Karlsruher Institut für Technologie

Assessment of homogenization methodologies for pin-by-pin neutron transport calculations using DYN3D

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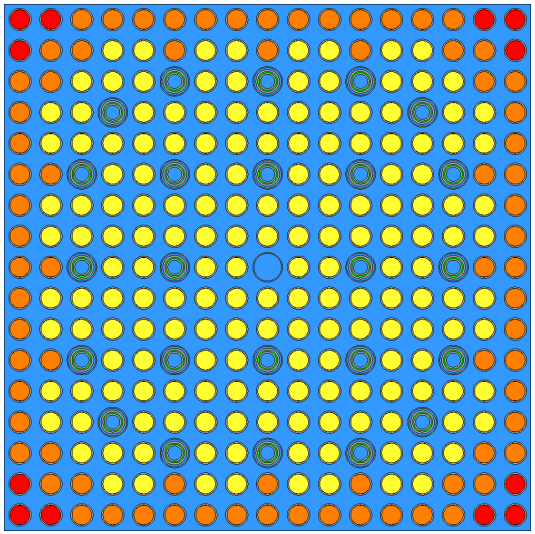
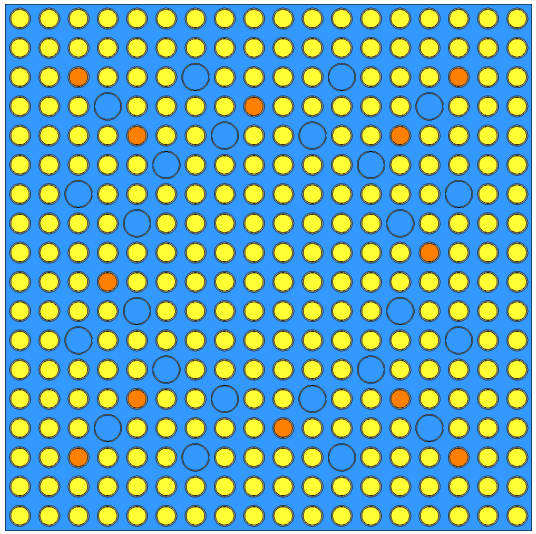
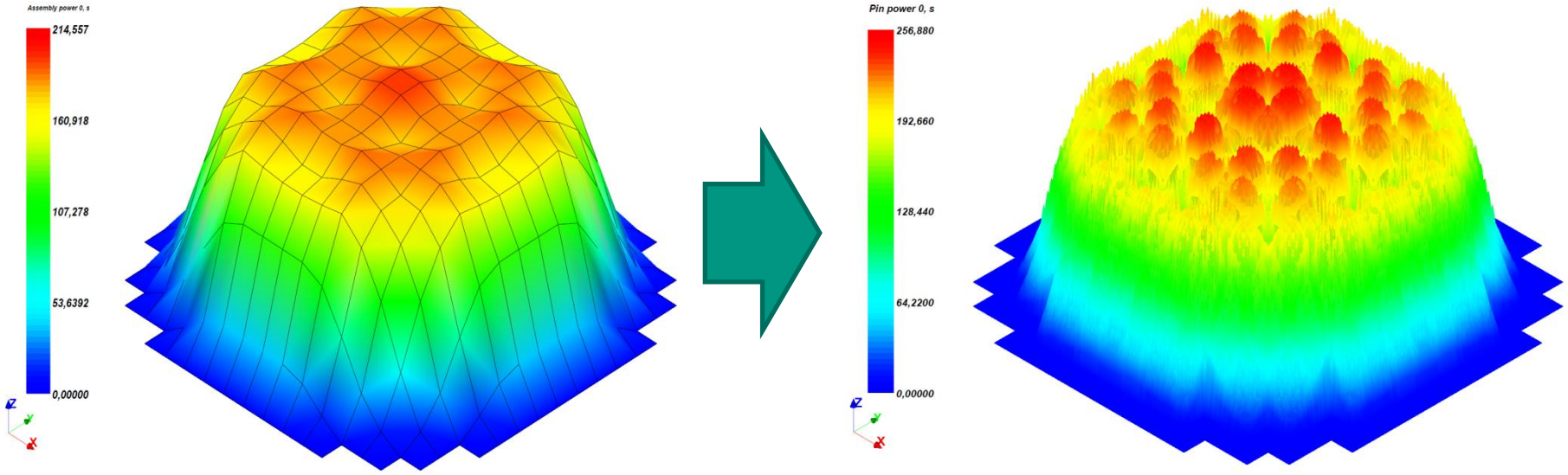




Upcoming pin-by-pin multi-physics simulations in need of accurate few-group constants



Fuel assembly / channel resolution coupled NK – TH simulation

Fuel pin / sub-channel resolution coupled NK – TH simulation

Multi-physics simulations done with DYNSUB.
OECD/NEA and U.S. NRC PWR MOX/UO2 core transient benchmark core under HFP conditions.

Homogenization methodologies for pin-by-pin neutron transport calculations

1. Finite lattice pin cell calculations
2. Super-cell calculations, one material per pin type
3. Super-cell calculations, one material per pin position
4. Super-cell calculations
   + homogenization corrections

Homogenization corrections diffusion only

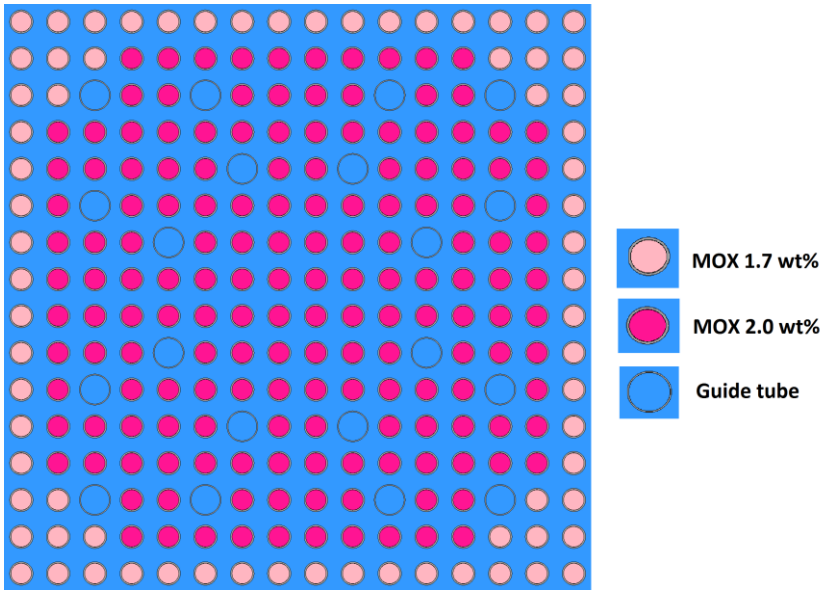


Fig. 1. Composition of a 16x16-25 MOX Fuel Assembly

Super-homogenization factors

- in case of zero currents across cell boundaries, SPH factors are the inverse of an ADF/CDF

- SPH factors are defined as for diffusion

$$\mu = \frac{\overline{\Phi}_{het}}{\overline{\Phi}_{hom}}$$

- They have to be obtained by an iterative procedure using the lower order formulation of the homogeneous system (DYN3D), based on the following expressions

$$\tilde{\Sigma} = \mu \, \Sigma$$
$$\tilde{\Sigma} \, \overline{\Phi}_{hom} = \Sigma \, \overline{\Phi}_{het}$$

Interface discontinuity factors

- Generalized Equivalence theory (GET) flux discontinuity factors

$$f_{GET}^{s} = \frac{\phi_s^{het}}{\phi_s^{hom}}$$

- Black-box homogenization (BBH) current discontinuity factors

$$f_{\pm_{BBH}}^{s} = \frac{J_{\pm_s}^{het}}{J_{\pm_s}^{hom}}$$

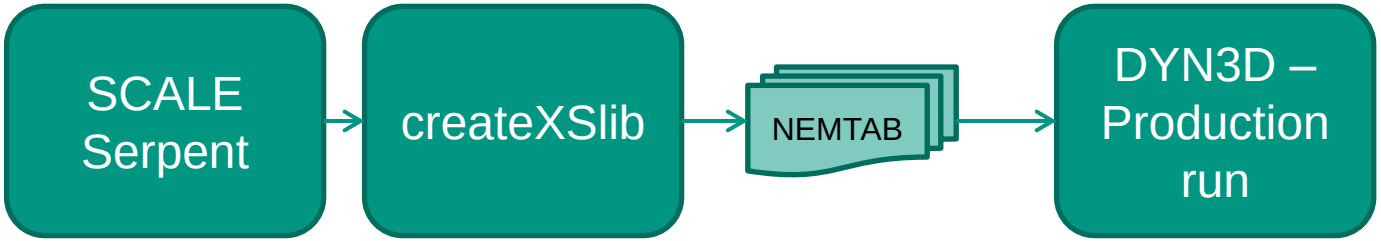
In case of the diffusion approximation can be written as flux discontinuity factor:

$$f_{BBH}^{s} = 2\,\frac{J_{-_s}^{het} + J_{+_s}^{het}}{\phi_s^{hom}}$$

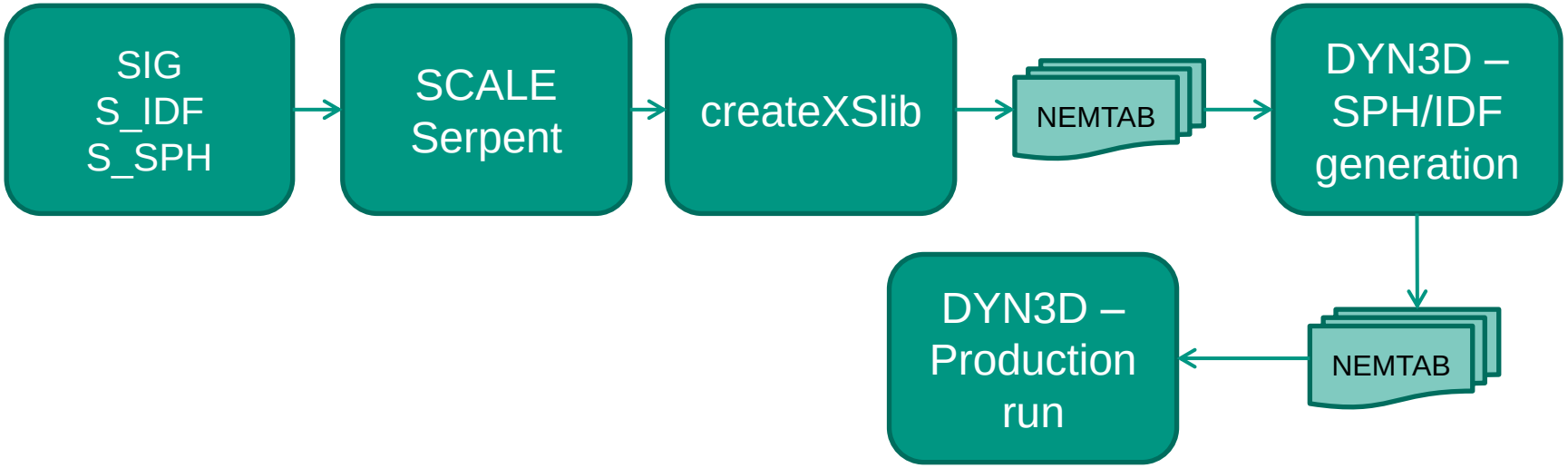
Energy group indices were omitted for simplicity

Calculation route for cross section generation

- Without homogenization corrections



- With homogenization corrections



Selected assessment case 1 (1/2)

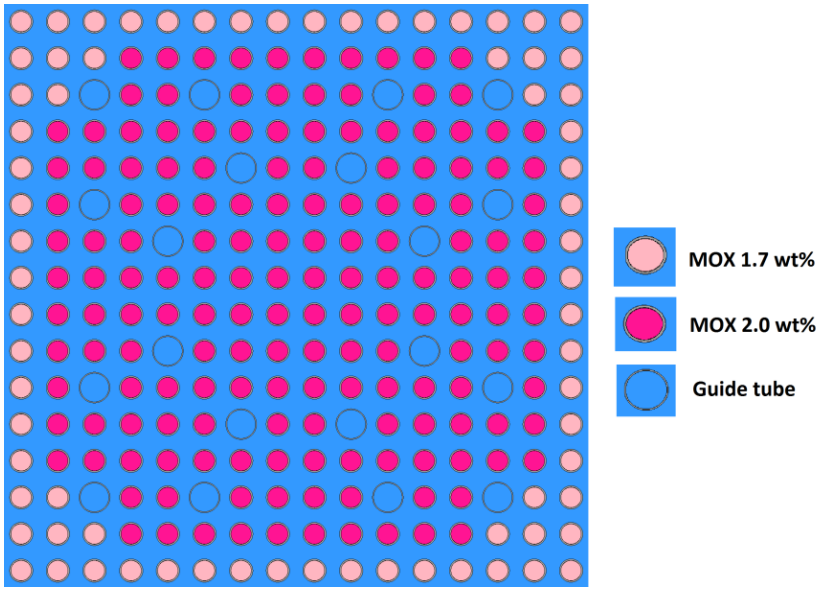
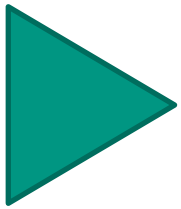


Fig. 1. Composition of a 16x16-25 MOX Fuel Assembly

Code	k-inf	Relative difference [pcm]
Serpent 2 CE	1.08496±0.000030	-
DYN3D 4g diff (3M)	1.087627	266.7
DYN3D 4g sp3 (3M)	1.086733	177.3
DYN3D 4g diff (32M)	1.087578	261.8
DYN3D 4g sp3 (32M)	1.086685	172.5
DYN3D 4g (256M) SPH	1.084951	0.9
DYN3D 4g (256M) GET IDF	1.084950	1.0
DYN3D 4g (256M) BBH IDF	1.084950	1.0

Selected assessment case 1 (2/2)

Code	Max. rel. pin power error [%]
DYN3D 4g diff (3M)	1.22
DYN3D 4g sp3 (3M)	1.50
DYN3D 4g diff (32M)	0.49
DYN3D 4g sp3 (32M)	0.28
DYN3D 4g (256M) SPH	0.01
DYN3D 4g (256M) GET IDF	0.05
DYN3D 4g (256M) BBH IDF	0.05



Going from pin type XS to pin position does not improve eigenvalue prediction but maximal pin power errors are more than halfed

Selected assessment case 2 (1/2)

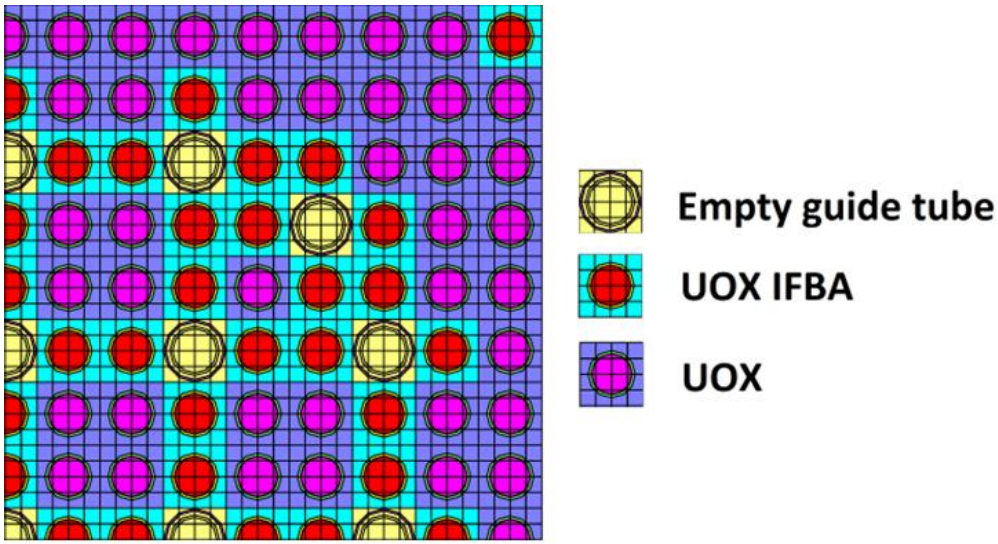


Fig. 2. Composition of a Quarter of a 17x17-25 UOX Fuel Assembly

Code	k-inf	Relative difference [pcm]
SCALE 238g	1.1231457	-
DYN3D 4g diff (3M)	1.070184	-5296.17
DYN3D 4g sp3 (3M)	1.123559	41.33
DYN3D 4g diff (37M)	1.123647	50.13
DYN3D 4g sp3 (37M)	1.123479	33.33
DYN3D 4g (289M) SPH	1.123142	0.37
DYN3D 4g (289M) GET IDF	1.123144	0.17
DYN3D 4g (289M) BBH IDF	1.123144	0.17

Selected assessment case 2 (2/2)

Code	Max. rel. pin power error [%]
DYN3D 4g diff (3M) DYN3D 4g sp3 (3M)	12.72 2.16
DYN3D 4g diff (37M) DYN3D 4g sp3 (37M) DYN3D 4g (289M) SPH DYN3D 4g (289M) GET IDF DYN3D 4g (289M) BBH IDF	0.74 0.54 0.01 0.005 0.005

If poisons are included in an assembly the previously observed effects are even more significant

Conclusions

- Pin-by-pin diffusion calculations should never be done without homogenization corrections
- Simplified transport did relatively well even without homogenization corrections
- Always one cross section set per pin position should be employed, greatly improved reaction rate prediction
- More work needs to be done on the selection of super-cells for engineering sized cases
- Efforts to determine homogenization corrections for SP3 are on-going