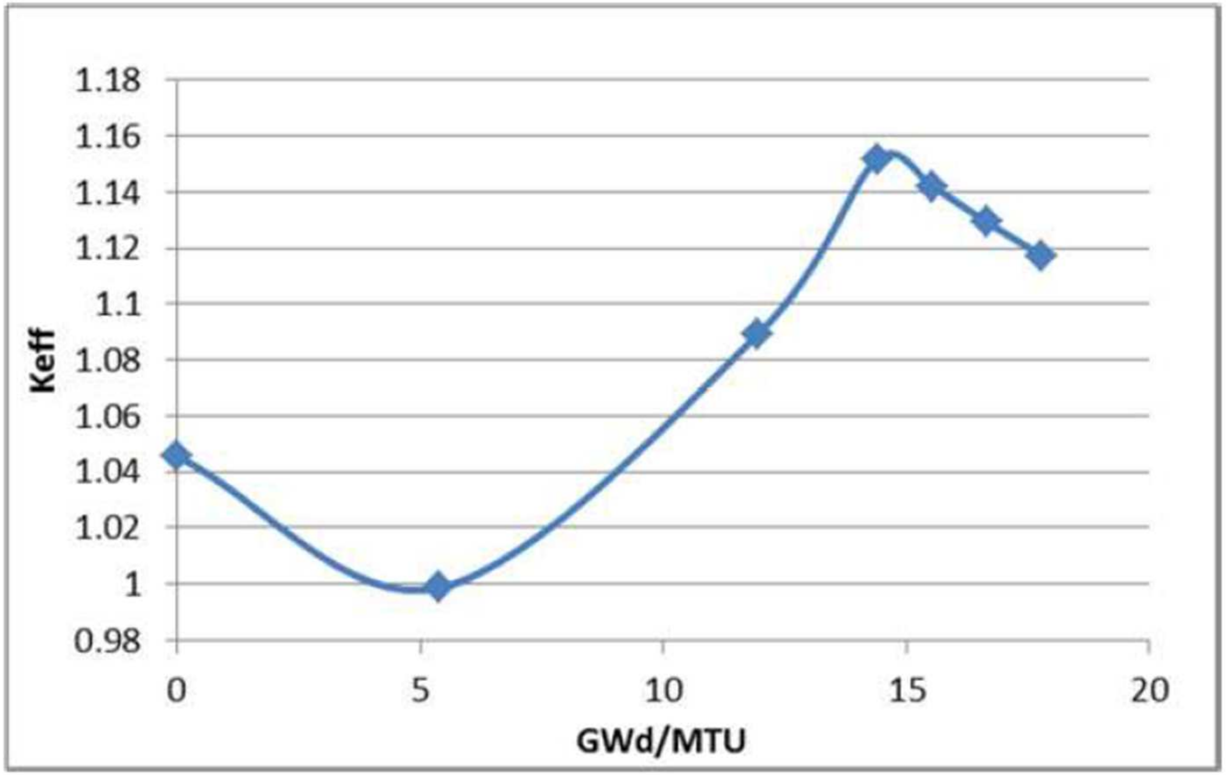
Impact of void without reflection at the boundary (II)

- The reference calculations without inner longitudinal walls:
  (with reflection) Keff: 0.8023
- Void only in the inner spaces between the rows of the fuel elements without reflection: Keff=0.7875
  (less by : $\Delta k_{eff} \approx 0.13$ for the full reflection case) (former page)



Change of criticality due to burn up of Gd loaded BWR fuel element





Fuel Element of about 14GWd/MTU exhibit up to $\Delta k_{eff} \approx 0.15$

Geometrical model of fuel assembly and rack

Two geometrical models analyzed (2d + 3d):

- Infinite lattice of single fuel assemblies
  (simplified model)

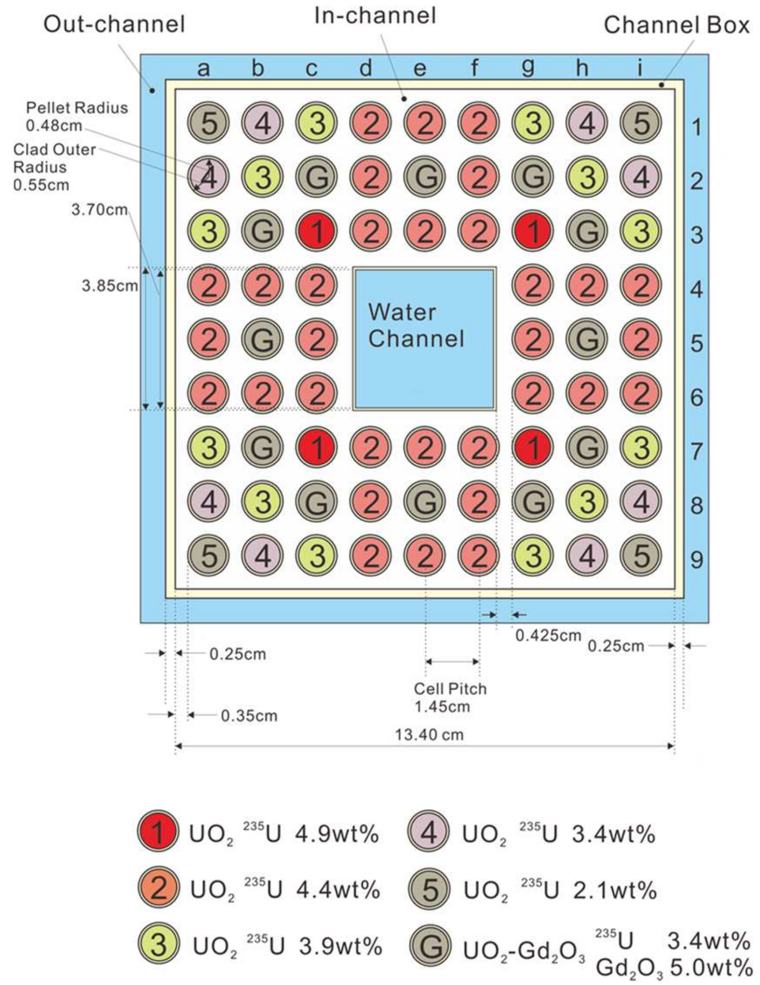
- Infinite lattice of fuel racks
  (still simplified but more realistic)

Two different fuels considered:

- Fresh fuel

- Burn up of 13 GWd/tHM

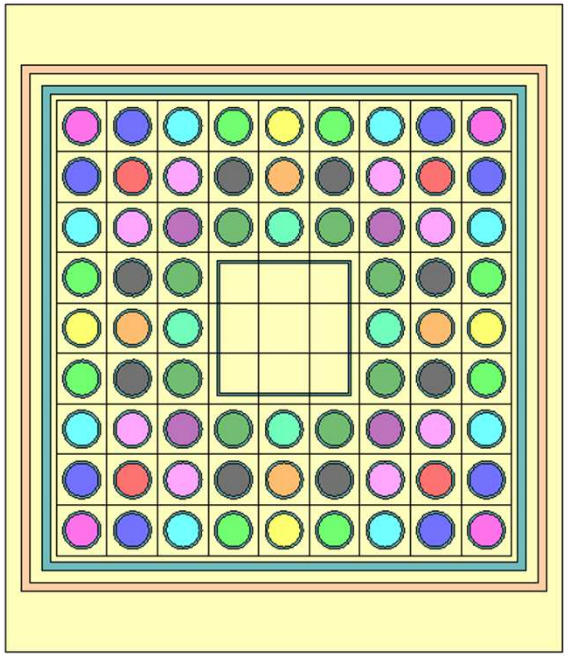
  (considered Nuclides: $^{234, 235, 236, 238}$U, $^{238, 239, 240, 241, 242}$Pu, ^{237}Np, $^{241, 243}$Am, ^{109}Ag, ^{133}Cs, ^{153}Eu, $^{155, 157}$Gd, ^{95}Mo, $^{143, 145}$Nd, ^{103}Rh, ^{101}Ru, $^{147, 149, 150, 151, 152}$Sm, ^{99}Tc, ^{16}O)



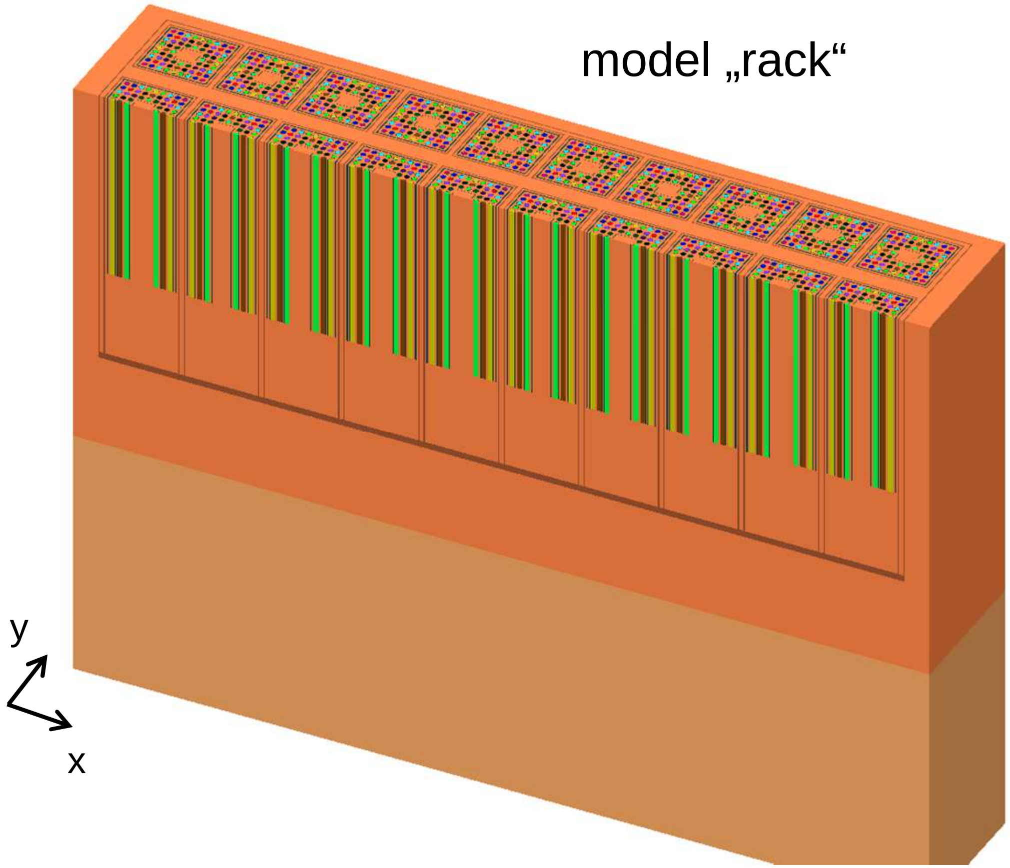
Geometrical model of fuel assembly and rack

- Different enrichments per fuel pin considered
- Assumed distance between racks: 10cm in x and 6 cm in y
- Reflective boundary conditions

model „BE“



model „rack“



k_{eff} calculations

Neutron multiplication factor k_{eff} of considered models:

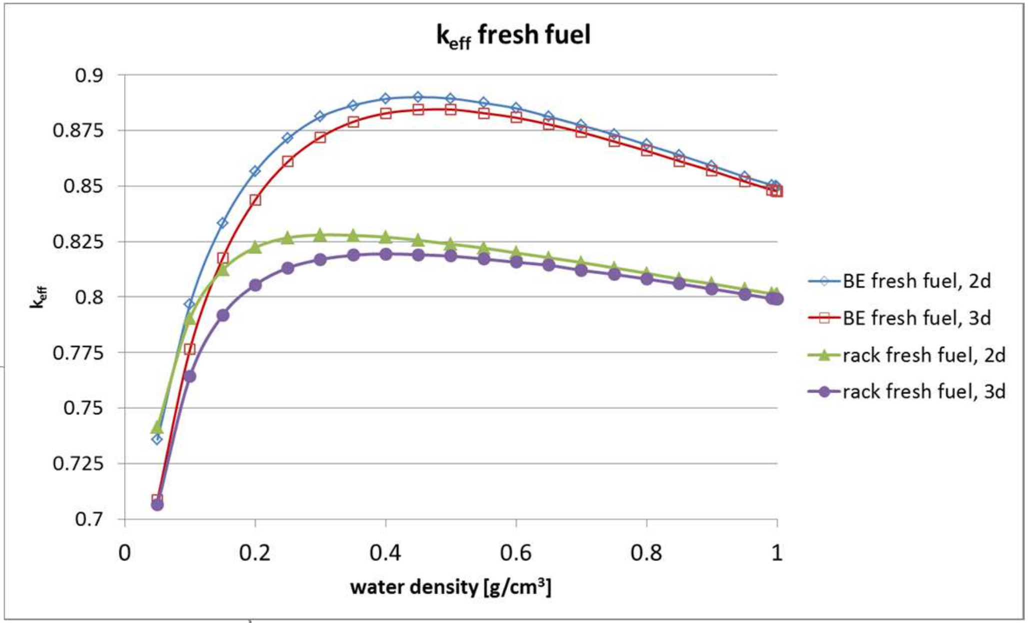
	$k_{eff,BE}$		$k_{eff,rack}$	
	2d	3d	2d	3d
Fresh fuel	0.8504	0.8481	0.8014	0.7994
13 GWD/tHM	0.9797	0.9773	0.9232	0.9212

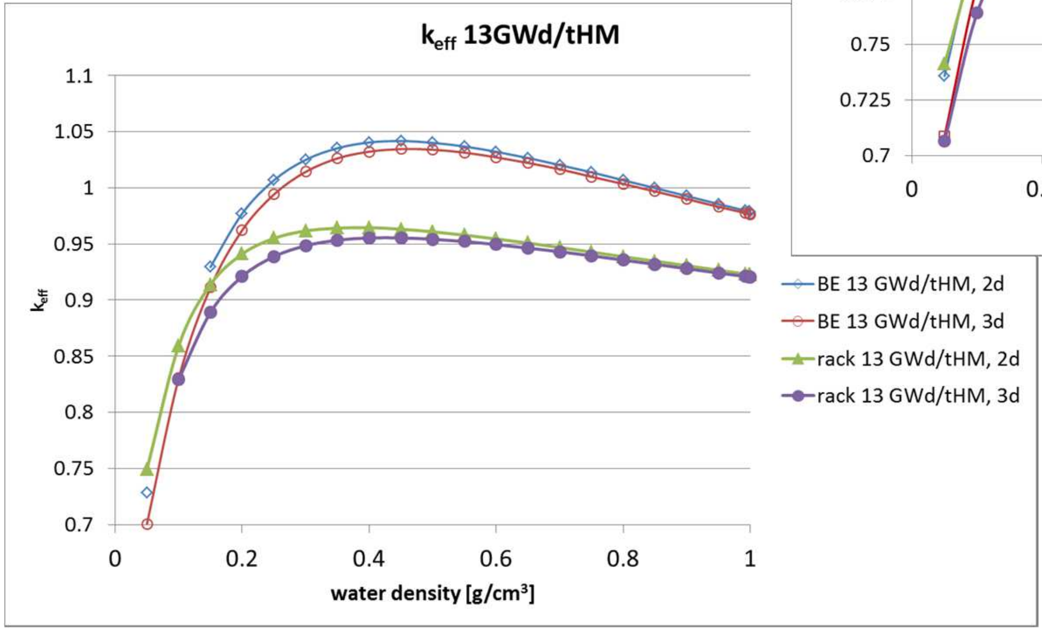
- Reactivity increases with burnup, maximum at reactor conditions at about 13 GWd/tHM, increase in k_{eff}: $\Delta k_{eff} \approx 0.12$
  (from OECD/NEA Expert Group BUC Phase IIIc Benchmark)
- Realistic model „rack“ results in a k_{eff} well below the administrative limit of 0.95
- Model „BE“ more conservative $\Rightarrow$ structure of the rack important to keep k_{eff} below 0.95

k_{eff} calculations

Variations of water density between 0.05 g/cm^3 and 1.0 g/cm^3 :

- Scenario: Heating up of the water

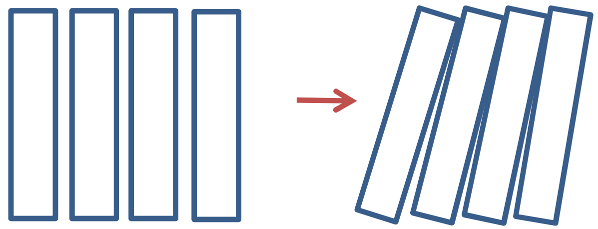


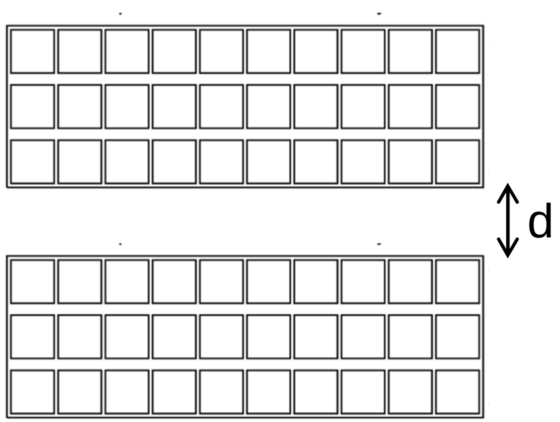


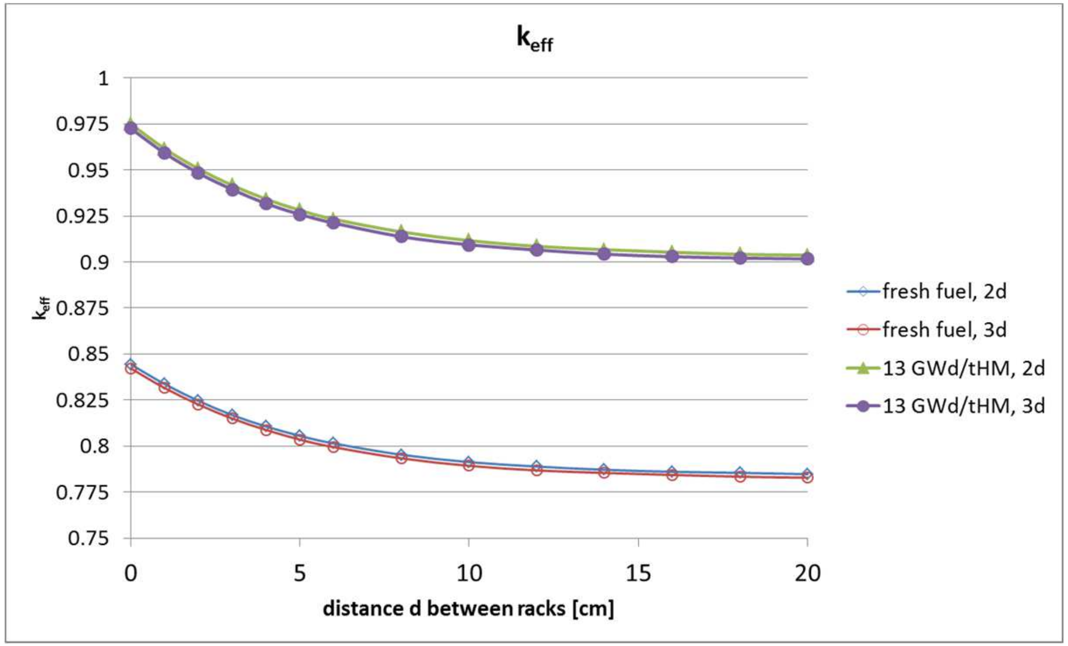
k_{eff} calculations

Variations of the rack separation in y between 0.0 cm and 20.0 cm:

- Scenario: steel looses its stability due to heating up, legs and spacers between racks deform and racks „topple down“ („domino effect“):
- Approximation: reducing the distance between racks

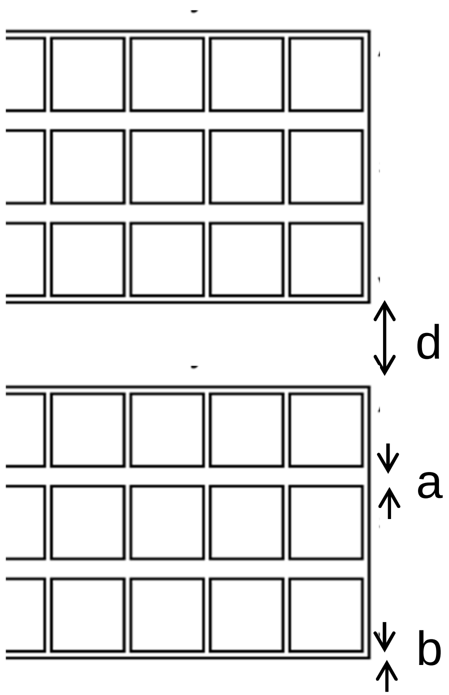


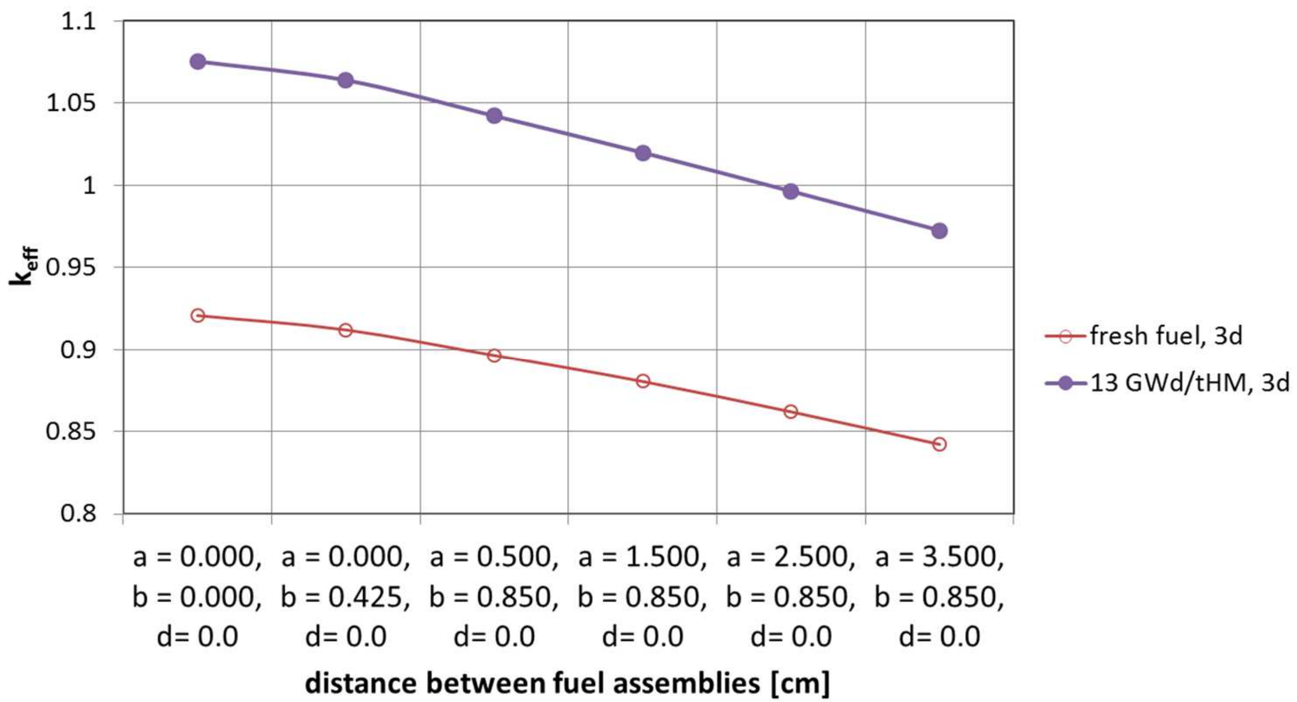




k_{eff} calculations

Variations of the fuel assembly separation in y inside the racks between 0.0 cm and 3.5 cm:





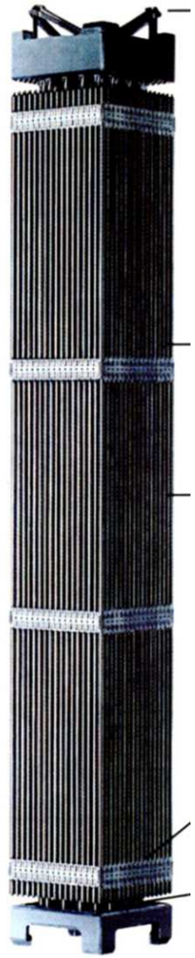
^{14}C Production

- Physical formation of ^{14}C in fuel assemblies by
  - neutron capture reactions
  - ternary fission in the fuel

  during reactor operation

$^{14}_{7}N(n,p)^{14}_{6}C$	$^{14}_{7}N + {}^{1}_{0}n \rightarrow [^{15}_{7}N]^{*} \rightarrow {}^{14}_{6}C + {}^{1}_{1}p$
$^{17}_{8}O(n,\alpha)^{14}_{6}C$	$^{17}_{8}O + {}^{1}_{0}n \rightarrow [^{18}_{8}O]^{*} \rightarrow {}^{14}_{6}C + {}^{4}_{2}He$
$^{13}_{6}C(n,\gamma)^{14}_{6}C$	$^{13}_{6}C + {}^{1}_{0}n \rightarrow [^{14}_{6}C]^{*} \rightarrow {}^{14}_{6}C + \gamma$

ternary fission in LWR fuel	1.7×10^{-6} per thermal ^{235}U fission [1]
	1.8×10^{-6} per thermal ^{239}Pu fission [1]

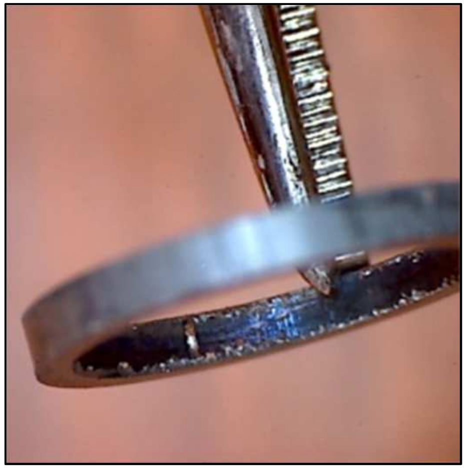


[[1] Neeb (1997) The radiochemistry of nuclear power plants with light water reactors. de Gruyter, Berlin. // Nucl. Engineering International (2003) vol. 48, no. 590, Fuel design data.

Results: inventory analysis

- experimentally obtained results for ^{14}C, ^{55}Fe and ^{125}Sb are in good agreement with calculations
- The build up of C14 was linear to the N14 concentration about 1000 Bq/gr per 1ppm N14.
- C/E ^{137}Cs inventory is different by factor 117

  → The precipitation of volatile (light blue) ^{137}Cs on the inner cladding surface during operation can not be taken into account in the MCNP calculations.



radionuclide	^{14}C	^{55}Fe	^{137}Cs	^{125}Sb
		[Bq/(g Zyr-4)]		
Experimental	$3.7(\pm0.4)\times10^{4}$	$1.5(\pm0.2)\times10^{5}$	$3.4(\pm0.3)\times10^{6}$	$2.4(\pm0.2)\times10^{5}$
calculated	3.2×10^{4}	1.3×10^{5}	2.9×10^{4}	2.6×10^{5}

Conclusions

- With the conservative consideration it is seen that the sub criticality is well below the limit of 0.95 (~0.7-0.80)
- Expected void should in principle decrease the sub criticality due to lack of moderation.

- The Gd impact is worth about 0.15 in criticality, at maximal conservative condition .

- Only fuel elements , all of which, with the maximal Gd worth combined with (unrealistic)
  - with dedicated location of void between the fuel elements
  - or compaction of the racks to a "reactor like" configuration

    might lead to super criticality.
- Release of Activated nuclides is unavoidable and should be considered for any fuel deformation scenario.

Acknowledgment

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