SMR multi-physics calculations with Serpent at VTT

Serpent UGM 2016
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Outline

- Serpent-COSY coupling
- Future work

COSY

- Three-dimensional thermal-hydraulics analysis tool developed at VTT
- Both steady state and transient problems with finite volume method on unstructured grid
- Flow solution is based on a porous-medium three-field flow model
- Also axial and radial temperature distributions in the fuel and the cladding as well as radial expansion of the fuel rods
- Currently able to solve single phase flow
- Multiphase flow model with phase transitions is in development

Coupling method

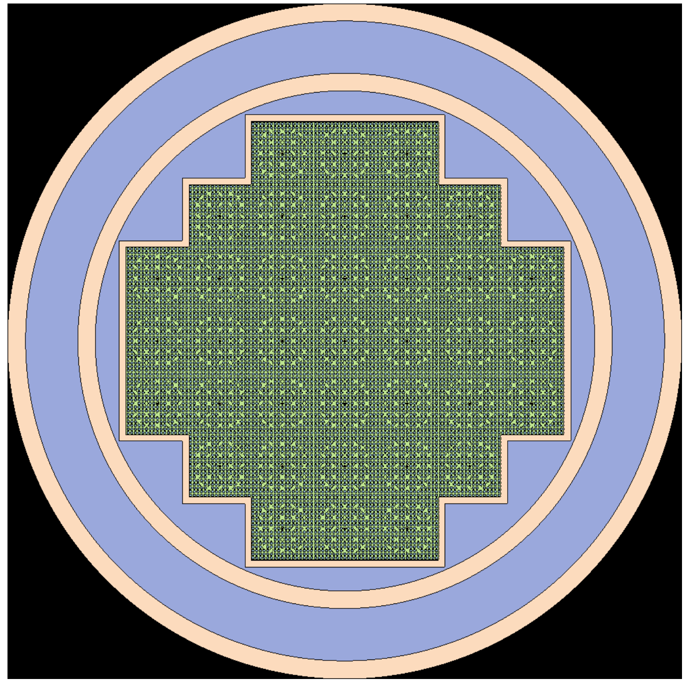
- On the top level simple coupling program to run Serpent and COSY in turns
- COSY is restarted on each iteration
- Serpent communicates with the coupling program using POSIX-signals
- Iteration is initialized by running a thermal hydraulics calculation using cosine shaped power profile
- The temperature/density/power distribution data is transferred between the codes using Serpent's multiphysics interface

Coupling method

- Coolant density and temperature distributions are transferred to Serpent with unstructured mesh based interface (type 7)
  - The interface supports OpenFOAM file format so a routine was written in order to convert the CGNS grid used in COSY to OF grid
- Fuel and cladding temperature distributions as well as radial expansion of the fuel rods and power distribution are transferred with fuel behaviour interface (type 5)
  - A simple output routine was written to COSY in order to write temperature and radial expansion data using the syntax required by the interface
  - The interface also defines the power binning in Serpent
  - Serpent power output file is read by COSY to update power distribution

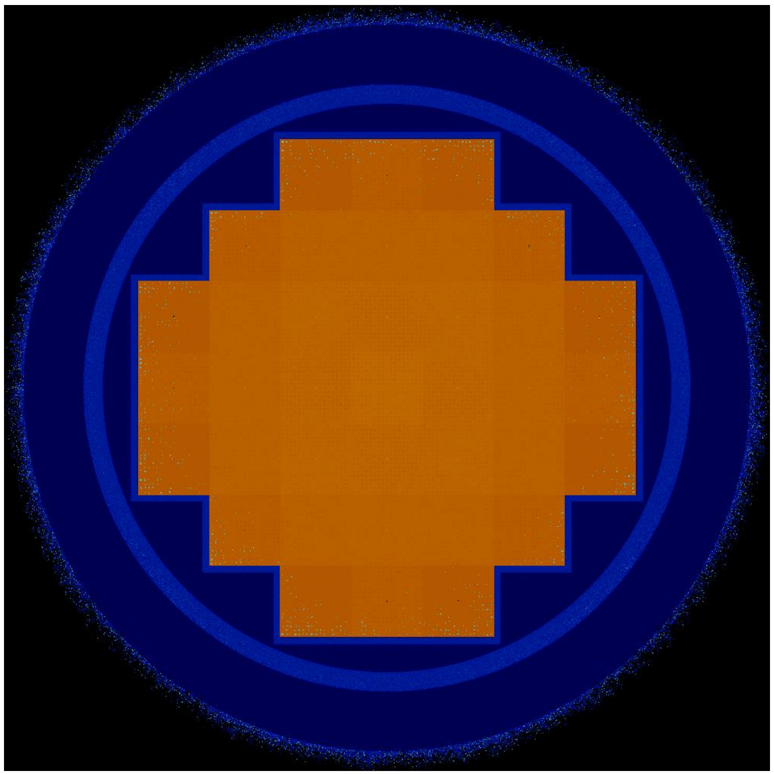
Example Case: SMR core

- Steady-state at full power with one phase flow
- Core specifications based on publicly available data from NuScale SMR design
  - Thermal power: 160 MW
  - Number of assemblies: 37
  - Assembly array: 17x17 square
  - Fuel: Standard UO2
  - Fuel active length: 2 m
  - Coolant/Moderator: Light water

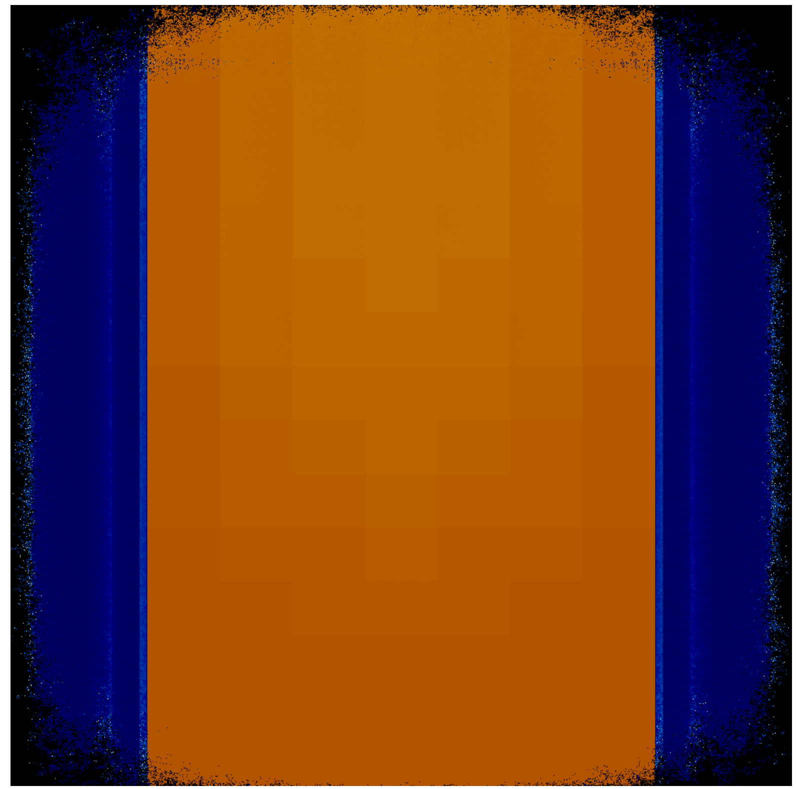


Example Case: SMR core

- Coolant temperature distribution



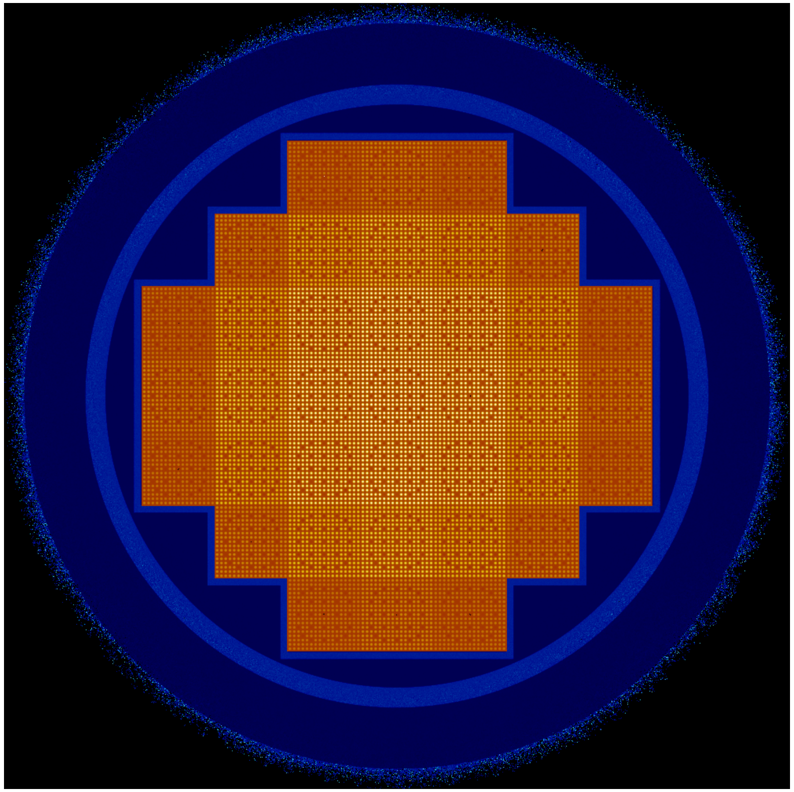
Radial



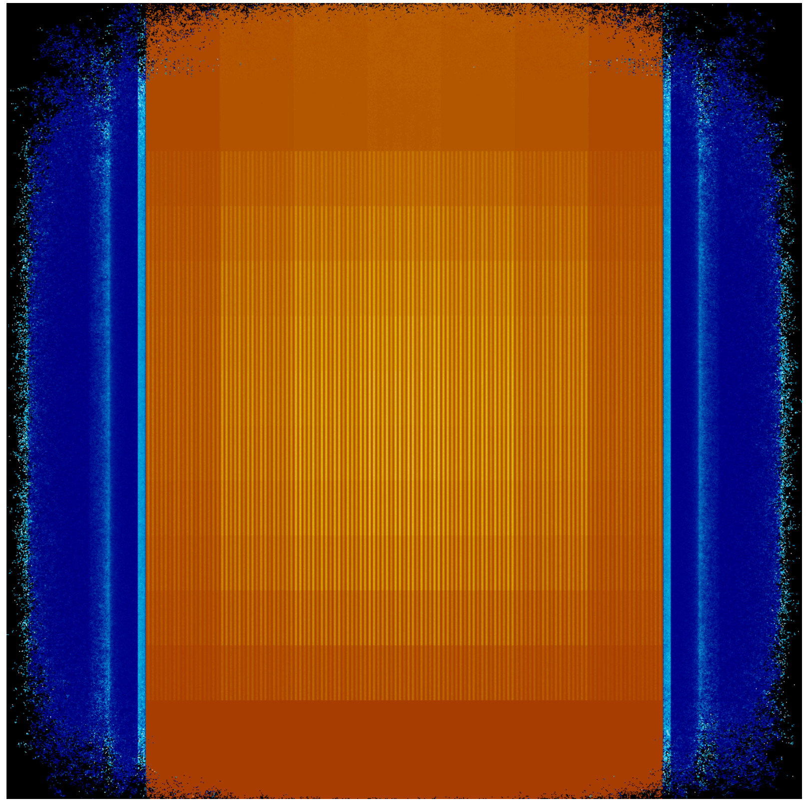
Axial

Example Case: SMR core

- Fuel temperature distribution



Radial



Axial

Future work

- I'm currently starting my doctoral studies in Aalto University
- My doctoral thesis will focus on multi-physics modeling of small modular reactors (SMRs)
- Both steady state and transient calculations with coupled thermal-hydraulics/Monte Carlo neutronics
- Burnup calculations
- One key point is to find out if the traditional deterministic neutronics solvers can be bechmarked against Serpent in the analysis of some design based accidents such as CREA
- The small size of the SMR cores makes it possible to do full-core calculations that would be too expensive for larger reactors
- Serpent is used for neutronics but there are several possibilities for the thermal-hydraulics solution

Some options for the thermal-hydraulics solution

- COSY
  - Already coupled with Serpent
  - New code with very limited testing done
  - Multiphase flow model is still in development
  - Currently, there are no plans for further development after the multiphase flow model has been completed
- Subchanflow (SCF)
  - Subchannel code developed at KIT
  - Previously coupled internally with Serpent
  - The internal coupling must to be updated to work with new versions of SCF and Serpent

Some options for the thermal-hydraulics solution

- TRACE
  - Widely used US-NRC's best-estimate reactor system code
  - Capable of analyzing LOCAs, operational transients and other accident scenarios in PWRs and BWRs
  - Coupled with US-NRC's 3D nodal diffusion code PARCS
  - Recently reactor dynamics solver DYN3D was integrated to TRACE/PARCS code system at KIT
- Some other subchannel or reactor system code?

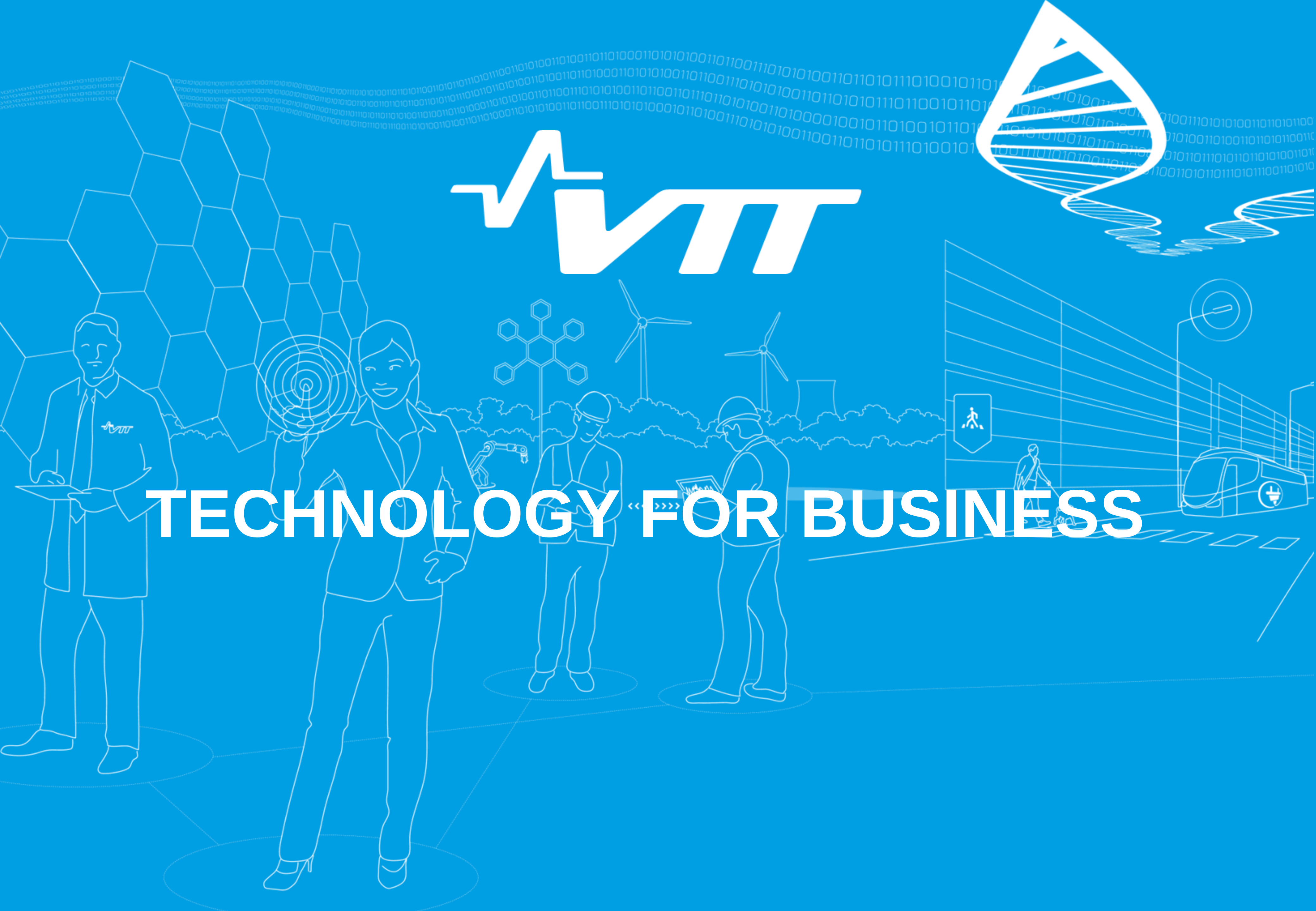
TRACE/Serpent

- Neutronics are solved with Serpent instead of PARCS
- First evaluate if an external coupling using Serpent's multiphysics interface is possible
  - Implement input and output routines to TRACE
  - Some simple coupling program
- Otherwise an internal coupling
  - TRACE acts as a master code in the coupling with PARCS/DYN3D and the data between the coupled codes is transferred through General Interface (GI)
  - Is a similar coupling possible with Serpent?

TRACE/Serpent

- Once the coupling works test calculations can be performed with both TRACE/Serpent and TRACE/PARCS code systems and the results compared
  - Cross sections for PARCS can be generated with Serpent
- One possible use for the coupling would be to simulate a control rod ejection accident in a SMR core
- The length of the simulated transients is limited by the high computational cost of the dynamic Monte Carlo simulations

Questions? Ideas?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