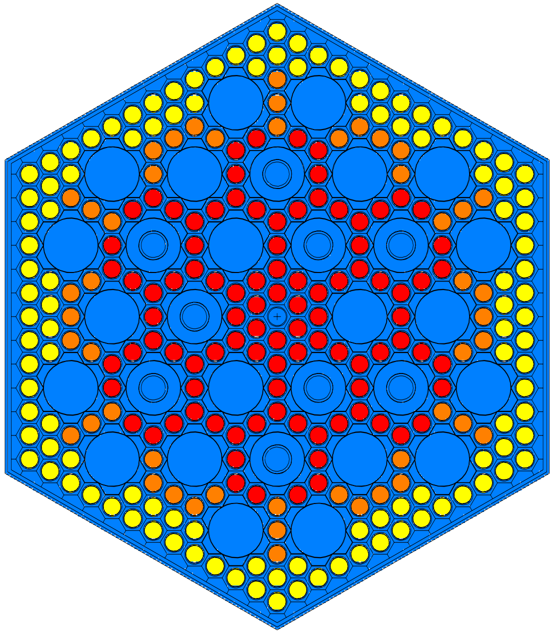
Validation of coupled neutron physics and thermal-hydraulic analysis for a high performance light water reactor (HPLWR)

C.H.M. Broeders, V. Sanchez, E. Stein, A. Travleev

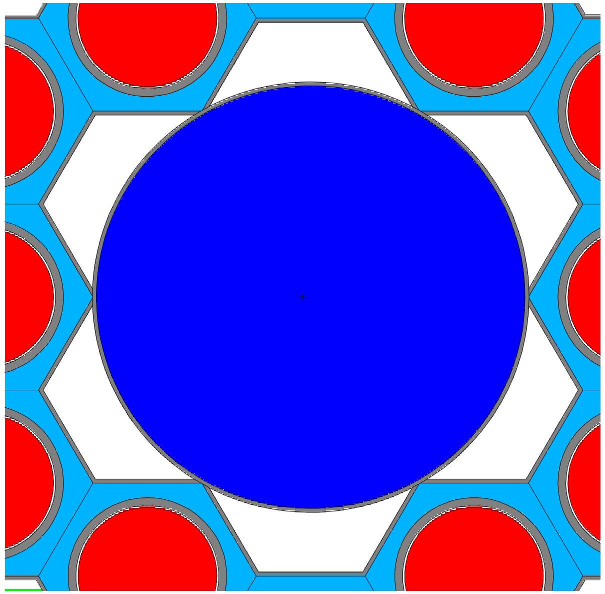
Outline of presentation:

- **Validation of neutron physics calculation tools and development of simplified fuel assembly models for neutron physics calculations**
- **Improvement and modeling of the thermal-hydraulic code RELAP5**
- **Coupling of the neutron physics and thermal-hydraulic codes and first results of coupled calculations**
- **Outlook**

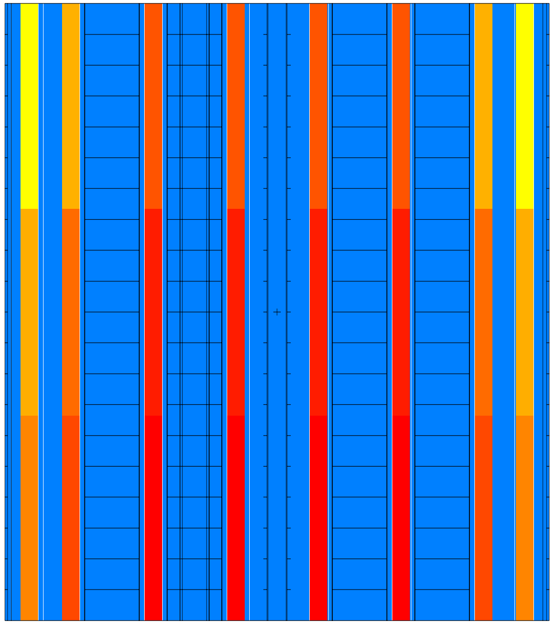
Part of the work was funded in the 5. Framework Program of the European Community, contract number FIKI-CT-2000-00033.



Horizontal cross section



Close look to the water rod



Vertical cross section
(not in scale)

Details of reference HPLWR fuel assembly design

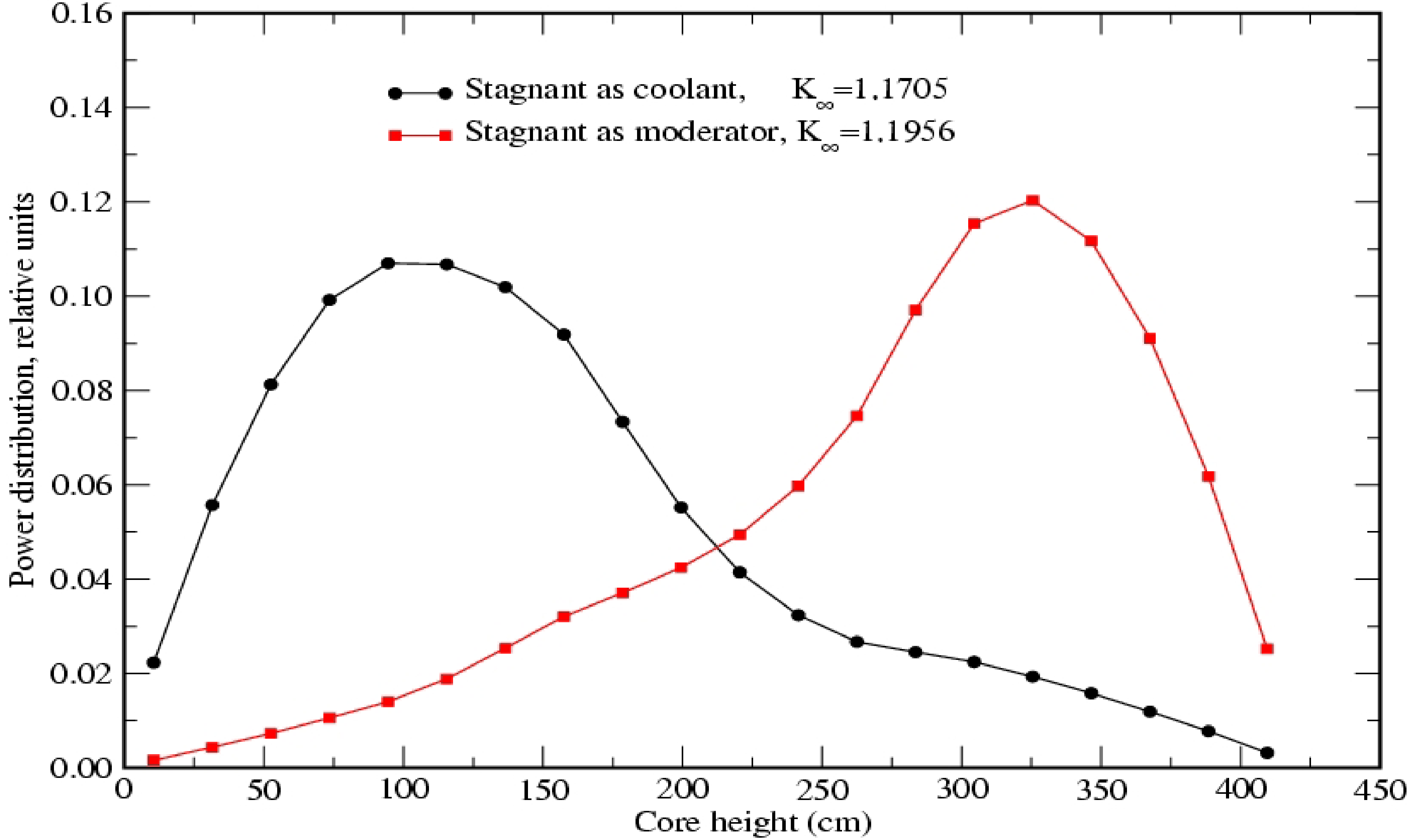
Development and validation of MCNP models at FZK

- MCNP models based on HPLWR reference design of EC project
- VTT 30^0 symmetry layout for 2-d slice model for comparisons
- First automatized input generation for 2-d slice model: FZK-S
- Second more compact 2-d model could be extended to 3-d: FZK-T
- Slightly modified FZK-T model for same modeling as VTT of guide tubes in moderator rods; FZK-Tmod
- Table of K_∞ results on separate slide

Description	K_∞
VTT geometry (30^0)	1.1730 $\pm$ 0.0006
FZK-S model (360^0)	1.1783 $\pm$ 0.0005
FZK-T model (360^0)	1.1790 $\pm$ 0.0010
FZK-T-mod [a]	1.1737 $\pm$ 0.0006

[a] same guide tube modelling as VTT

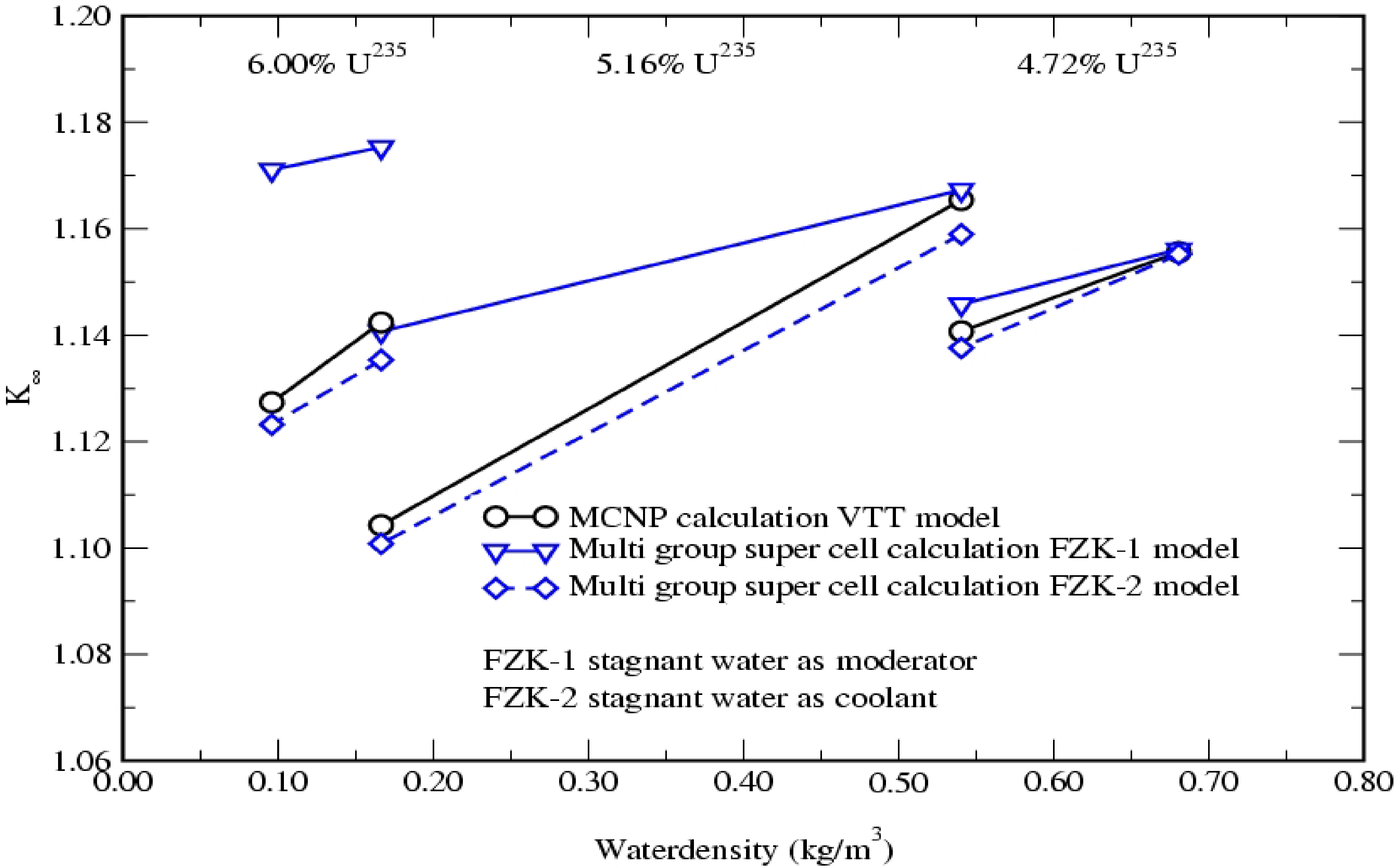
MCNP4C results based on temperature dependant libraries from VTT for different geometry models for HPLWR benchmark case 3



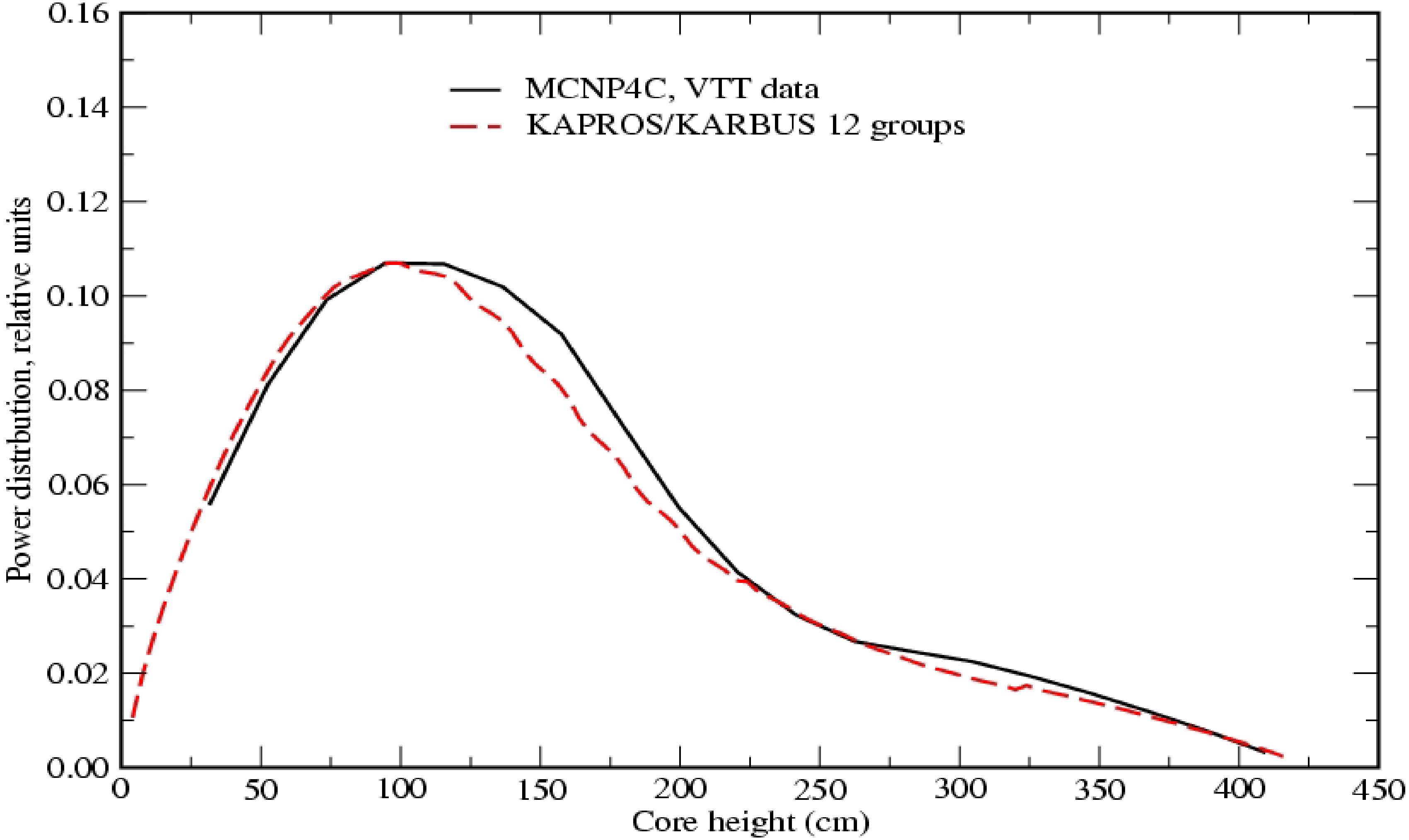
Comparison of MCNP results for axial power distributions for different treatment of stagnant water

Development of a cylinderized supercell FA model for HPLWR

- **Supercell based on moderator rod surrounded by wrapper zone and equivalent fuel zone (FA structures smeared in fuel zone)**
- **Fuel zone cross sections from unit cell calculations**
- **Water characteristics in wrapper zone have large impact on reactivity results for 2-d supercell slice calculations**
- **3-D supercell calculations with 3 axial mean fuel enrichments show strong sensitivity to wrapper treatment; confirmation with MCNP calculations for axial power distributions**
- **Good agreement of axial power distributions of supercell multi-group and MCNP calculations for same densities and temperatures**



Comparison of K_∞ values for HPLWR fuel assembly slices from super-cell calculations with Monte Carlo results



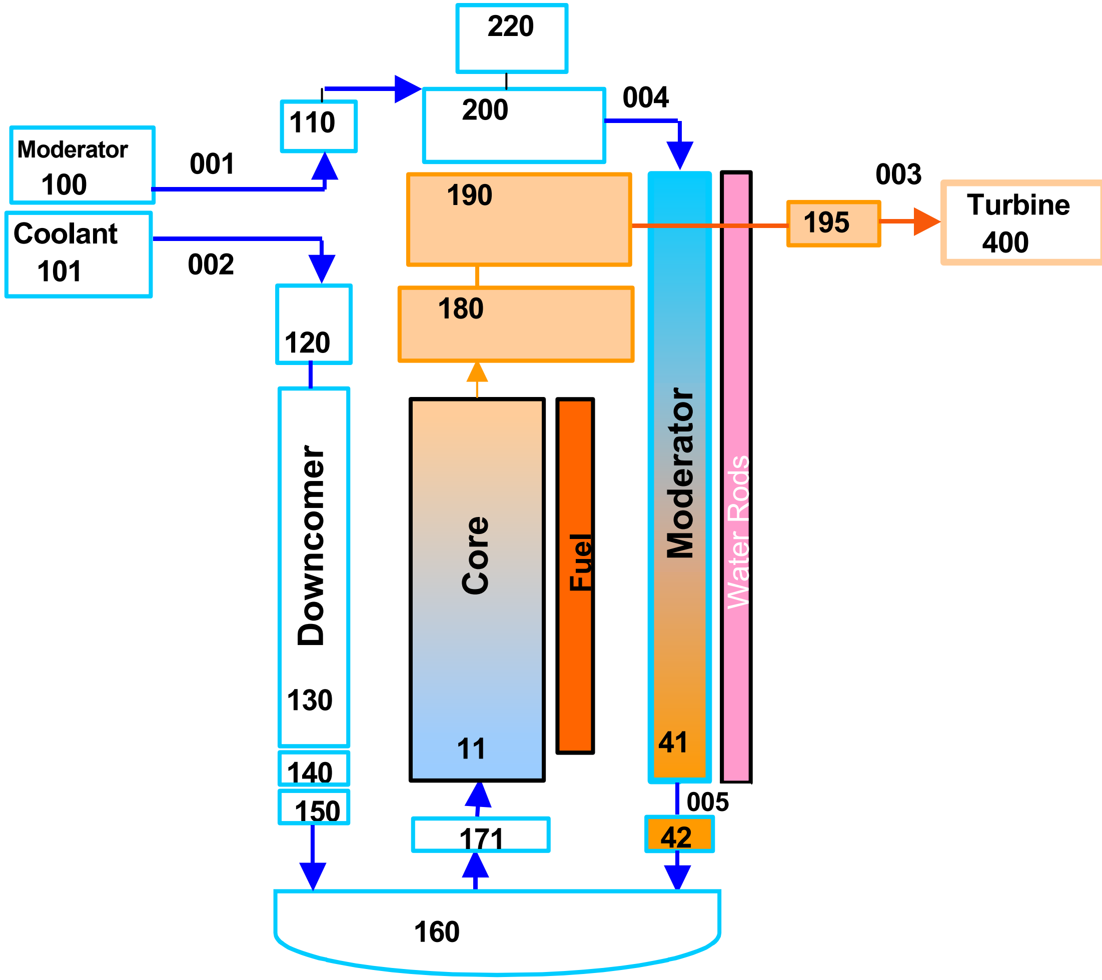
Comparison of axial power distributions in a HPLWR fuel assembly from deterministic and Monte Carlo calculations for the same material compositions and temperatures

RELAP5-Apppropriateness for HPLWR

- **RELAP5-capability to simulate NPP operating at thermodynamically supercritical conditions checked (steady state conditions)**
  - **Physical models (e.g. heat transfer, thermo-physical properties of steam, etc.)**
  - **Numeric (e.g. interpolation scheme around critical point)**
- **RELAP5-Capability to different kind of transients checked:**
  - **Operational transients**
  - **Accidents**
- **Original RELAP5/MOD3.2.2 poorly predicted steady state conditions**
- **Performed code extensions (in cooperation with ISL)**
  - **Refinement of interpolation point for the pressure and temperature around and above the critical point**
  - **Modification of two phase flow definitions for single phase supercritical water e.g. void fraction**
- **Present status (RELAP5/MOD3.3):**
  - **Good prediction of steady state conditions**
  - **Simulation of transients with depressurisation (P>Pcrit) possible**
  - **Simulation of LB-LOCA need further improvements and code validation**
    - **Modification of the interpolation scheme for the prediction of steam properties**
    - **Overall qualification of heat transfer correlations for wall/supercritical water, critical flow, etc.**

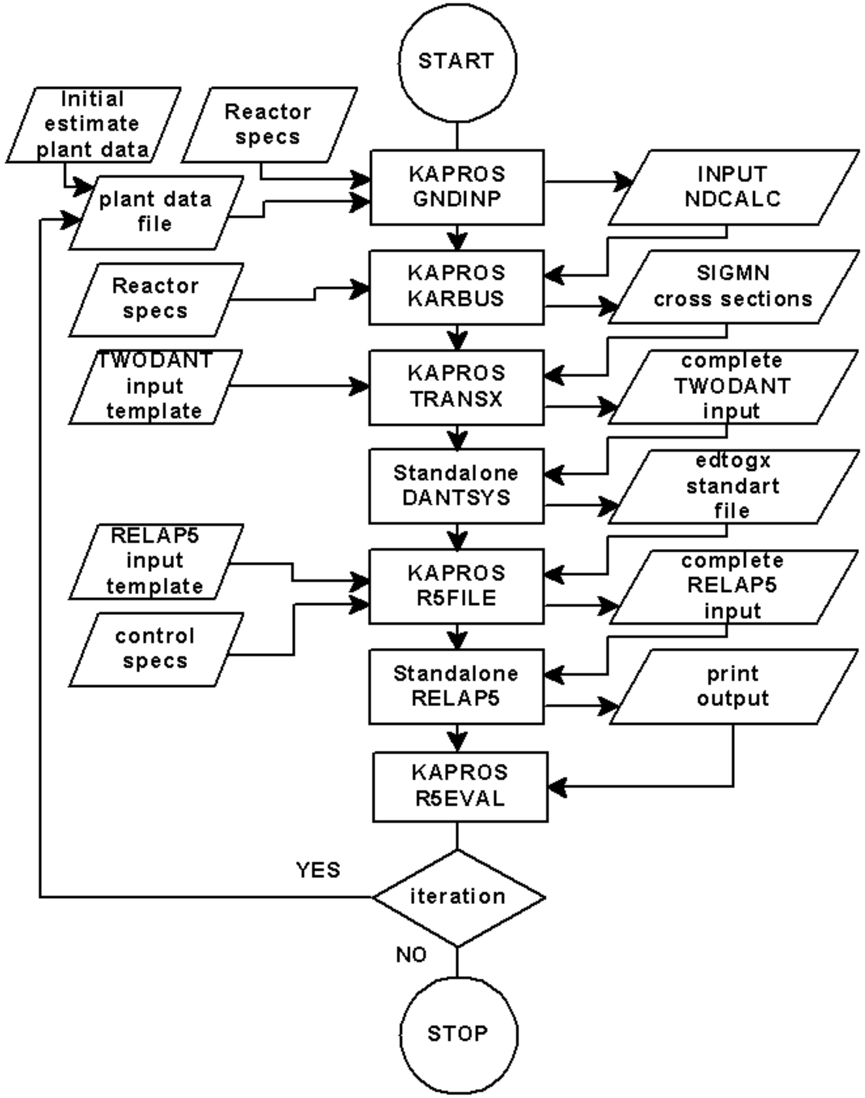
Simplified Model of the HPLWR-Plant

- **Direct cycle plant model**
  - Detail representation of the reactor pressure vessel (RPV)
  - Simplify representation of feed-water and steam lines
  - Two main flow stream within RPV: coolant and moderator
- **Core model**
  - Average fluid channel
  - Average heat structure
- **Moderator model**
  - One average fluid channel
  - One average heat structure

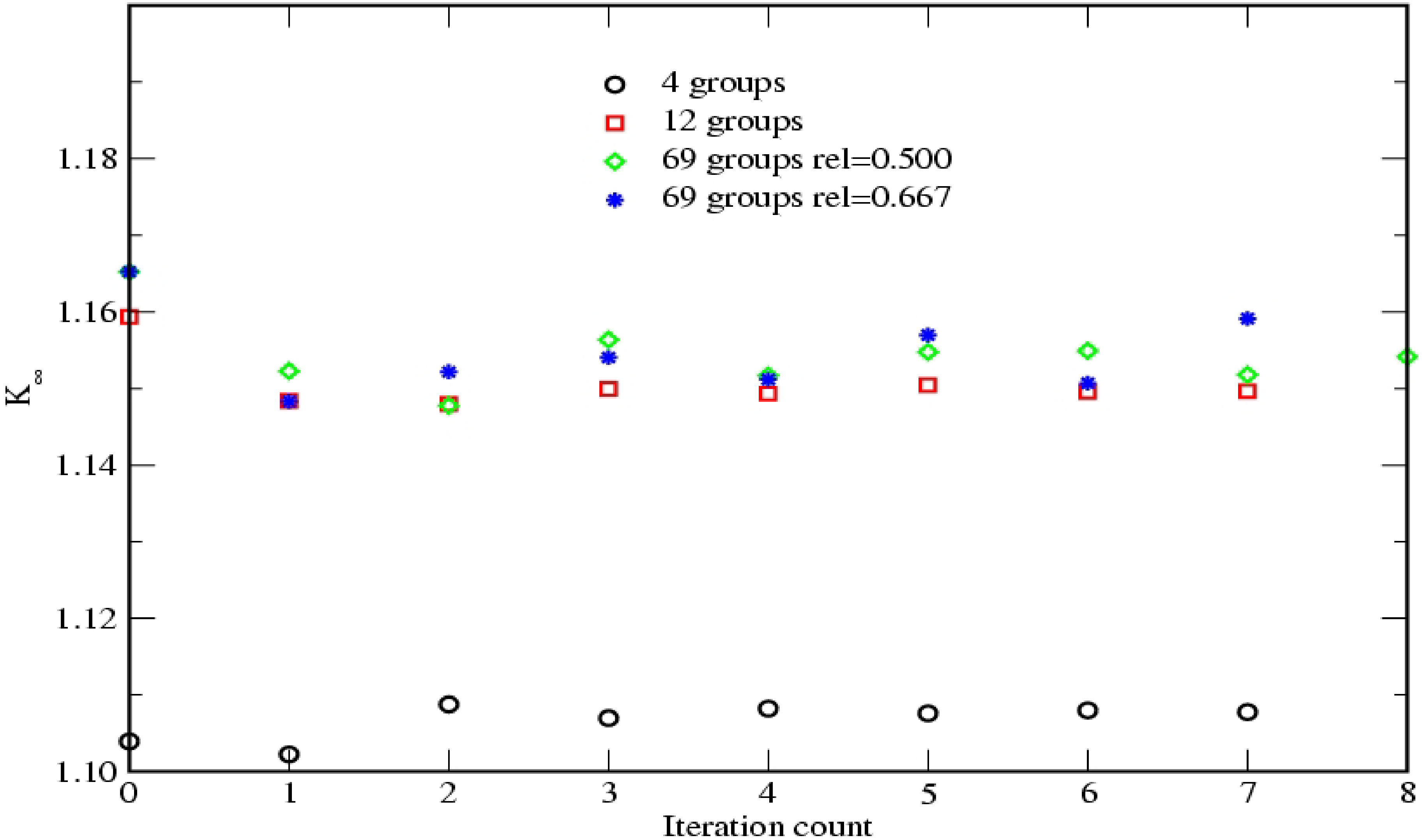


Current coupling of neutron physics and thermal-hydraulic codes

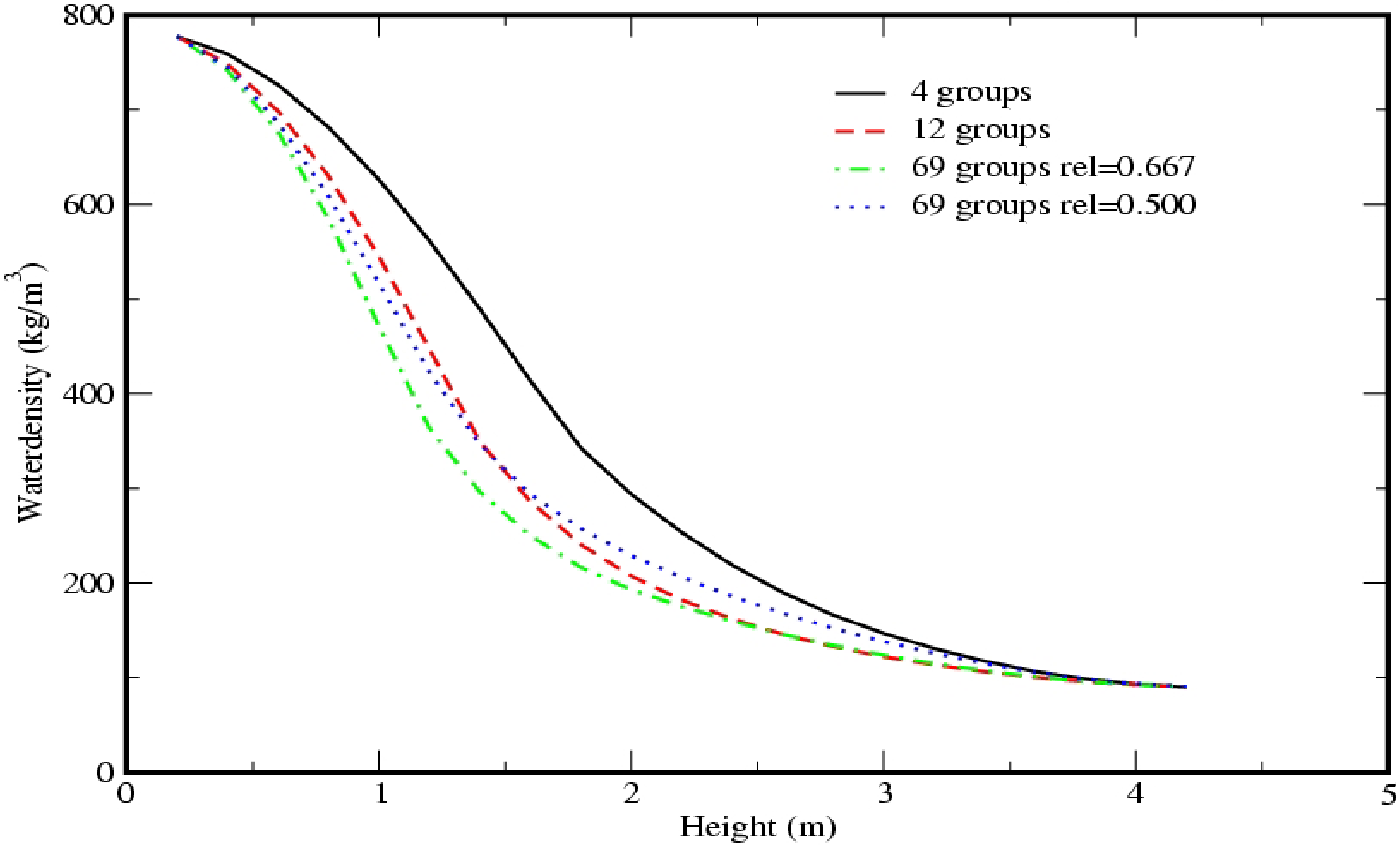
- **Neutron physics code: KAPROS/KARBUS modular system developed at FZK with large efforts since mid-seventies:**
  - **Cross section generation with procedures developed and validated for Tight Lattice Light Water Reactor investigations**
  - **Supercell (R-Z) calculations with loosely to KAPROS coupled TWODANT transport code**
- **Thermal-hydraulic code: RELAP5 version improved at FZK for HPLWR investigations**
  - **Integral plant simulation**
  - **One channel core representation**



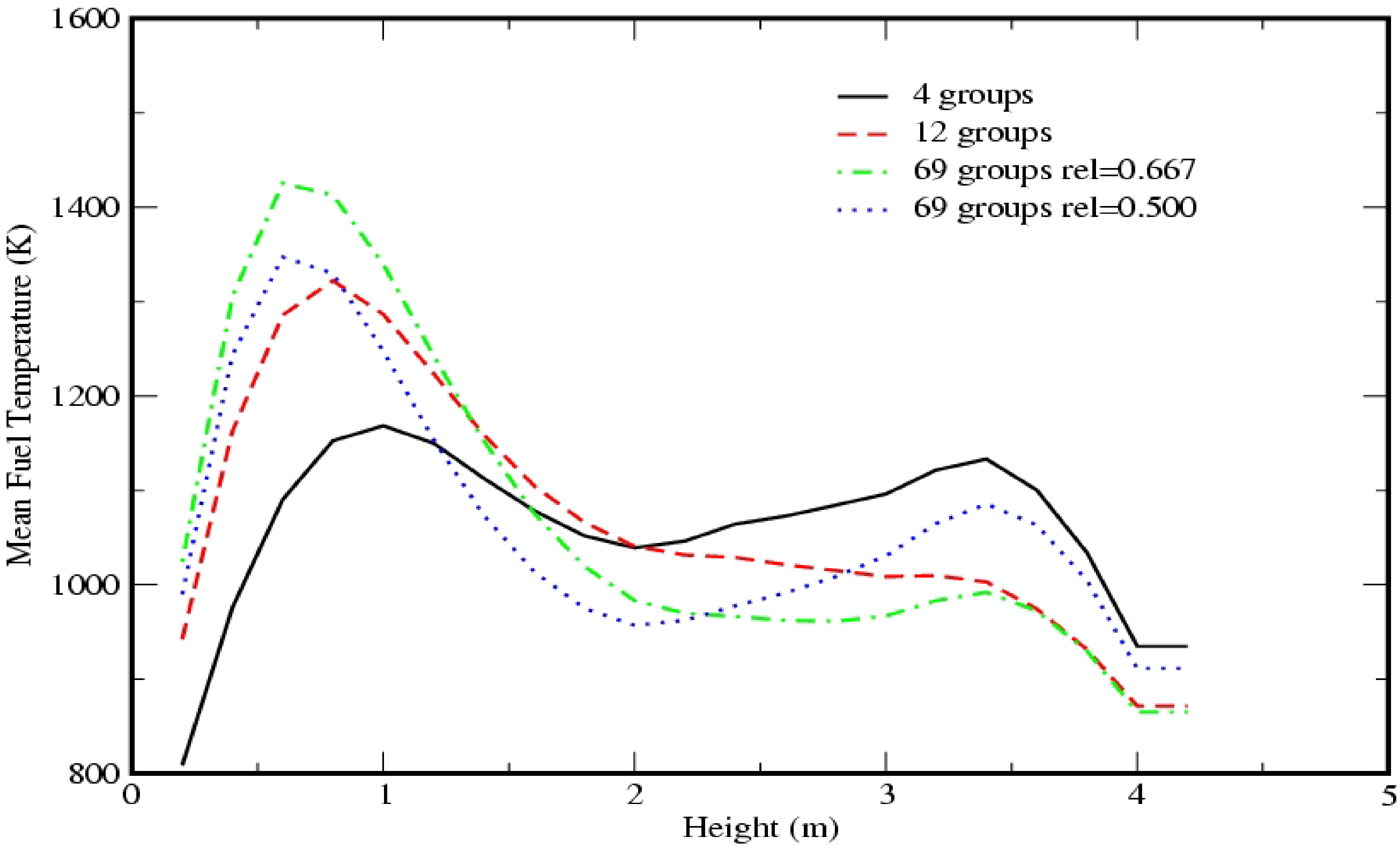
Procedure R5PROC for KARBUS / RELAP5 Coupling



Reactivity changes during iteration steps for coupled RELAP5/KARBUS calculations



Axial distributions of the water density after 8 iterations of coupled RELAP5/KARBUS system



Axial distributions of the mean fuel temperature after 8 iterations of coupled RELAP5/KARBUS system

Coupling Neutron Physics and Thermal Dynamics for HPLWR

Outlook

- **The existing coupling within the KAPROS system easily may be modified to use other thermal-hydraulics fuel assembly codes**
- **Extension of the RELAP5 application to more core channels is possible but needs also the implementation of a new core model for the neutron physics calculation, including adequate cross section generation**
- **Determination of reactivity coefficients and burn-up effects needs full core calculations**
- **The complexity of the neutron physics and thermal-hydraulics calculations should be comparable with respect to geometrical approximations and CPU-times if possible**