Three-dimensional Space and Time-dependent Analysis of Molten Salt Reactors

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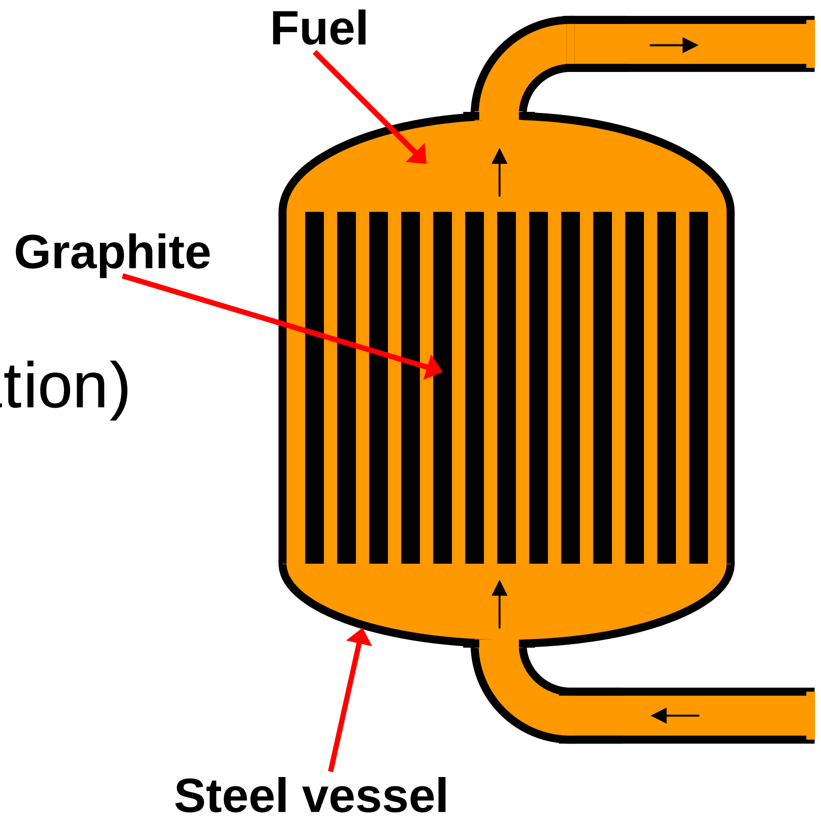
Molten Salt Reactors

- Fuel dissolved in molten salt
- Molten salt serves as coolant
- Circulated in the primary loop
- Optional graphite stringers (moderator and flow parallelization)



Notable advantages

- Continuous reprocessing ($\Rightarrow$transmutation, breeding)
- High temperature operation
- Low pressure operation
- No mechanical valves, freeze valves instead
- Nonflammable materials (in contrast to LMR)
- Chemically inert (H_2O-Zr, H_2O-C reactions impossible)

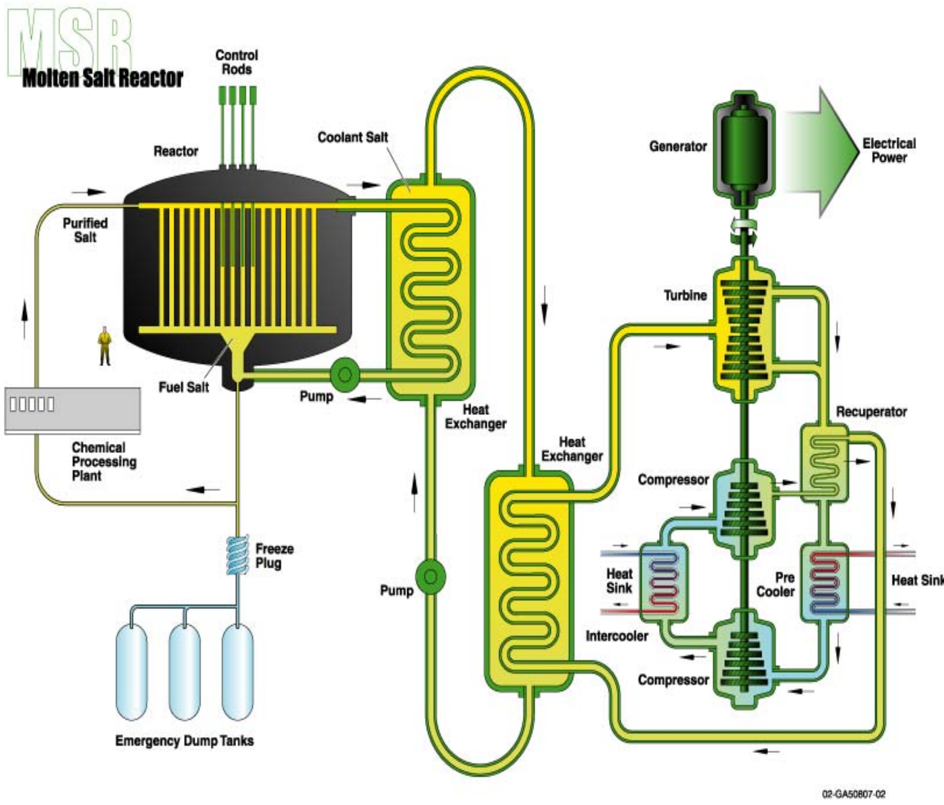
Drawbacks:

- Proliferation issues
- Corrosion
- Toxicity of the salt
- Limited experience

Molten Salt Reactor: unconventional phenomena

Delayed neutron precursors drift

- precursors emit neutrons at positions different from the location of the fission
- moreover they decay outside core
- →reactivity loss
- → kinetics dependent on fluid flow



Most of the fission heat deposited directly into the coolant, small part in the graphite moderator

Moderator cooled by the fuel salt

Neutronics

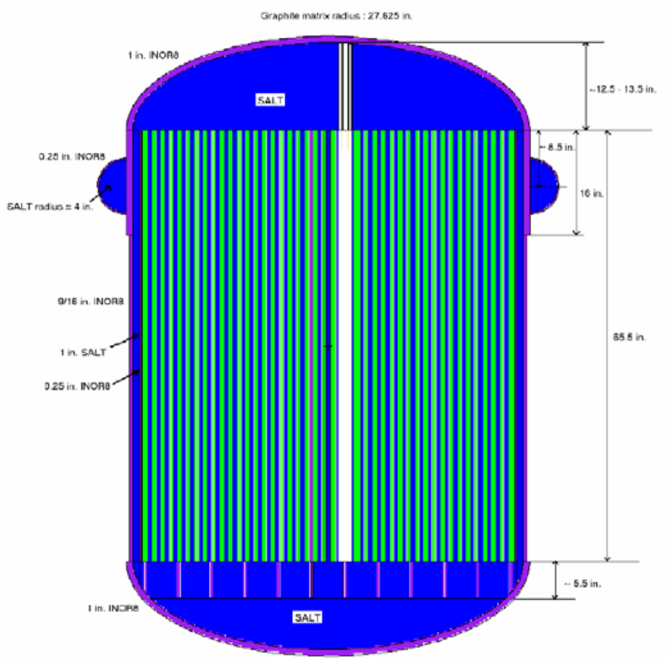
$$\frac{1}{v_g}\frac{\partial \Phi_g}{\partial t} = \nabla D_g \nabla \Phi_g - \Sigma_g^r \Phi_g + \sum_{g \neq g'}^{G} \Sigma_{g \to g'}^s \Phi_{g'} + \chi_p \sum_{g'}^{G} (1-\beta) \nu \Sigma_{g'}^f \Phi_{g'} + \sum_i^I \lambda_i \chi_d C_i$$

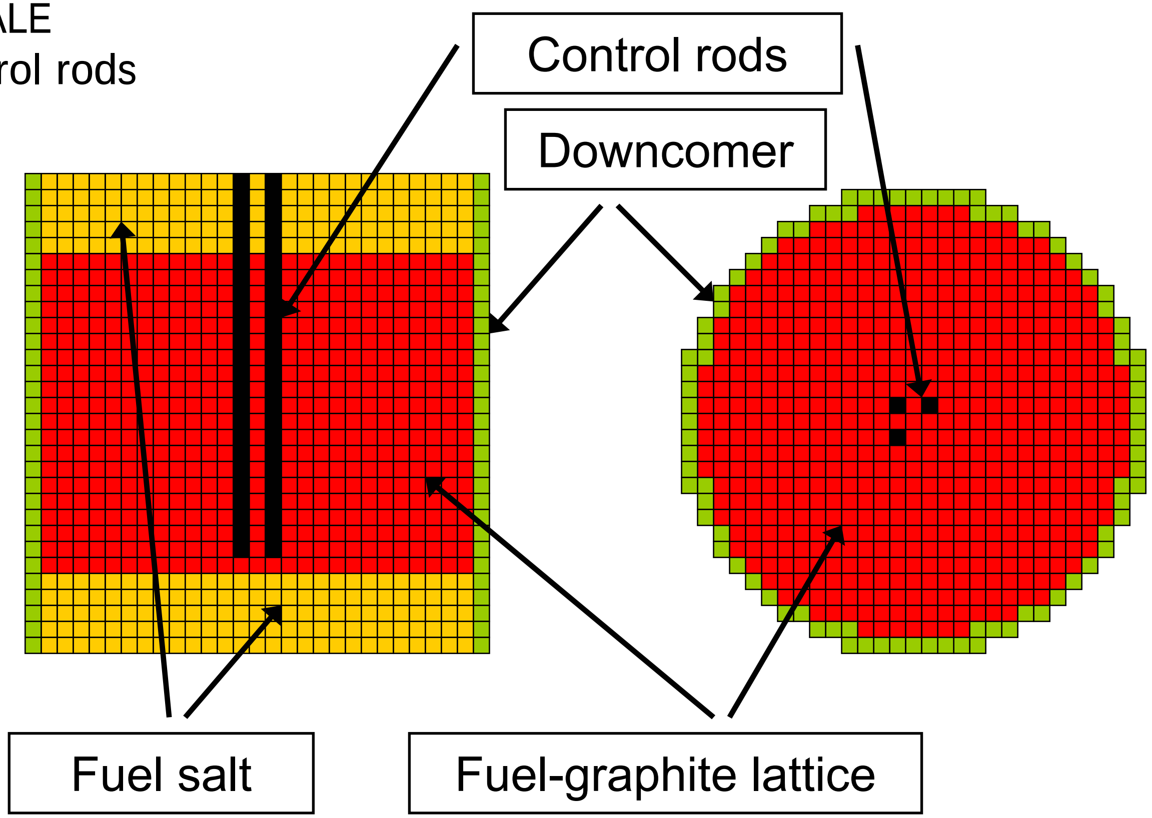
$$\frac{\partial C_i}{\partial t} = \sum_{g'}^{G} \beta_i \nu \Sigma_{g'}^f \Phi_{g'} - \lambda_i C_i - \nabla u C_i$$

- 3D-multigroup diffusion equations
- Precursor equations extended by streaming term
- Modifications introduced into the in-house developed code DALTON
- Assumptions:
  - Fuel velocity field is input
  - Flow parallel to the axis of the core

3D model of MSRE

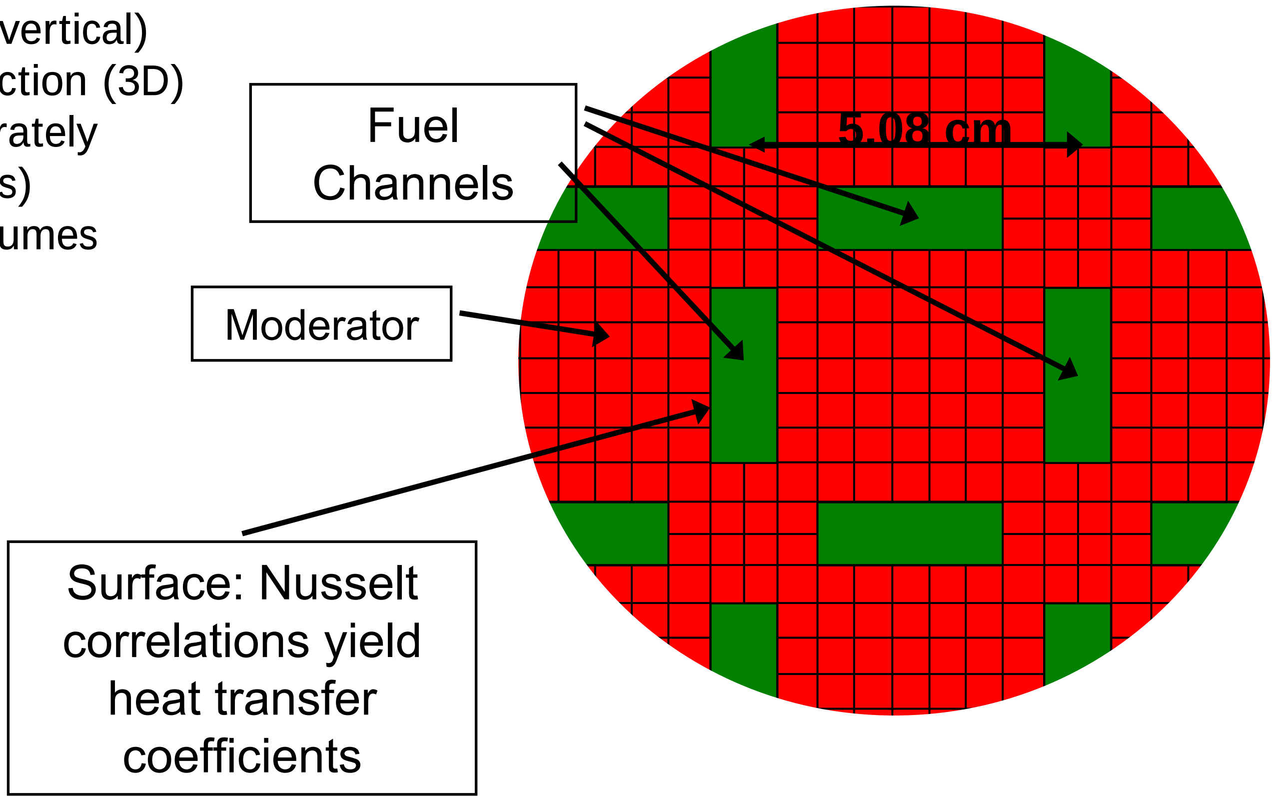
- Approximating cylindrical reactor in X-Y-Z geometry
- 8 group cross section library by SCALE
- Internal albedo boundaries for control rods





Thermal model

- Fuel: Heat convection (vertical)
- Moderator: Heat conduction (3D)
- Each fuel channel separately modeled (1150 channels)
- ~1.5 million control volumes



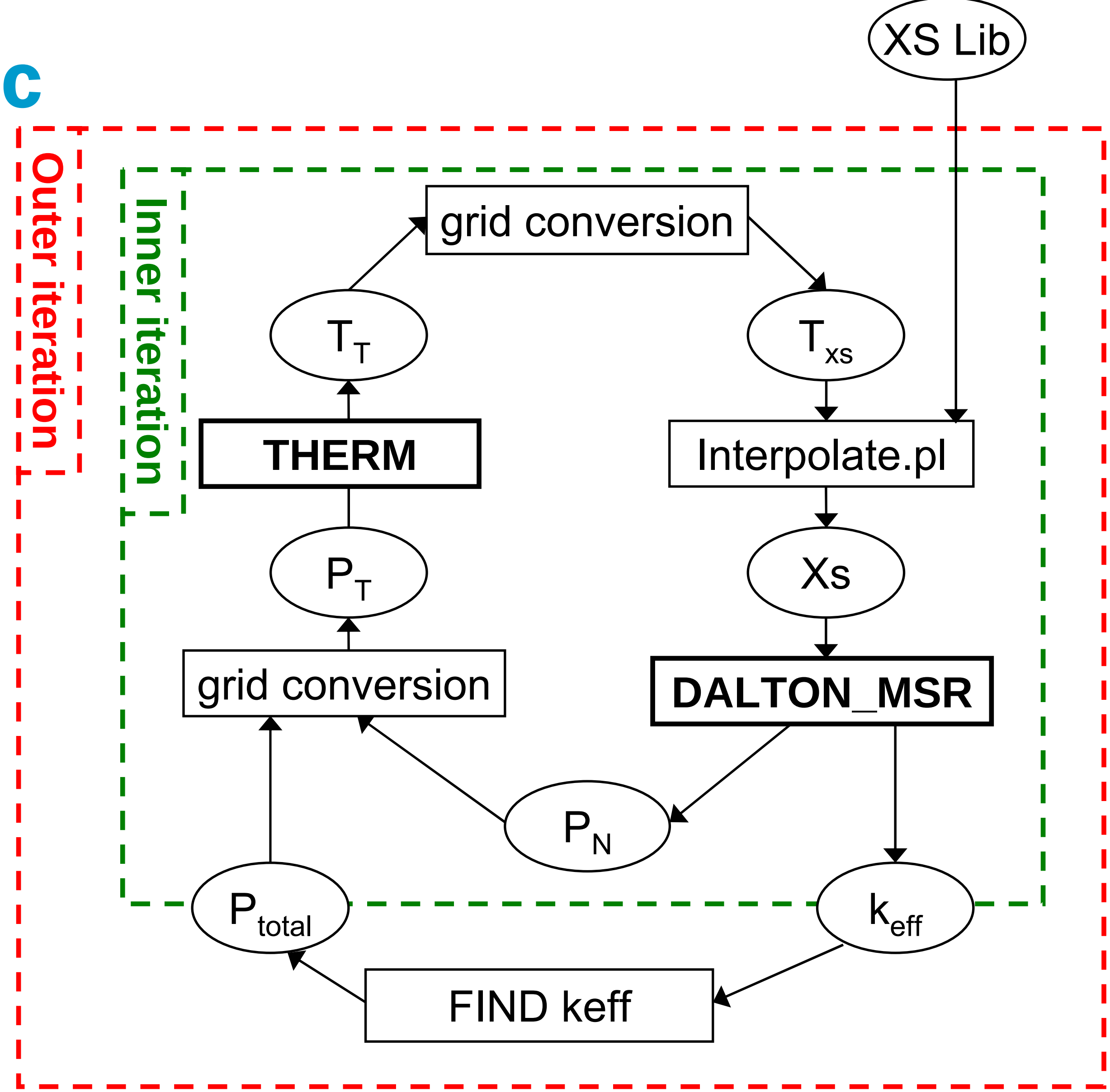
Coupling static

Nested iterations

- obtain k_{eff} for a given power
- obtain power for $k_{eff} = 1$

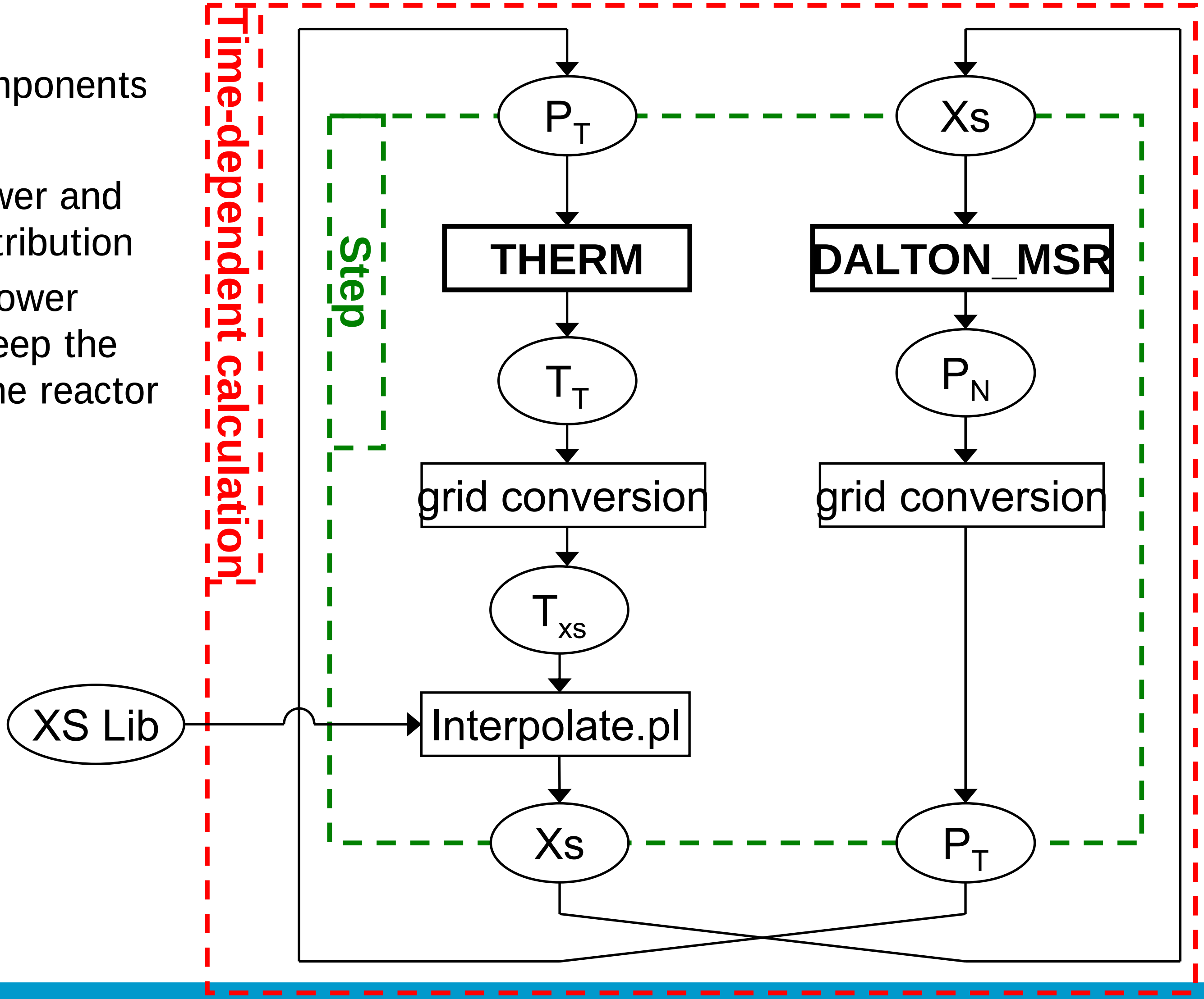
Temperature step of base XS library: ΔT=100°C

Interpolation by SCALE/ICE



Coupling (time-dependent)

- Rearranging components
- Explicit scheme
- Exchange of power and temperature distribution
- Renormalizing power distribution to keep the total power of the reactor

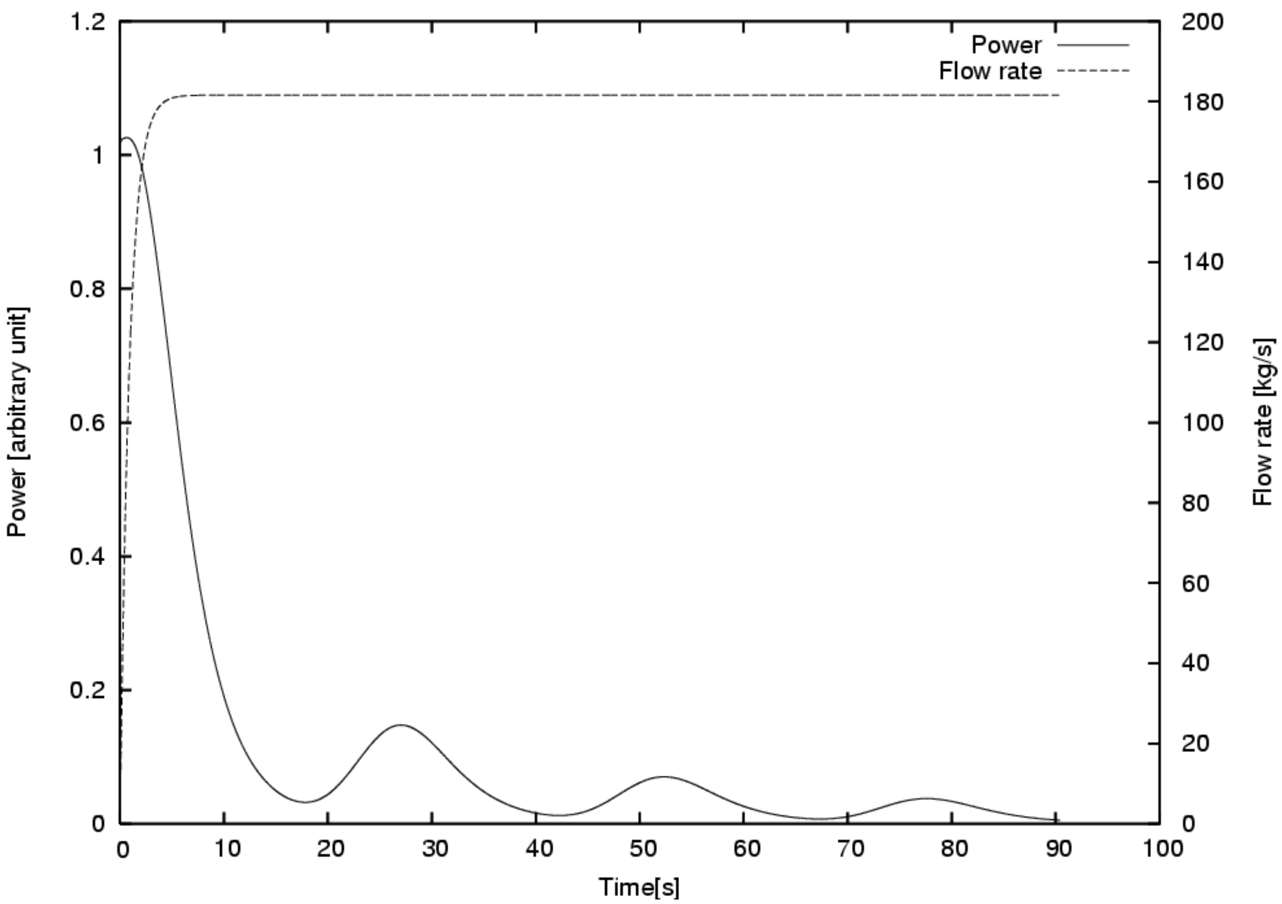


Results – Feedback coefficients

	Fuel temp. coeff. (α_f)	Moderator temp. coeff. (α_m)
Calculation	-9.77 pcm/K	-6.31 pcm/K
Measurement (MSRE)	-8.46 pcm/K	-4.68 pcm/K
Difference	14 %	26 %

Results – Pump startup I.

- Typical fluid-fuel transient
- Power: 1W – no feedback
- Beginning:
  - fuel stationary
  - $k_{eff} = 1$
- Starting fuel pump
- (2 group test libraries)



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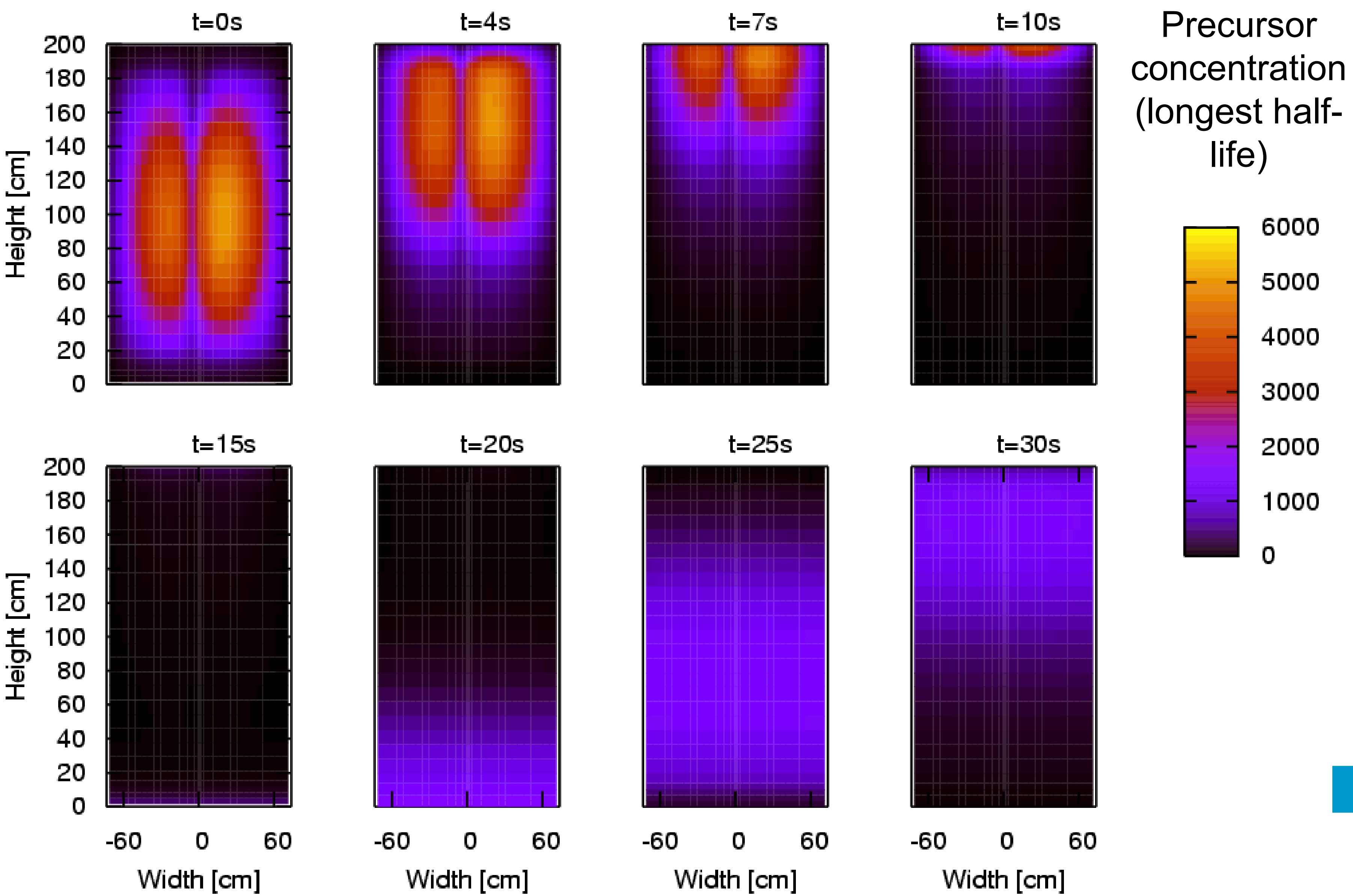
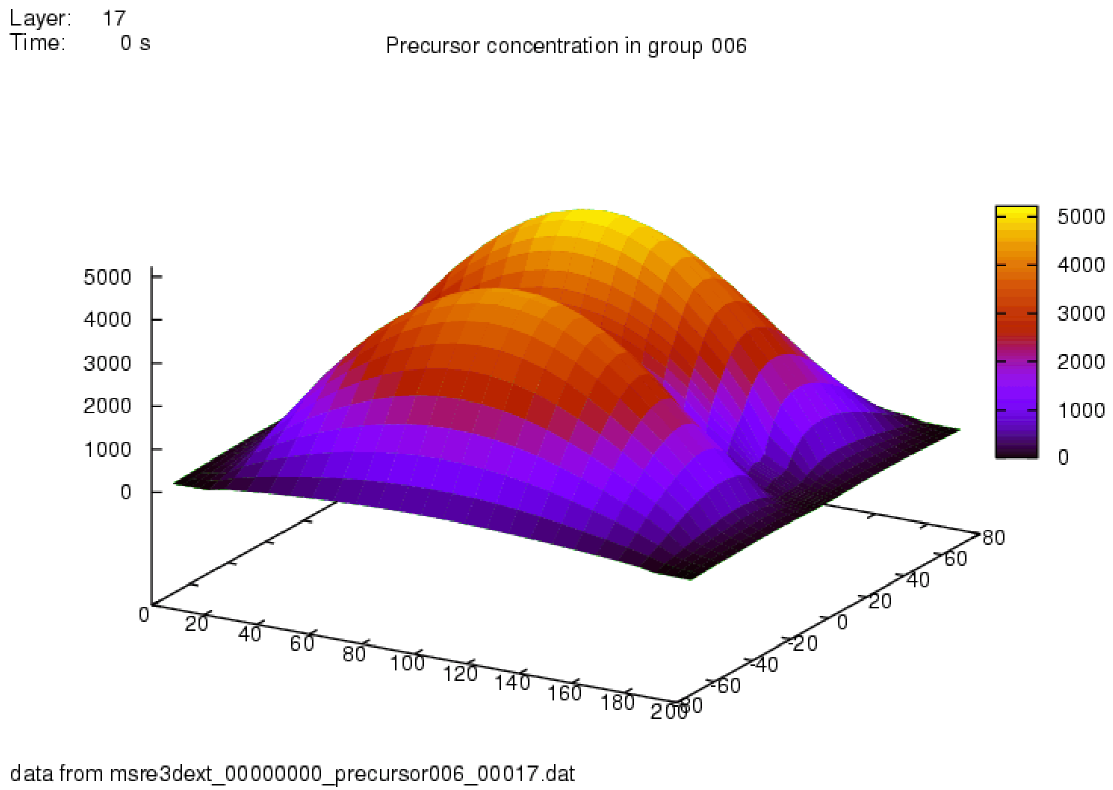
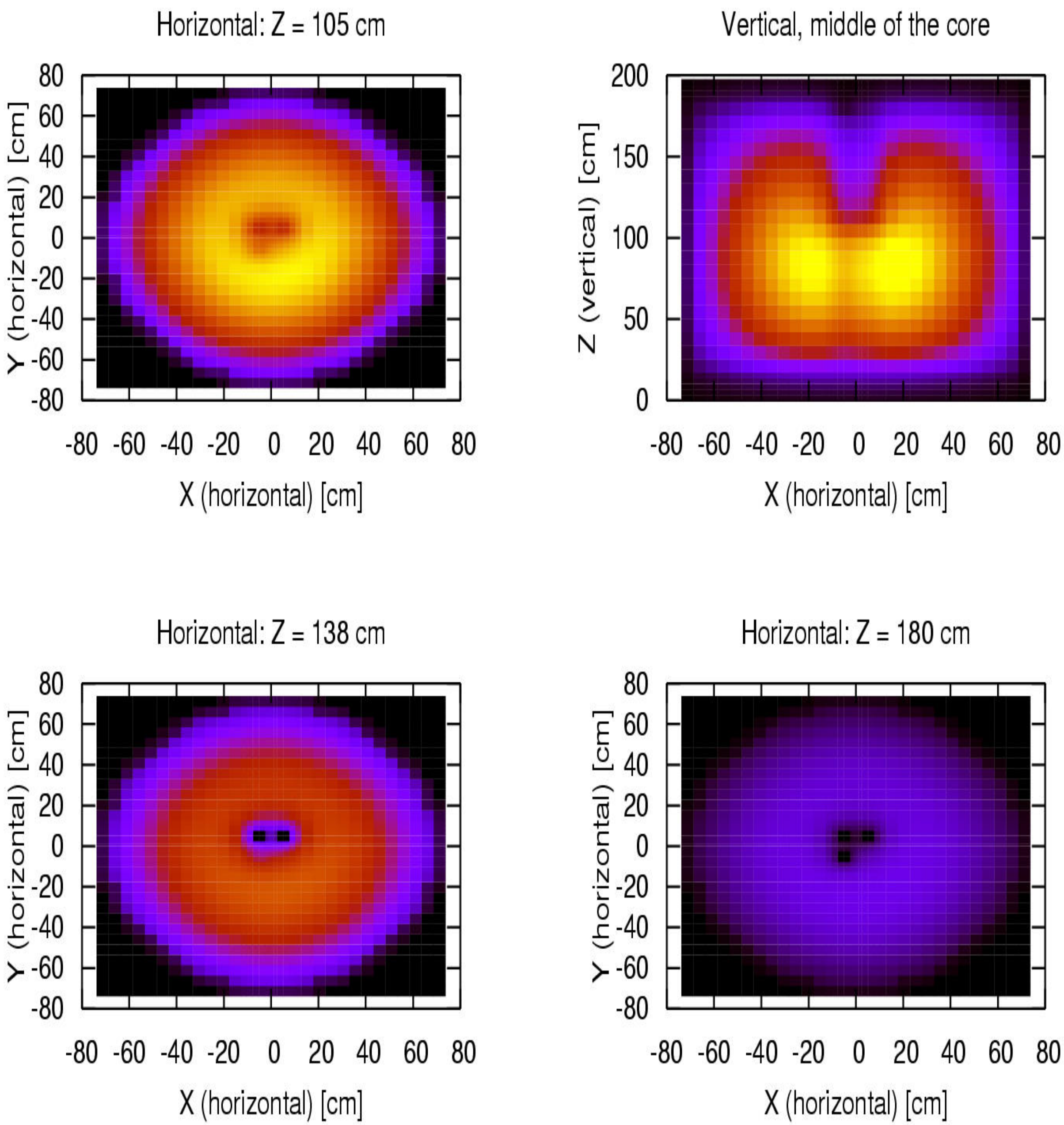
Results – Pump startup II.



Results – Pump startup III.



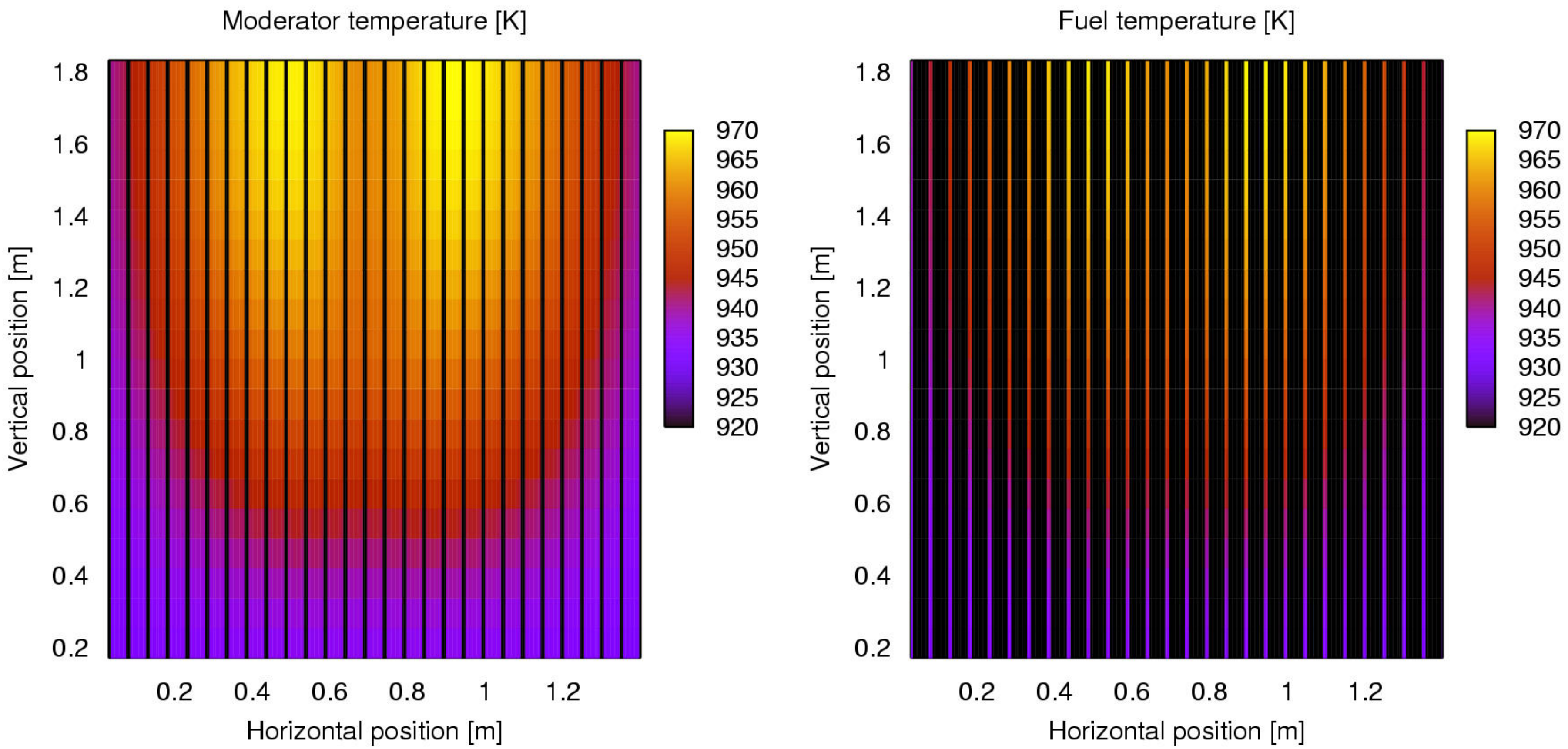
Results – Static coupled calculation - I



Thermal flux
Power: 8.41 MW

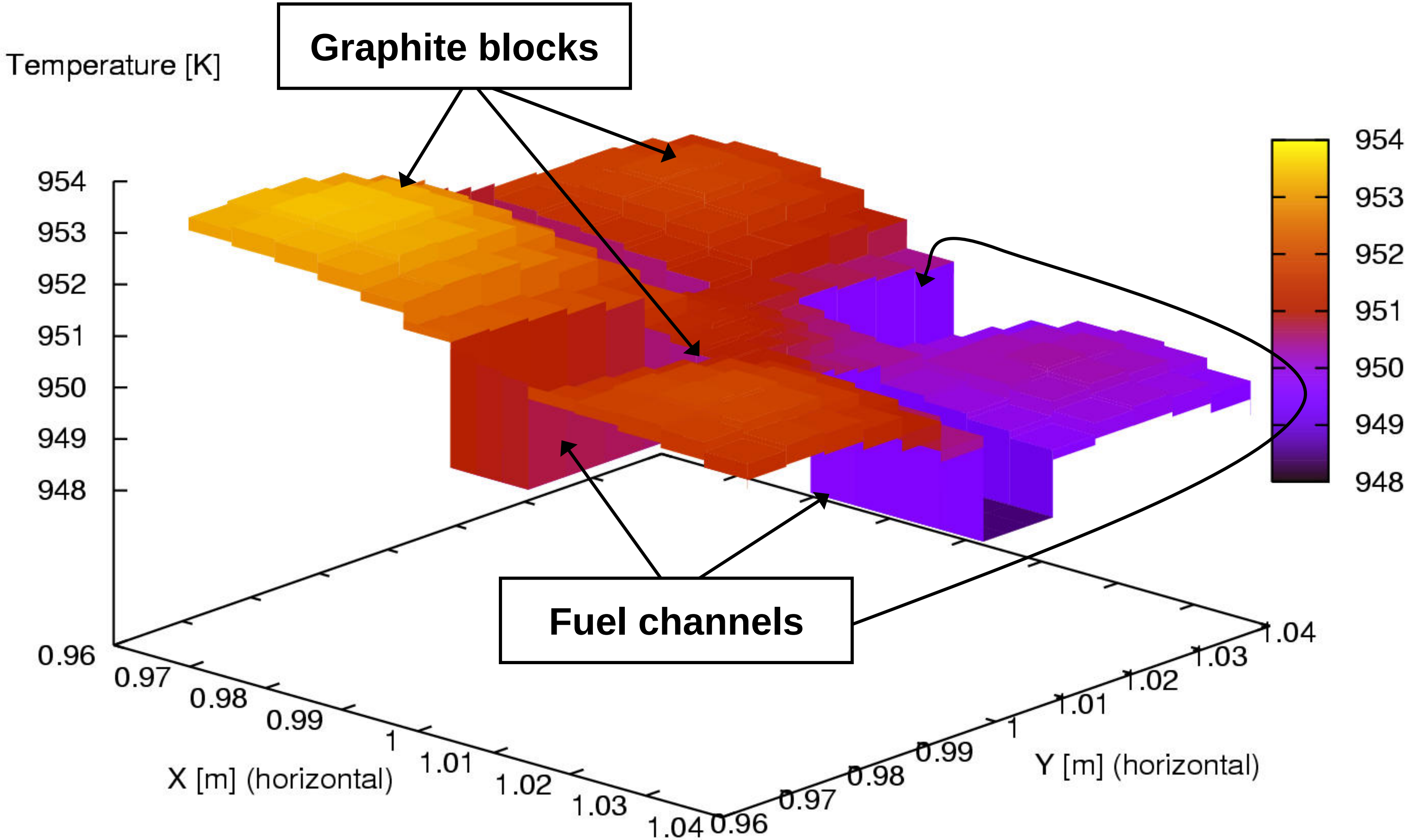
Results – Static coupled calculation - II

Vertical section of temperature fields at the middle of the core
Power: 8.41 MW



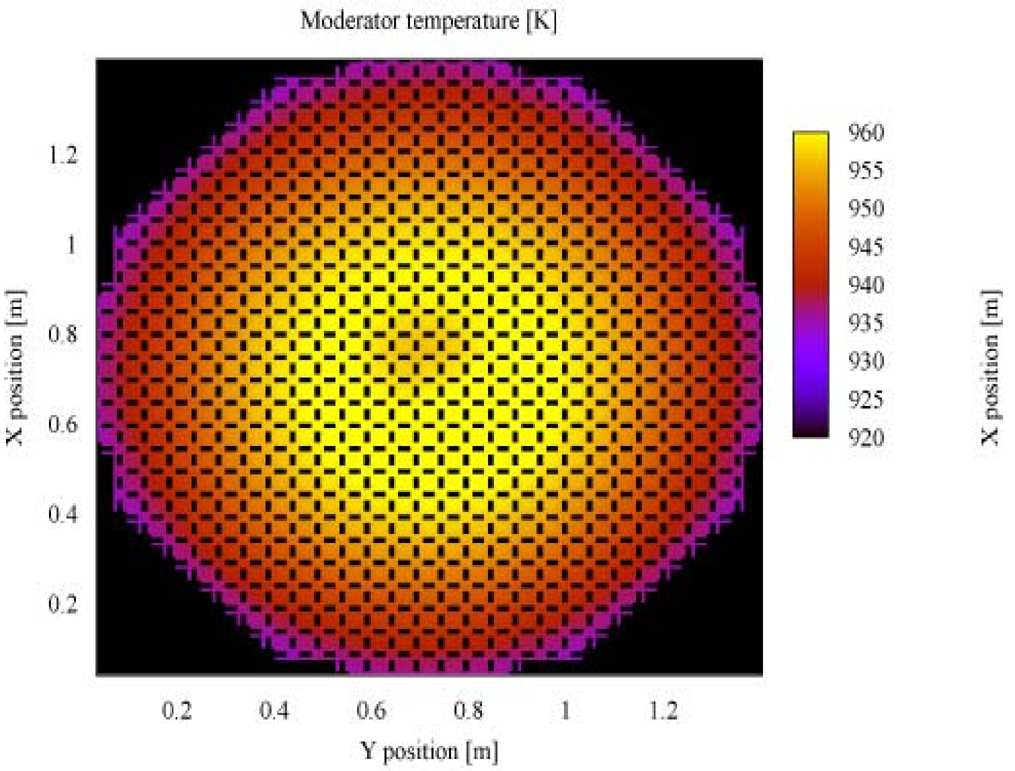
Close up view of temperature field

High resolution calculation to determine the surface temperature of the graphite and the heat transfer



Results – Static coupled calculation - III

Horizontal section of temperature fields at middle of the core



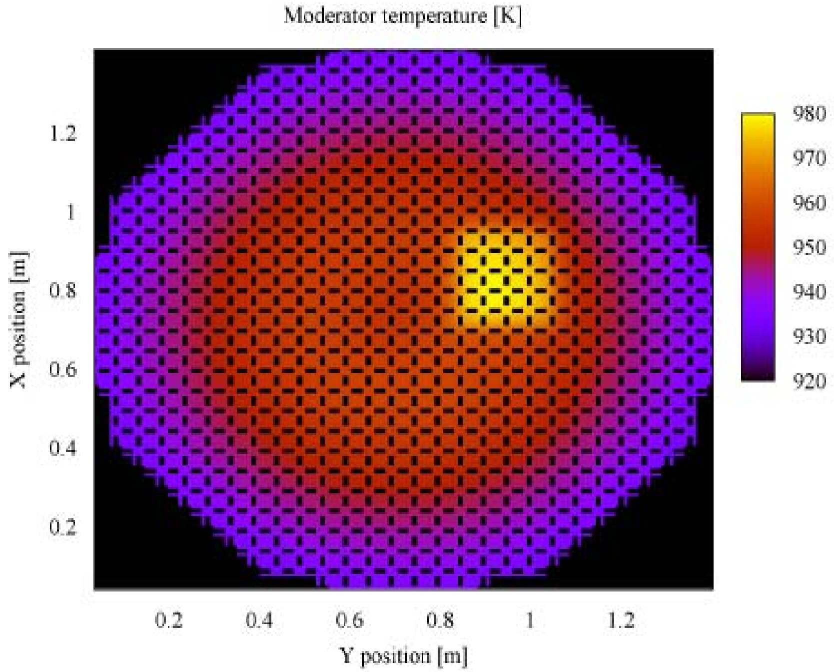
Results – Debris Incident I

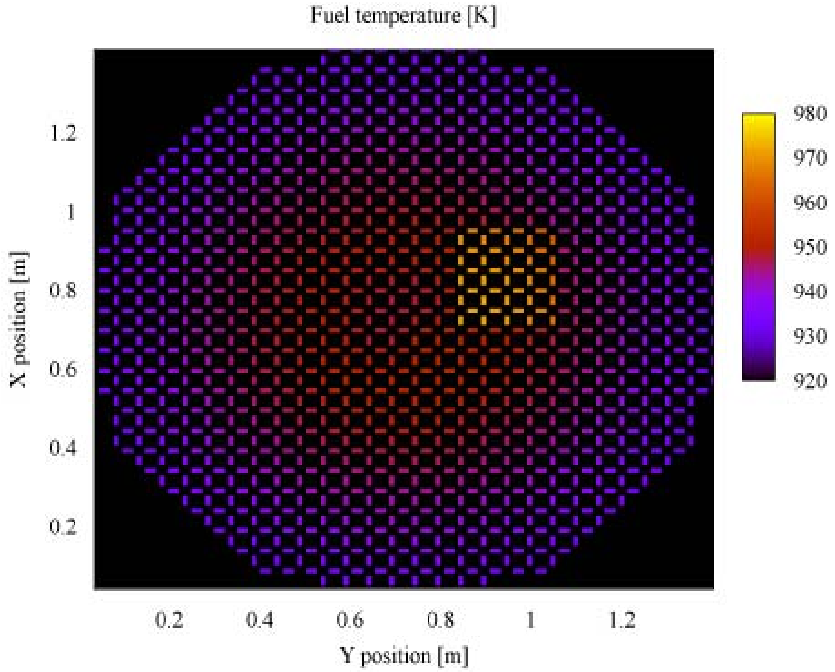
Debris gets into primary loop

45 fuel channels blocked - mass flow reduced by 50%

Total mass flow maintained

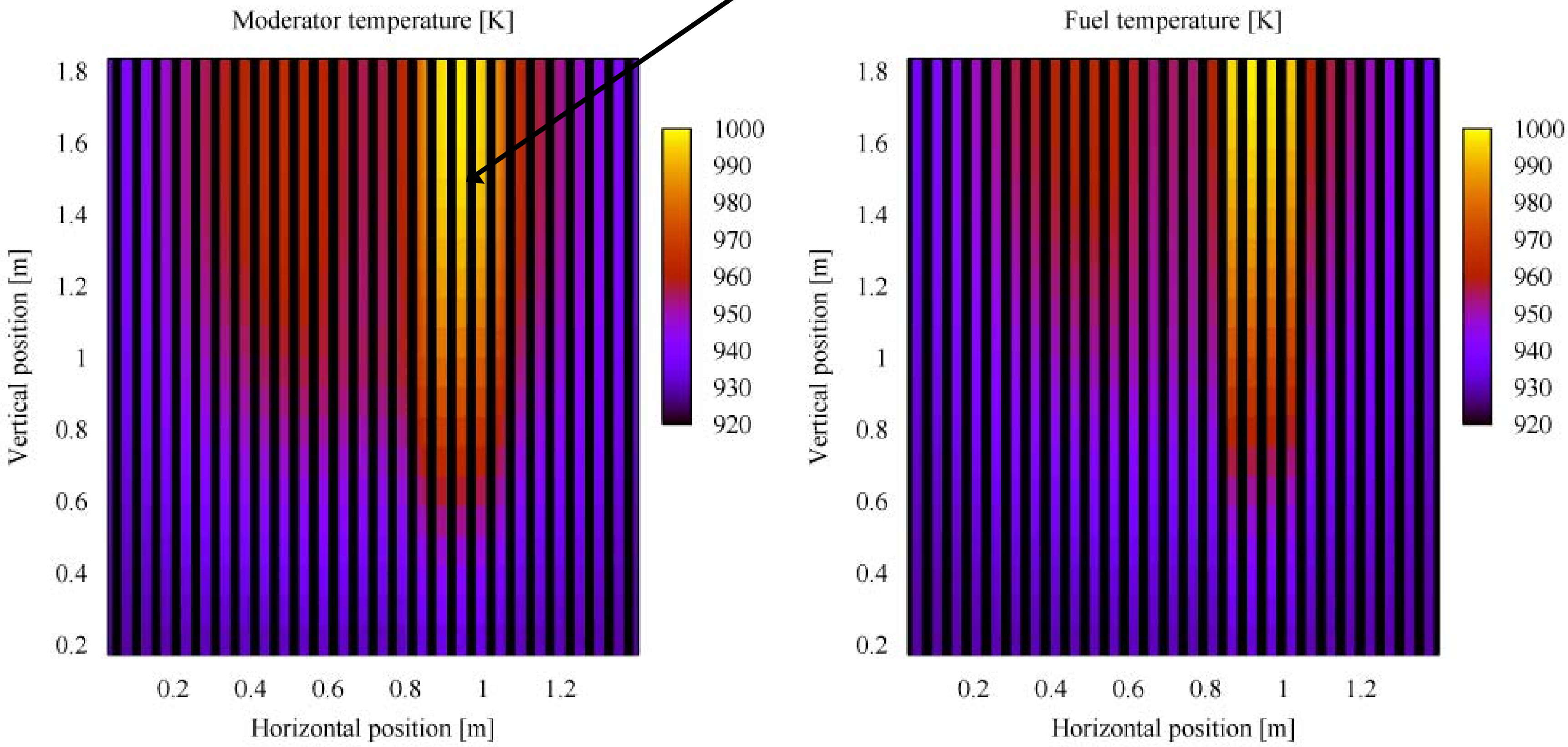
Power reduces: 8.41 MW → 8.34 MW



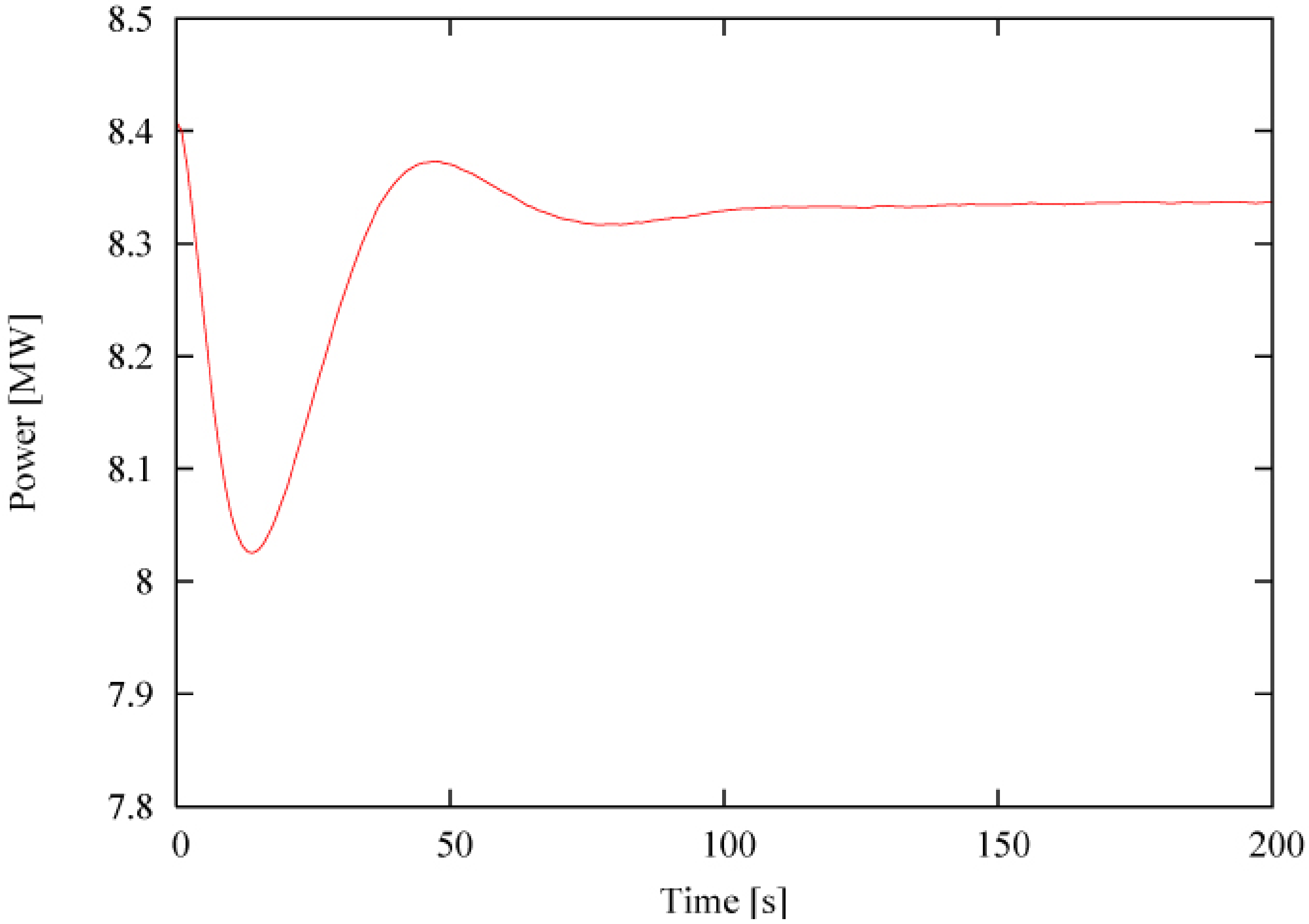


Results – Debris Incident II

Graphite conducts the heat from blocked channels



Results – Debris Incident III



Conclusions and recommendations

Three-dimensional code system capable of simulating MSR behaviour both at steady state and during transients.

Validation of the code system going on, but first results very promising. Natural circulation case in progress.

Improvements to the calculation scheme:

- Residual decay heat modeling
- Improved fuel flow model
- Include reprocessing model, burnup model, etc

Further plans

Design of a new Molten Salt Breeder Reactor

- Breeder reactor fueled with Th-232 only
- Static and dynamic design, safety assessment
- Advanced core design: driver fuel/breeder fuel zones
- Fuel cycle studies

NEW PHD Position at TU Delft

Contact

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