Business from technology

On-the-fly Doppler Broadening in Serpent

1st International Serpent User Group Meeting

16.9.2011, Dresden

Tuomas Viitanen

VTT Technical Research Centre of Finland

Outline

Fuel temperatures in neutronics modelling

On-the-fly Doppler-Broadening methods

New temperature treatment method for Super-Serpent

Fuel temperatures - basics

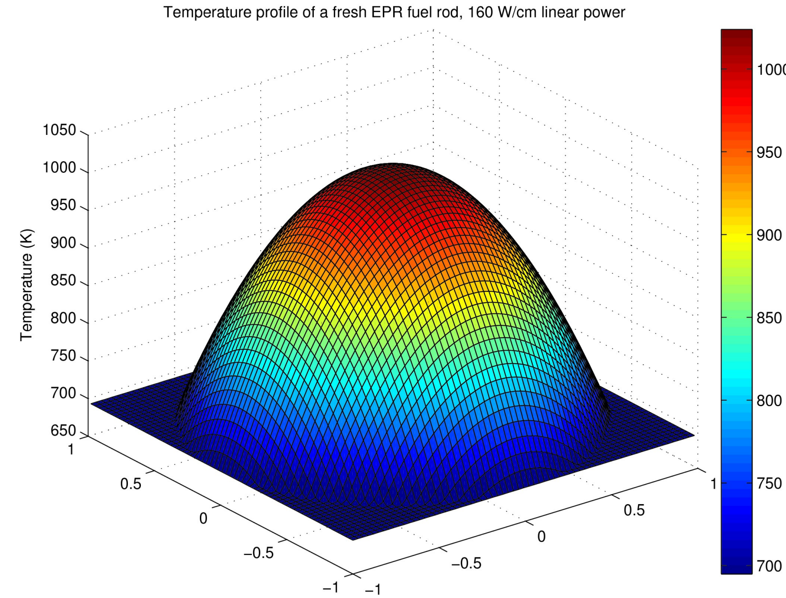
- Fuel temperatures in a reactor are ~never fully homogenous
  - Rods in different temperatures due to varying linear powers & burnups
  - Continuous temperature profile in rods with power > 0
- Fuel temperature significantly affects reactor physical parameters.
  - Main cause: Doppler-broadening of capture resonance peaks of U-238
  - Other causes: Doppler-broadening of other resonances, increase in potential scattering, changes in thermal scattering of bound nuclei, Dyson effect etc.

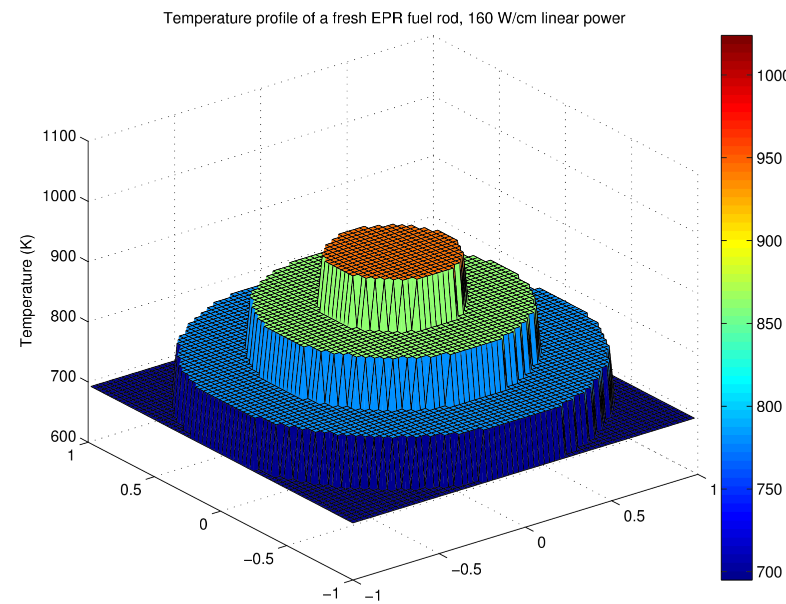
Modeling of fuel temperatures – traditional approach

- In Monte Carlo (MC) calculations temperature is taken into account using effective cross sections and thermal scattering libraries or a free gas thermal treatment.
- Temperature distributions are imitated with homogenous temperature zones.
- Since cross sections require a lot of computer memory, the number of temperature zones is limited.
  - Serpent consumes about 5 GB / temperature with 5E-5 reconstruction tolerance in burnup calculation mode.
  - The number of temperature zones must be limited somehow.

Reduction of temperatures – fuel rod level

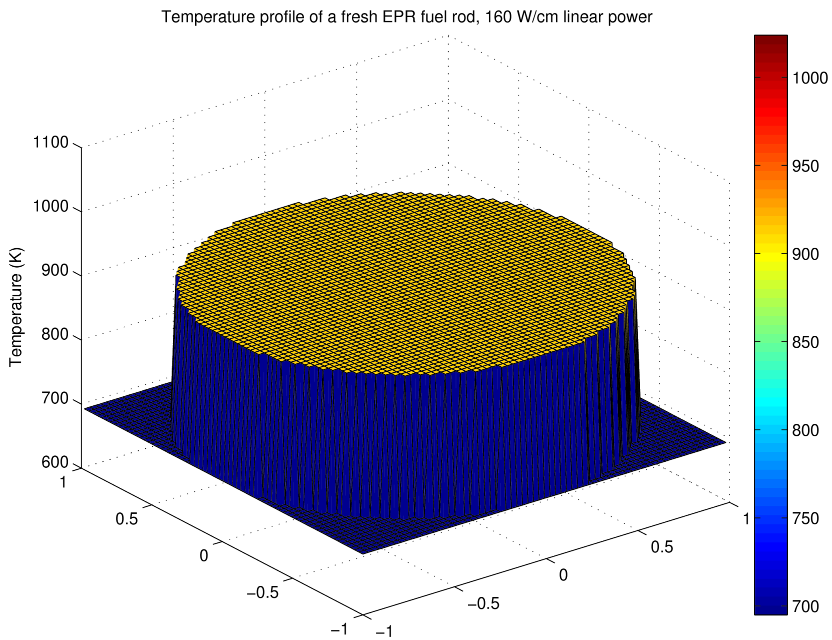
- The temperature in an EPR rod with 160 W/cm linear power (core average) varies more than 300 K.
- With traditional MC tracking methods the temperature distribution can be approximated with a step function.
  - Memory-consuming
  - Inaccurate modeling of self-shielding and Pu deposition





Upper figure: Temperature distribution in a EPR fuel rod.
Lower figure: The same distribution approximated with a 3-step function.

Reduction of temperatures – fuel rod level (2)

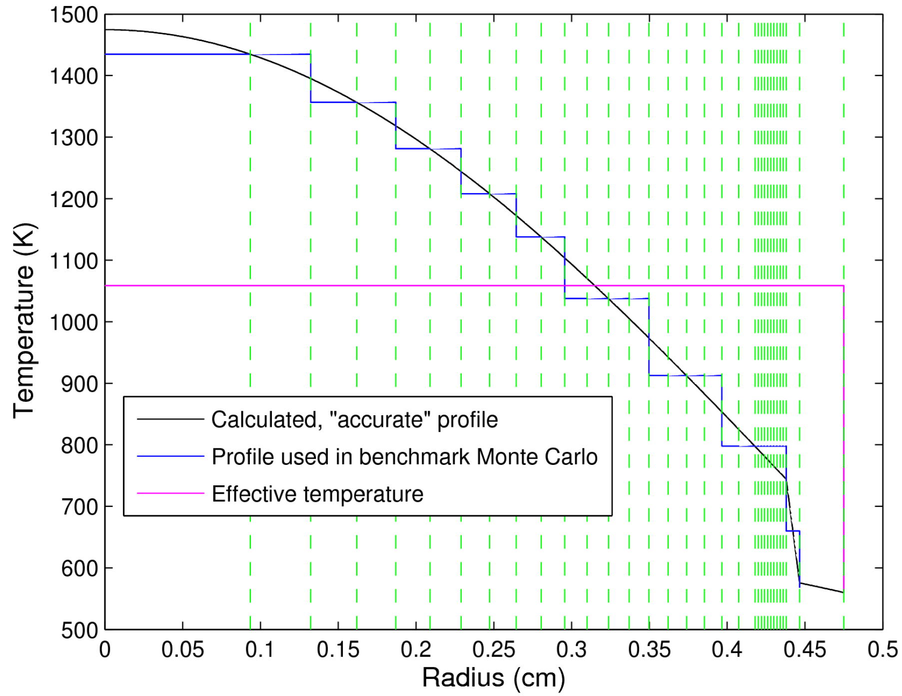


The same EPR case modeled using only one effective temperature.

- Usually (practically always) fuel rods are modeled using only one effective temperature.

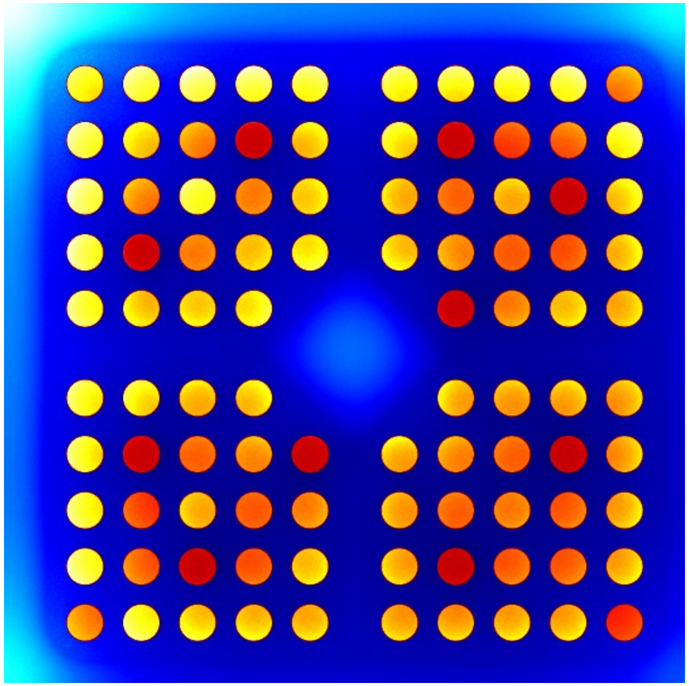
Reduction of temperatures – fuel rod level (3)

- Reactivity error in an infinite pin-cell lattice about 50 pcm (homog. vs. 10-step function case)



Reduction of temperatures – Fuel bundle level

- On fuel bundle level the linear powers and, consequently, the temperatures of different rods may vary significantly.
  - Emphasized in bundles containing Gd-doped fuel rods
- In many cases also bundles are modeled using only one fuel temperature.

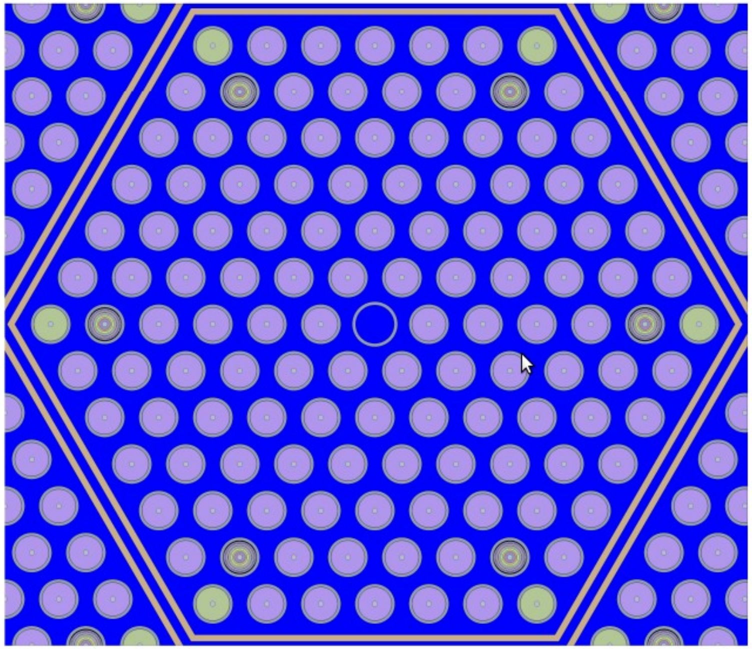


A BWR bundle with Gd-doped fuel rods.

Image source: Serpent website http://montecarlo.vtt.fi

Reduction of temperatures – Fuel bundle level (2)

- Reactivity error resulting from assuming Gd rods to be in the same temperature as surrounding rods is small in fresh fuel, but may accumulate to 1000 pcm as the burnup increases to 60 Mwd/kgU [1]



[1] *Valtavirta, V., "Effect of temperature homogenization on neutronics calculations of Gd-doped fuel", Special Assignment, Aalto University, preprint (2011)*

Reduction of temperature – Whole core level

- With the current MC codes and computers the modelling of whole power reactor cores is not yet feasible.
- However, in case this kind of simulations would be performed some day, the whole-core power distribution would further increase the need for different temperature zones.

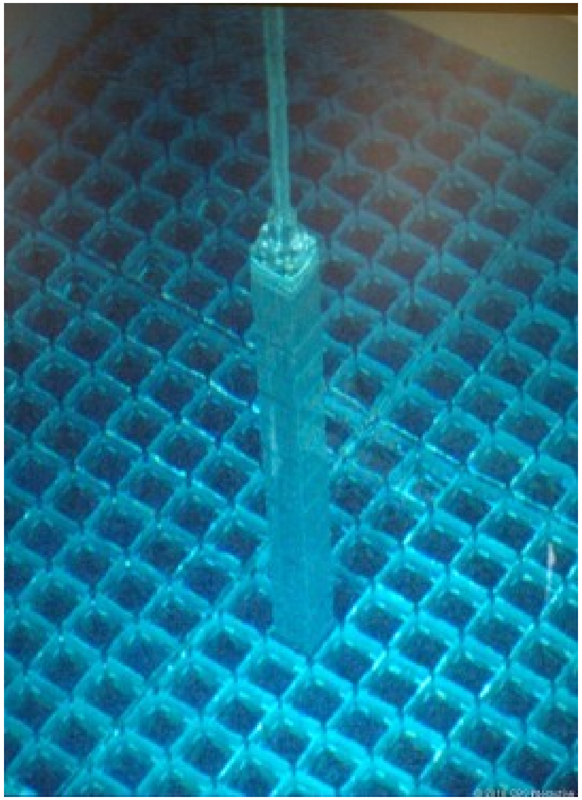


Image source: Martin LaMonica/CNET

Reducing the memory demand: on-the-fly techniques

- In case one wants to model temperatures with high accuracy the cross section data must be available for numerous temperatures.
  - Important in coupled MC/Thermal Hydraulics or MC/Fuel performance calculations
- It is possible to spare a lot of memory by calculating the doppler-broadened cross sections on-the-fly

- Trumbull [2]: Cross sections are tabulated for different temperatures and cross sections are obtained via on-the-fly interpolation

  + Fast and simple

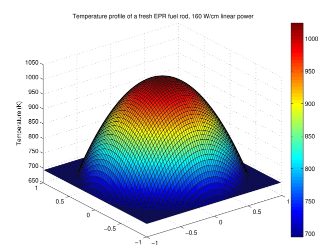
  – The cross sections need to be tabulated in very small (< 28 K) steps to reach sufficient accuracy in case of some nuclides.

[2] Trumbull, T.H., ”Treatment of nuclear data for transport problems containing detailed temperature distributions”, Nucl. Tech., 156, 75-86, (2006)

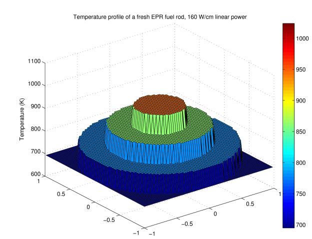
Reducing the memory demand: on-the-fly techniques (2)

- Yesilyurt et al. [3]: Fast Doppler-broadening directly from 0 Kelvin libraries with a method utilizing series expansions.
  + Only 0 K libraries need to be stored
  + Requires only 1 % extra calculation time compared to linear interpolation when implemented in MCNP [3]

- With the previous on-the-fly methods (at least the method of Yesilyurt et al) the number of different temperature regions is no longer a limiting factor.
  – However, the continuous temperature distributions must, still, be approximated with homogenous temperature zones.



vs.



[3] Yesilyurt, G., Martin, W.R., Brown, F.B., "ON-THE-FLY DOPPLER BROADENING for MONTE CARLO CODES", International Conference on Mathematics, Computational Methods & Reactor Physics (M&C 2009), Saratoga Springs, New York, May 3-7 (2009)

Coming Soon: Viitanen & Leppänen (2011) - ”Explicit treatment of target motion in continous-energy Monte Carlo tracking routines”

- A new approach to the temperature-correction problem
- The method is based on explicit treatment of target motion at collision sites
  - The new treatment does basically the same trick as on-the-fly Doppler broadening methods, but it is actually a neutron tracking method
- Hopefully will be published in NSE in the near future

Coming Soon: Viitanen & Leppänen (2011) - ”Explicit treatment of target motion in continous-energy Monte Carlo tracking routines” (2)

- Pros:
  - + Requires the basis cross section in only one temperature (0 K)
  - + **Is able to accurately model inhomogenous temperatures, i.e. continous temperature distributions.**
  - + Includes DBRC as a built-in feature
- Cons:
  - – Not yet implemented → the efficiency of the method is not yet known
  - – The first version does not support thermal scattering libraries or probability table treatment for the unresolved resonances
  - – Some challenges in the usage of flux esimators

Conclusion and future prospects

- A new promising on-the-fly Doppler broadening technique based on explicit treatment of target motion has been developed
- The new method will be implemented in the Super Serpent parallel to the traditional transport methods utilizing effective cross sections.
- Extension of the method to thermal scattering and unresolved region probability table treatment will be examined in the future.

VTT creates business from technology