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The POLCA8H nodal code for VVER-1000

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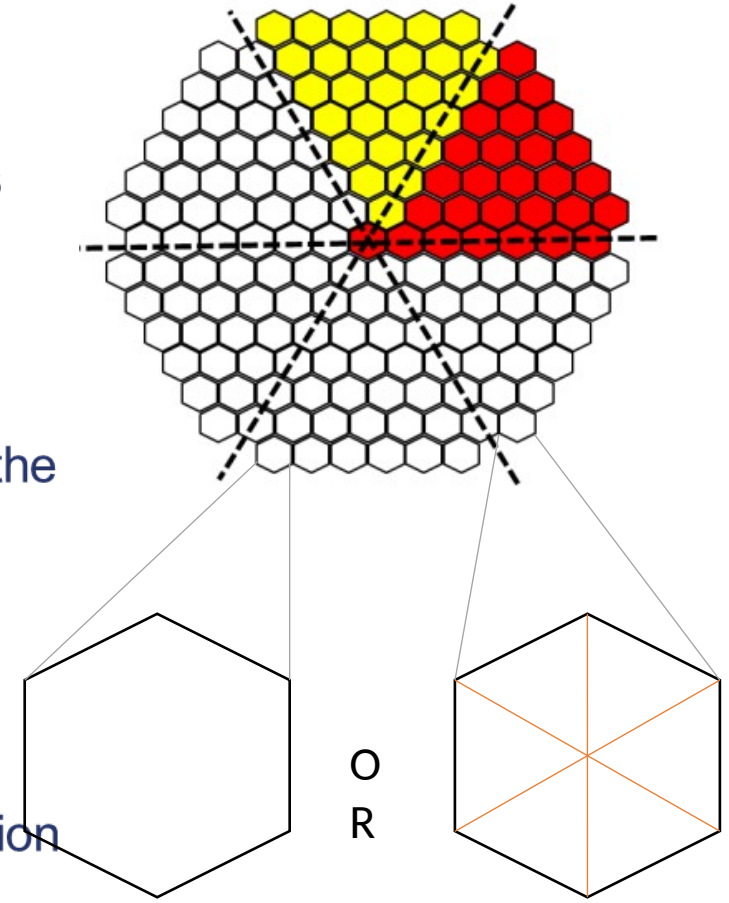
APIS

Outline

- Overview of the code
- Applications
- Parallel performance
- Verification and Validation

Neutronics

- Multigroup diffusion equation + Generalized Equivalence Theory
- Each assembly is modelled with hexagonal or triangular homogeneous nodes
- Reflector nodes are used radially and axially
- The diffusion equation is solved with the Fourier expansion method in the homogeneous domains
- The nodes are coupled via node to node boundary conditions with respect to flux and current
- k_{eff} and flux distribution are calculated iteratively with the Power iteration



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Cross section model

$$
\begin{aligned}
\Sigma \;=\; & \Sigma^{base}(E,\rho_h,\rho) \;+\; \Delta\Sigma^{SG} + \Delta\Sigma^{CR} \\
& + \Delta\Sigma^{BHI}(E,\rho,B_h) \\
& + \Delta\Sigma^{DBA} \\
& + b_{B1}\left[C_B - C_B^{base}\right] + b_{B2}\left[C_B - C_B^{base}\right]^2 \\
& + c_{Xe}\left[N_{Xe} - N_{Xe}^{base}(E,\rho_h,w_{CBH})\right] \\
& + d_{Dop}\left[\sqrt{T_f} - \sqrt{T_f^{base}}\right] \\
& + c_{T_m}\left[T_m - T_m^{base}\right] \\
& + \sum_i \sigma_i\left[N_i - N_i^{base}(E,\rho_h,B_h,w_{CBH},DBA)\right] \\
& + w_{CBH}\left[(1-\delta_{CR})\Delta\Sigma^{CBH,out} + \delta_{CR}\Delta\Sigma^{CBH,in}\right] \\
& + \Delta\Sigma^{spat}
\end{aligned}
$$

- XS = baseXS(E,ρ_h,ρ) + space grid + control rod
  - + deviation in boron history
  - + discrete burnable absorber history
  - + soluble boron deviation
  - + deviation in xenon concentration
  - + deviation in fuel temperature
  - + deviation in moderator temperature
  - + deviation of nuclide inventory
  - + effect of control rod history
  - + intranodal spatial variation

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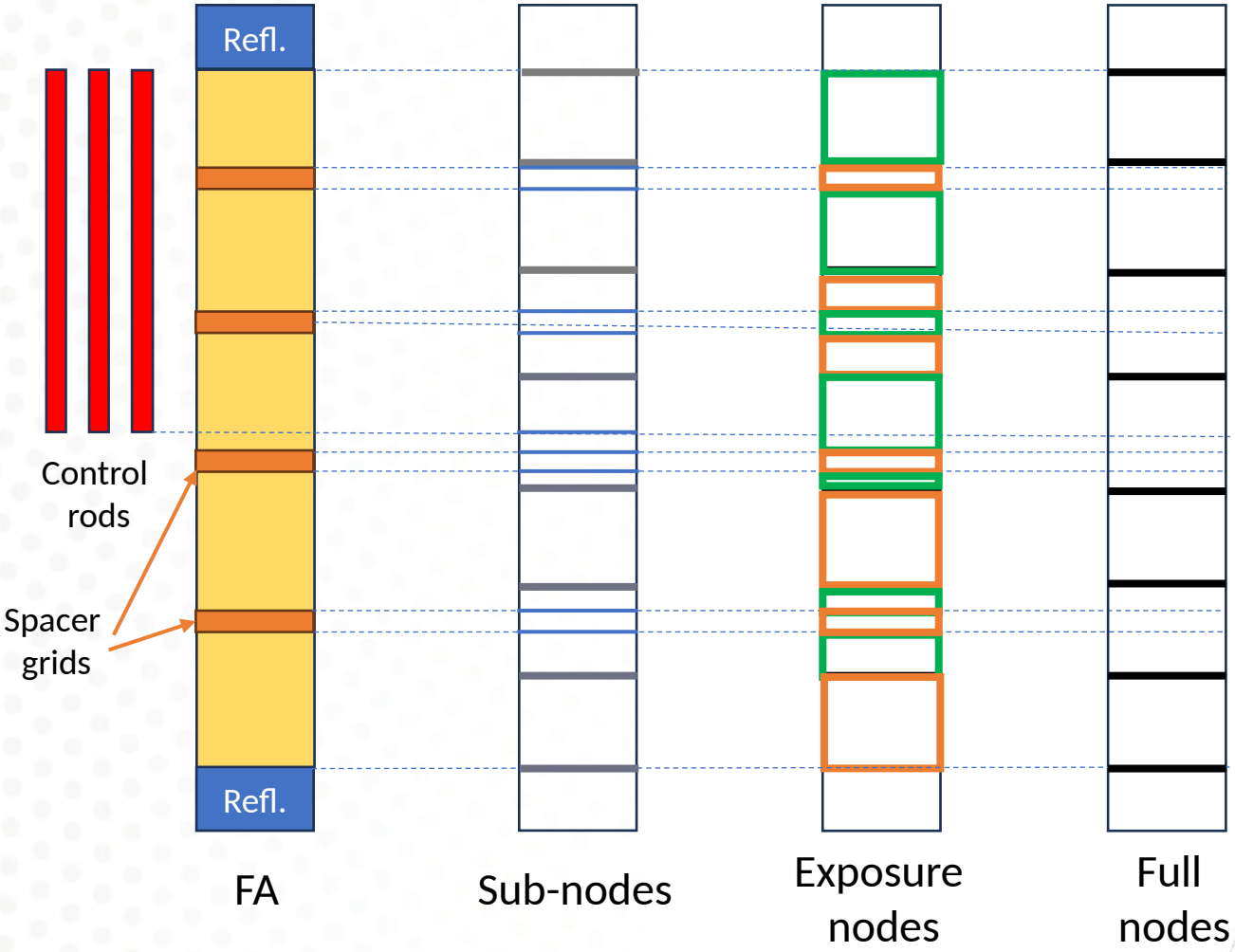
Axial nodalization



- Solves 1D diffusion eq. for each channel with all heterogeinities to compute detailed flux and axial discontinuity factors
- Uses those to axially homogenize submesh XS to full node ones
- Updates the axial channel information
- Iterates to achieve consistent local and global neutronic solutions
- Fuel depletion is tracked in the level of exposure nodes

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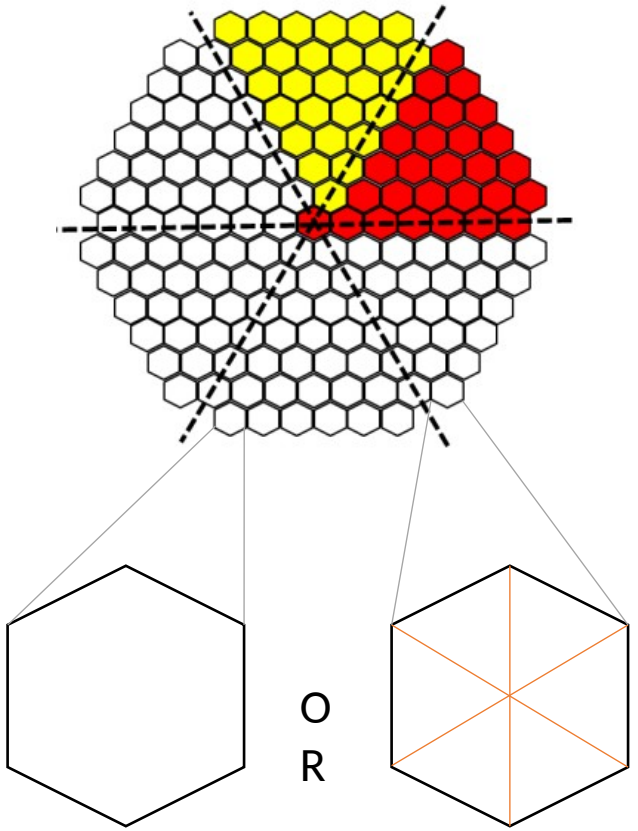
Thermal Hydraulics

- One Hexagonal channel per assembly or six triangular channels per assembly
- The TH module is based on mass, momentum and energy conservation
- Optional calculation of cross flows
- Flow rate distribution is computed iteratively seeking an equal pressure drop for all assemblies
- The TH iteration is tightly coupled with the neutronic solution via the Power-Density iteration



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Target applications

- All VVER steady-state design and licensing applications
- All reload specific calculations intended to guarantee applicability of deterministic safety analyses of anticipated operational occurrences (AOOs) and accident conditions (Reload Safety Analysis Checklist)
- Any necessary Core Limits calculations related to Technical Specifications
- The PHOENIX5/POLCA8H package is also used to prepare input for and initialize dynamic AOO and accident analyses

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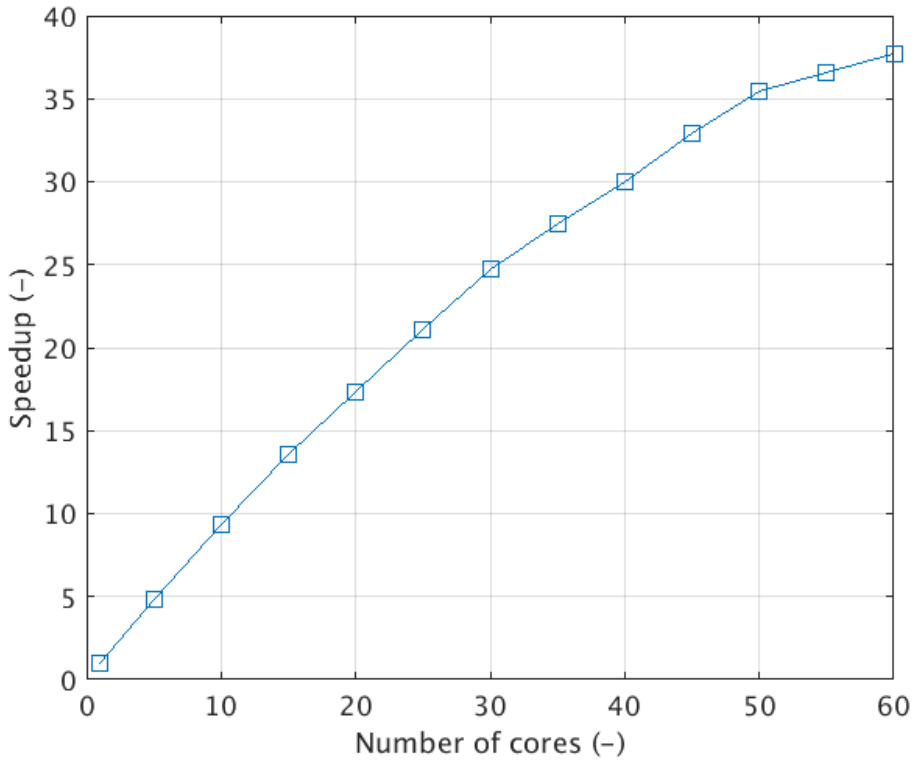
Parallel performance

- The code is parallelized with OpenMP (shared memory parallelization)



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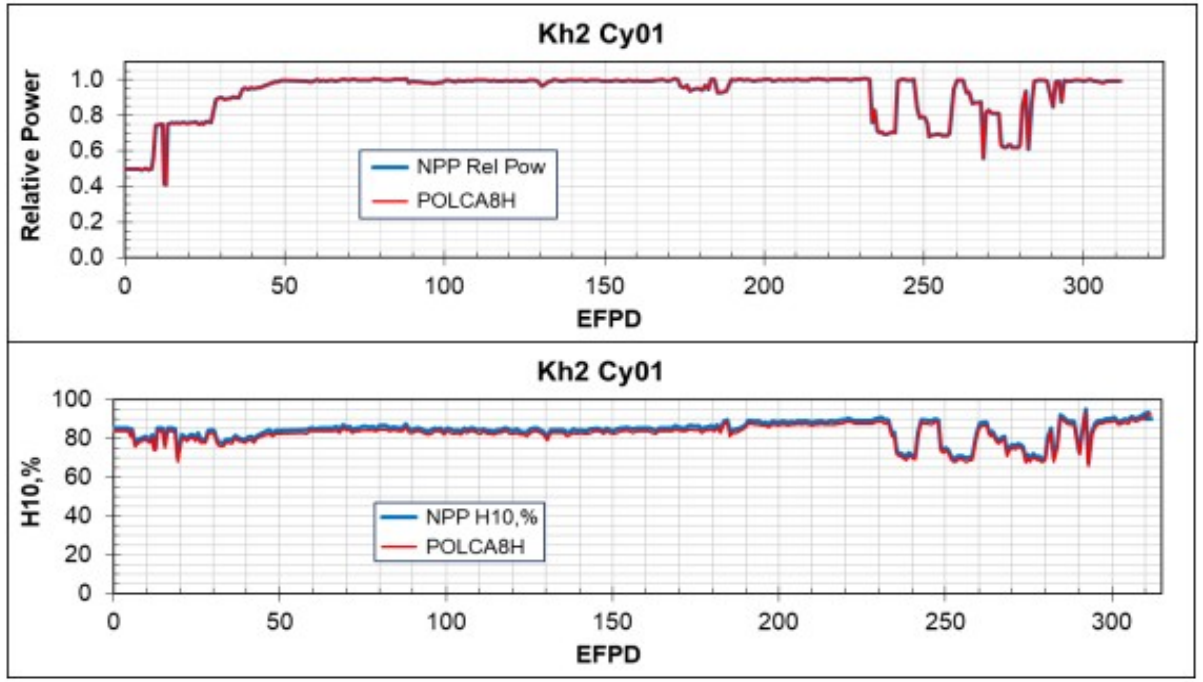
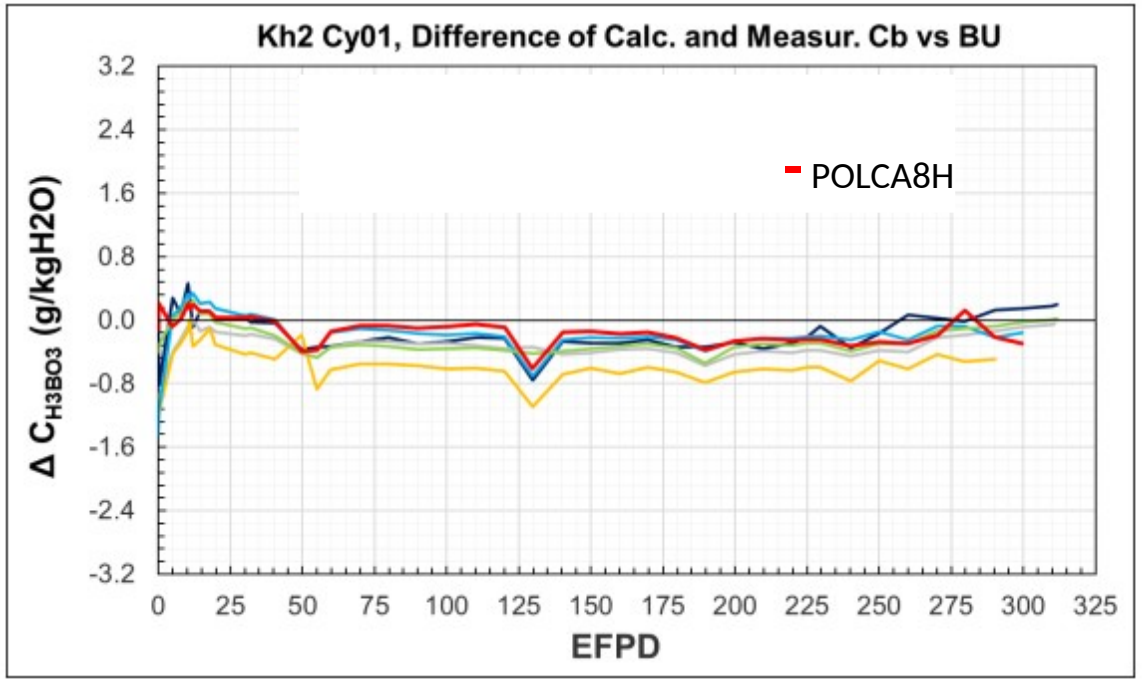
V&V – The X2 benchmark





Lötsch et al., *The X2 benchmark for VVER-1000 reactor calculations. Results and status*, Int. Conf. "Novel Vision of Scientific & Technical Support for Regulation of Nuclear Energy Safety", Kiev, 2017

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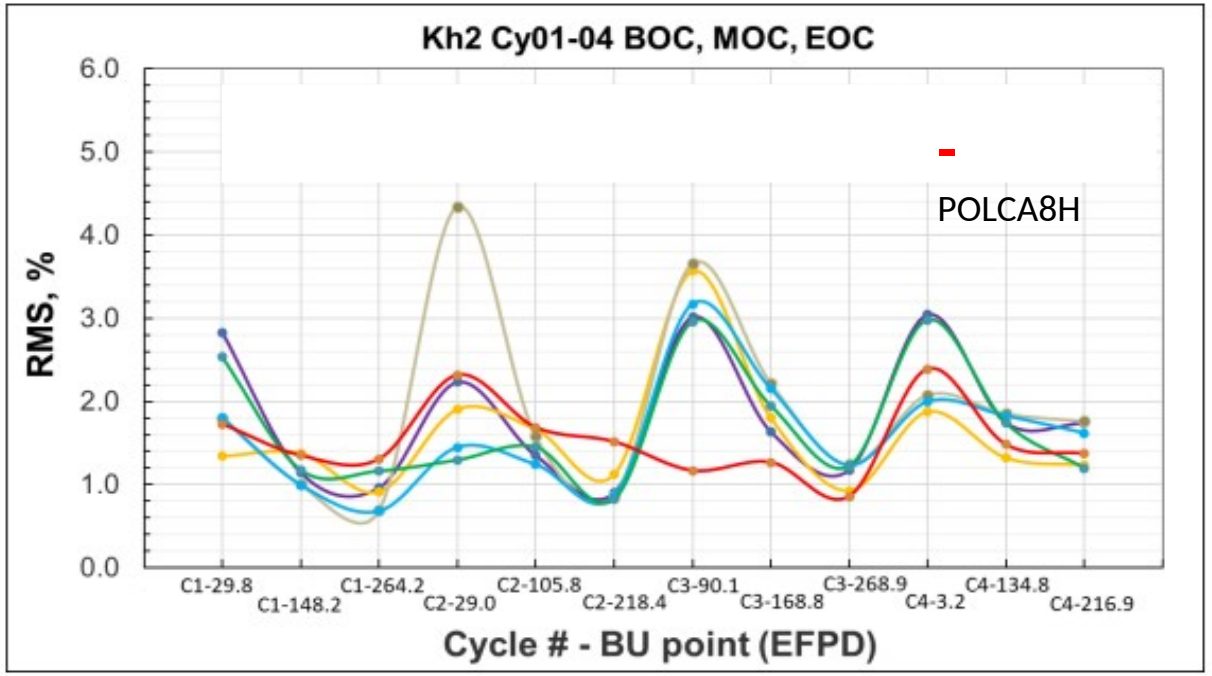
V&V – The X2 benchmark



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Summary

- Westinghouse recently introduced POLCA8H 1.0.0 for VVER-1000
- POLCA8H is a nodal code solving neutronics, TH & depletion
- The code utilizes modern programming and parallelization
- It targets core design and steady-state safety applications
- International benchmarks and core follow data have been used for verification and validation

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