Coupling of neutronic and thermal-hydraulic calculations for nuclear reactors

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

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New reactor concepts and safety analyses for the Polish Nuclear Energy Program POWR.03.02.00-00.I005/17

Agenda

- Introduction
- Neutronic – thermal feedbacks
- Serpent & OpenFOAM
- MCB & POKE
- GeN-Foam
- MCB & FLUENT
- Summary

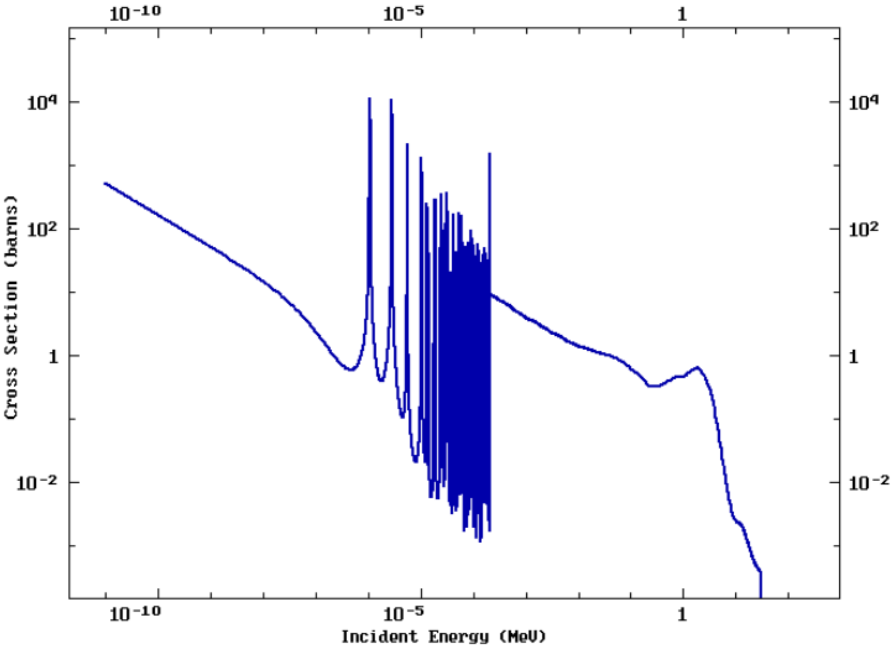
Introduction

- Dissertation topic
  - Development and validation of coupled neutronic and CFD calculations for HTR applications
  - Basing on MCB code and open source CFD code OpenFOAM the development of coupling scheme for neutronic and thermal-hydraulic calculations will be undertaken.
- The aim of the first stage of the research is to familiarize with basics of coupled calculations and aforementioned codes.
- Research based on publications.

Neutronic – thermal feedbacks

Neutronic – thermal feedbacks

- Doppler temperature effect
  - microscopic cross-section resonances broadening by temperature increase
- Thermal expansion
  - changes of materials density
  - affects macroscopic cross-sections
  - void coefficient



Microscopic cross-section of neutron capture in U238 (ENDF)

Neutronic – thermal feedbacks

When the reactors power does change
Also temperature does rearrange

It causes material thermal expansion
Can fix or deny their permansion

It affects almost every cross-section
No resonance has its protection

Neutrons modify their interactions
Thus they provoke power variations

The vicious circle gets closed then
and so it goes on again and again

Serpent & OpenFOAM

Serpent & OpenFOAM

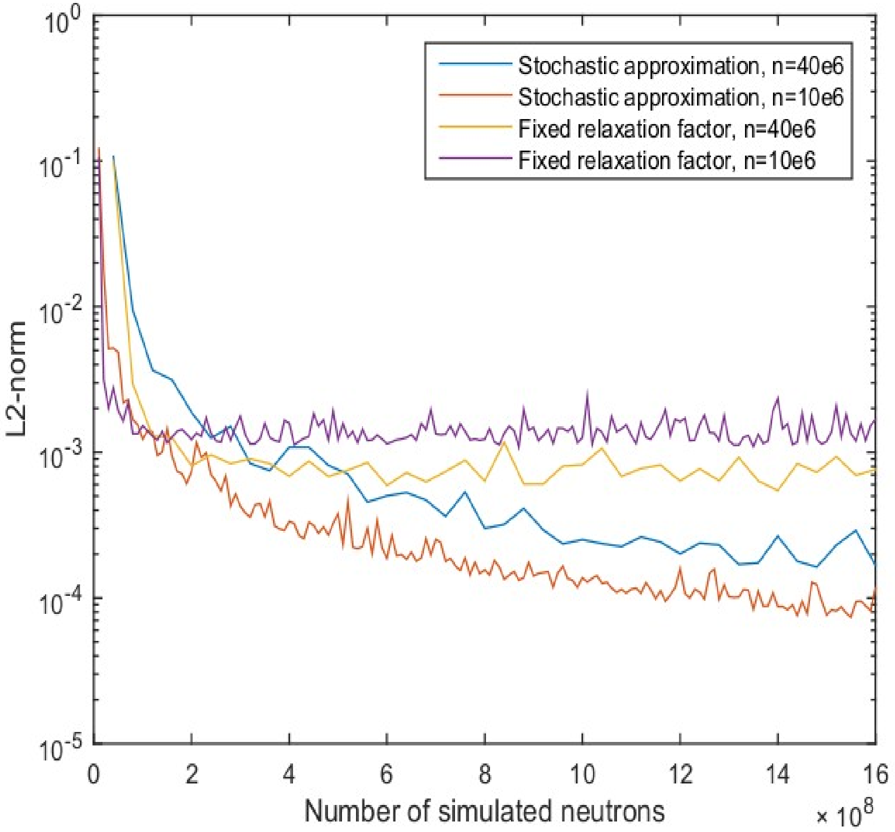
- Serpent
  - Monte-Carlo reactor physics code
  - Built in multi-physics interface
    - Allows coupling to external codes
    - E.g. CFD, fuel performance etc.
    - On-the-fly Target Motion Sampling treatment of temperature
- OpenFOAM (Field Operation And Manipulation)
  - Open source C++ toolbox for continuum mechanics problems
  - Based on a large library
    - Tensor and field operations,
    - Discretization of partial differential equations,
    - Turbuence models
  - Over 80 ready made solvers

Serpent & OpenFOAM

- Serpent
  - Calculation of the model with uniform temperature and density distributions, fission power distribution is obtained
  - Relaxation of the power distribution
  - Generation of OpenFOAM field file for the power distribution
- OpenFOAM
  - Loading of the power distribution file to the OpenFOAM input
  - Calculation of temperature and density distributions with chtMultiRegionSimpleFoam solver
  - Determination of convergence by monitoring energy balance
  - Generation of new temperature and density field files

Serpent & OpenFOAM

- Test case was a mock-up 5x5 fuel assembly based on PWR TMI-1
- Two relaxation schemes were tested: fixed relaxation factor and stochastic approximation with the under-relaxation factor α=0.1.
- With the stochastic approximation the limitation of the Monte-Carlo uncertainties was ommited
- Steady-state calculation
- Single-phase flow

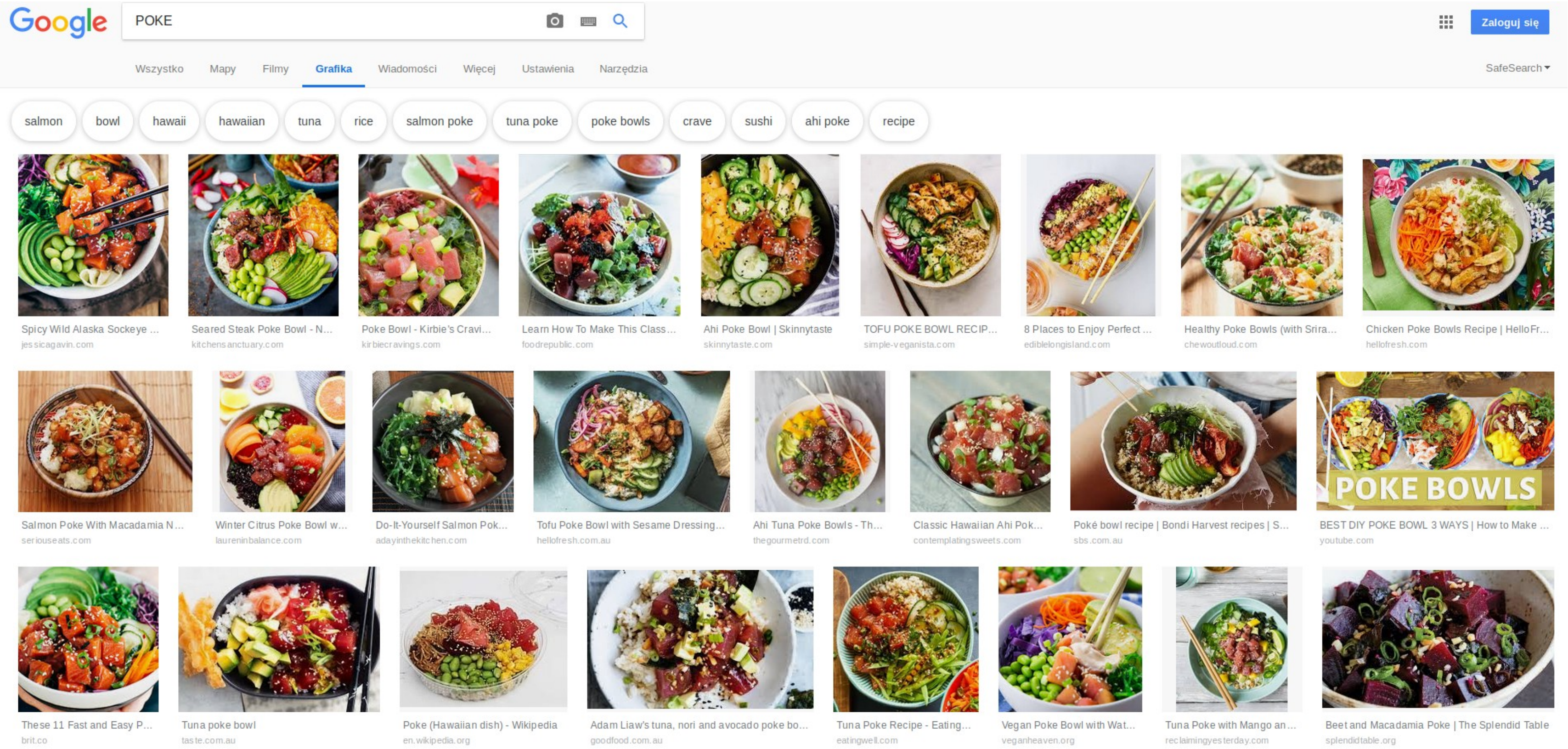


MCB & POKE

MCB & POKE

- MCB (Monte Carlo Continuous Energy Burn-up Code)
  - Internally integrates the MCNP and TTA (Transumation Trajectory Analysis) codes
  - Transmutation probabilities are assessed directly in the process of neutron transport calculation
  - Availability of material processing
- POKE
  - Designed for Ft. St. Vrain reactor
  - Steady-state calculation of fuel and cooland temperature distributions and mass flow

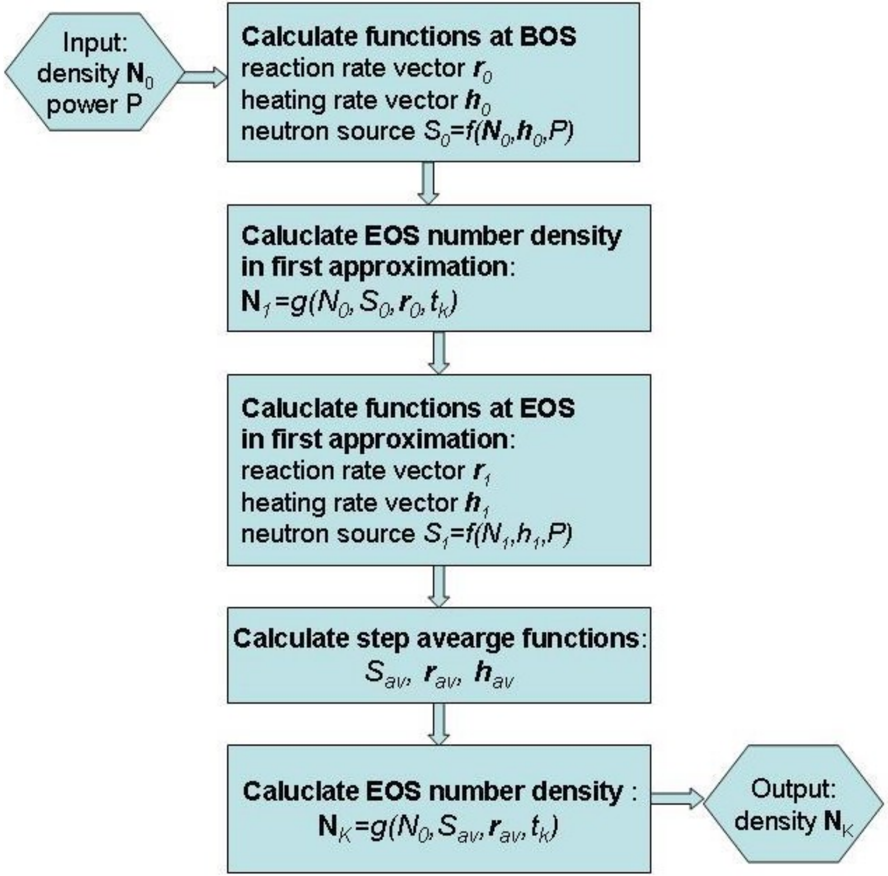
MCB & POKE



Google
POKE
Zaloguj się
Wszystko
Mapy
Filmy
Grafika
Wiadomości
Więcej
Ustawienia
Narzędzia
SafeSearch
salmon
bowl
hawaii
hawaiian
tuna
rice
salmon poke
tuna poke
poke bowls
crave
sushi
ahi poke
recipe
Spicy Wild Alaska Sockeye ...
jessicagavin.com
Seared Steak Poke Bowl - N...
kitchensanctuary.com
Poke Bowl - Kirbie's Cravi...
kirbiecravings.com
Learn How To Make This Class...
foodrepublic.com
Ahi Poke Bowl | Skinnytaste
skinnytaste.com
TOFU POKE BOWL RECIP...
simple-veganista.com
8 Places to Enjoy Perfect ...
ediblelongisland.com
Healthy Poke Bowls (with Srira...
chewoutloud.com
Chicken Poke Bowls Recipe | HelloFr...
hellofresh.com
Salmon Poke With Macadamia N...
seriouseats.com
Winter Citrus Poke Bowl w...
laureninbalance.com
Do-It-Yourself Salmon Pok...
adayinthekitchen.com
Tofu Poke Bowl with Sesame Dressing...
hellofresh.com.au
Ahi Tuna Poke Bowls - Th...
thegourmetrd.com
Classic Hawaiian Ahi Pok...
contemplatingsweets.com
Poké bowl recipe | Bondi Harvest recipes | S...
sbs.com.au
POKE BOWLS
BEST DIY POKE BOWL 3 WAYS | How to Make ...
youtube.com
These 11 Fast and Easy P...
brit.co
Tuna poke bowl
taste.com.au
Poke (Hawaiian dish) - Wikipedia
en.wikipedia.org
Adam Liaw's tuna, nori and avocado poke bo...
goodfood.com.au
Tuna Poke Recipe - Eating...
eatingwell.com
Vegan Poke Bowl with Wat...
veganheaven.org
Tuna Poke with Mango an...
reclaimingyesterday.com
Beet and Macadamia Poke | The Splendid Table
splendidtable.org

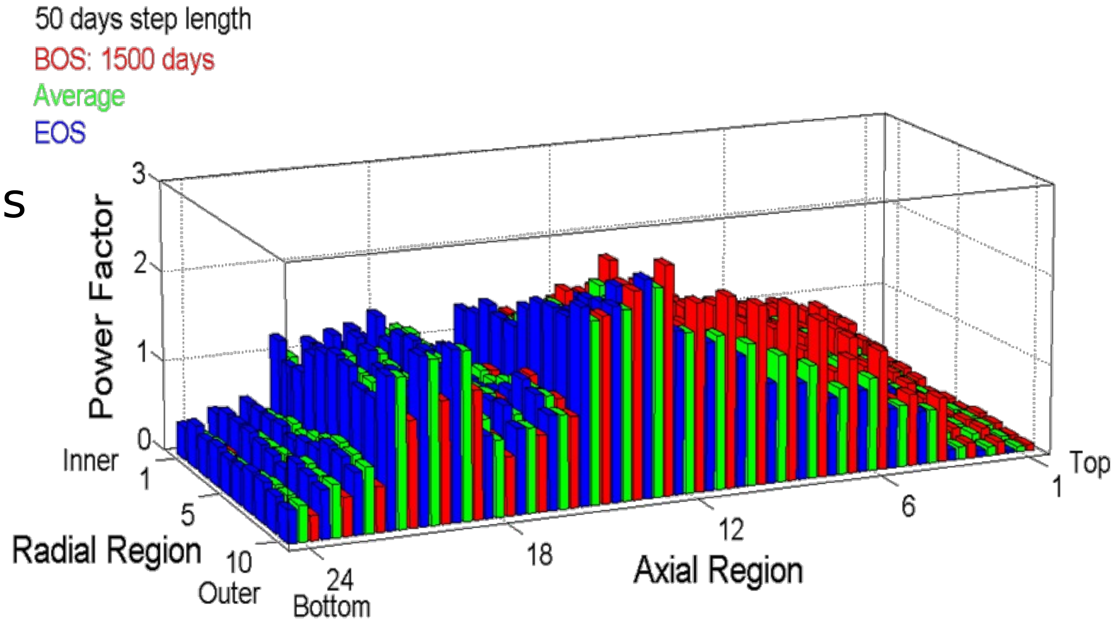
MCB & POKE

- Coupling made on the level of source code – modified POKE incorporated into the MCB
- Data exchange left on external files in order to allow recalculation
- Bridge scheme of burnup step is applied
  - Neutron source normalization
  - Specific values are calculated at the beginning and at the end of step and then averagted
  - The process reduces numerical oscillations



MCB & POKE

- Calculations of prismatic HTGR PuMA operation cycle in a deep burn design
- Several features were included:
  - Burnup
  - Fuel shuffling
  - Control rod operations
  - Burnable poisons
- Applicability only for prismatic HTGRs



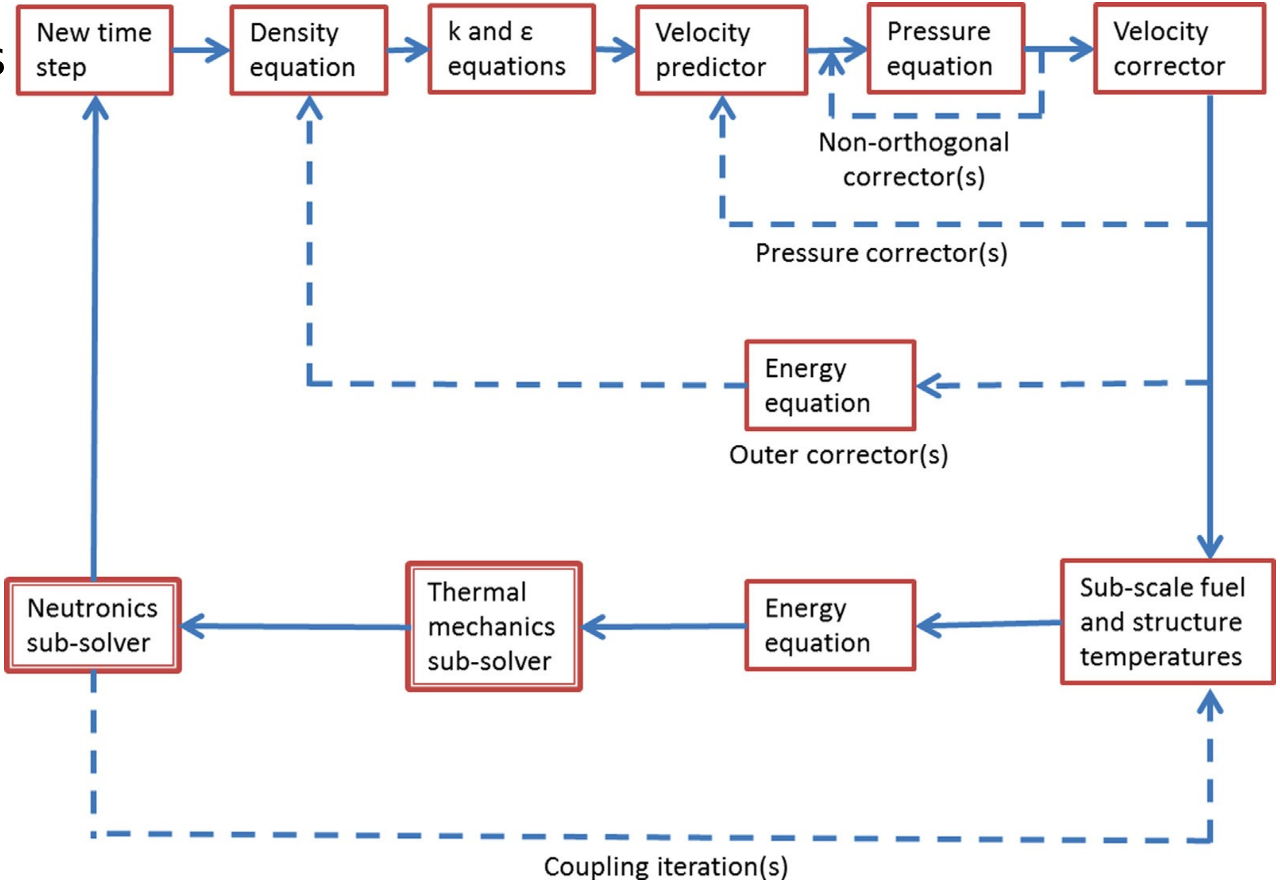
GeN-Foam

GeN-Foam

- Multi-physics solver based on OpenFOAM libraries
- Consists of several sub-solvers:
  - Thermal-hydraulic sub-solver based on standard k-ε model, porous media approach
  - Thermal-mechanic sub-solver based on ready-made OpenFOAM solver
  - Sub-scale fuel model evaluating local temperature profile in fuel and cladding
  - Neutronic sub-solver based on multi-group neutron diffusion equations
    - Crosss-sections are obtained by interpolation between nominal and perturbated sets
    - The sets has to be prepared earlier by full-core Serpent calculations
    - Deformed mesh is applied according to thermal-mechanic results

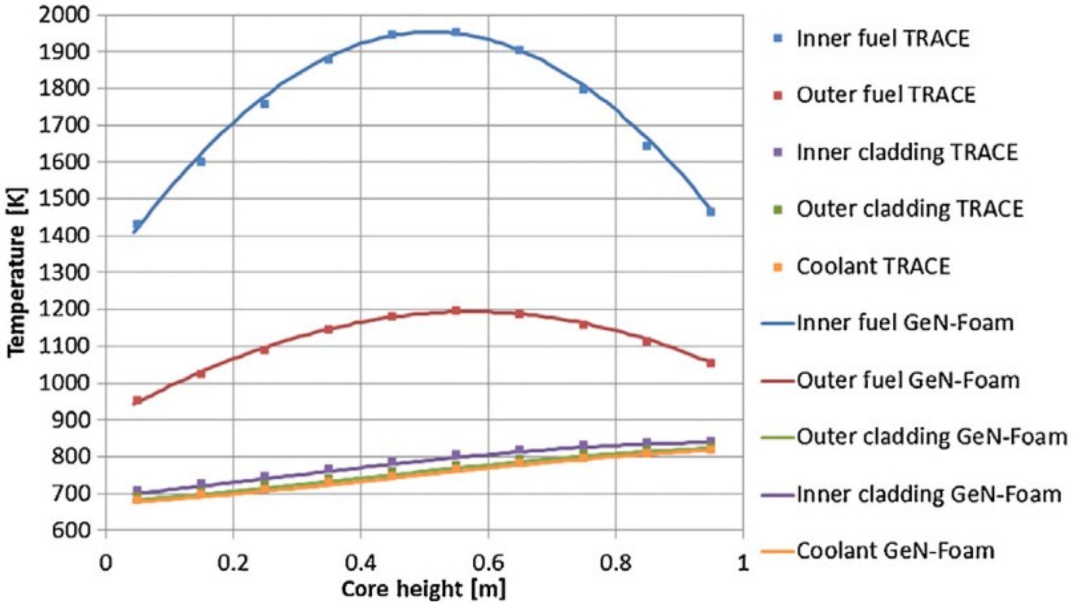
The correction loops are repeated until the desired degree of convergence is obtained.

Initial residuals are evaluated, the next step start when all of them are lower than a user-defined tolerance



GeN-Foam

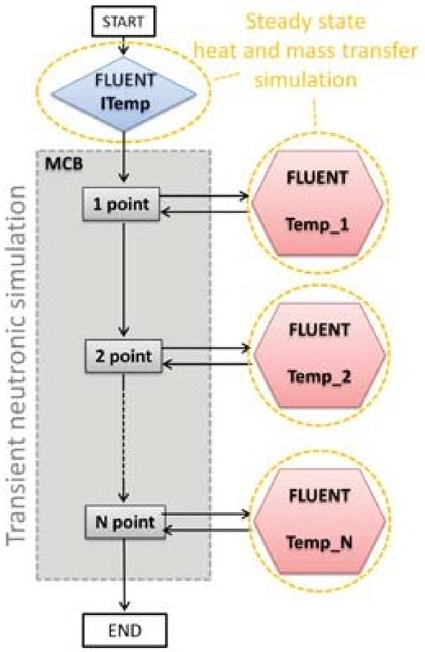
- Performance of ESFR (European Sodium Fast Reactor) was simulated
- Results were validated by comparison with TRACE
- Limited applicability for thermal reactors due to possible numerical oscillations
- Thermal expansion
- Single-phase flow

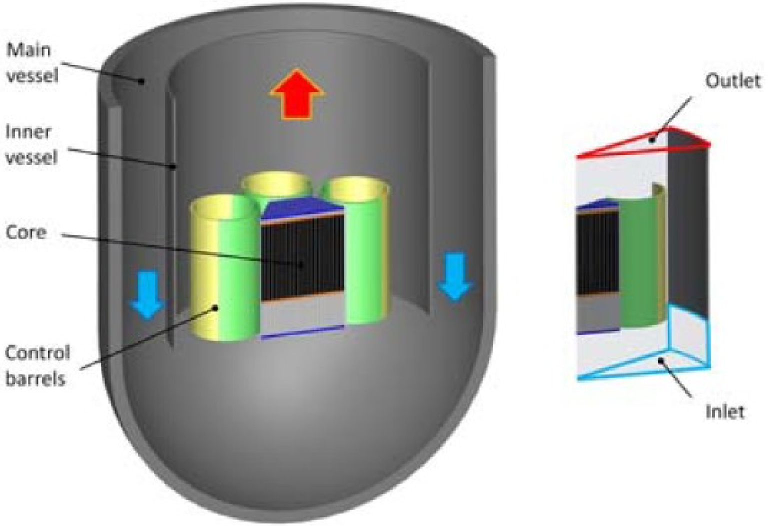


MCB & FLUENT

MCB & FLUENT

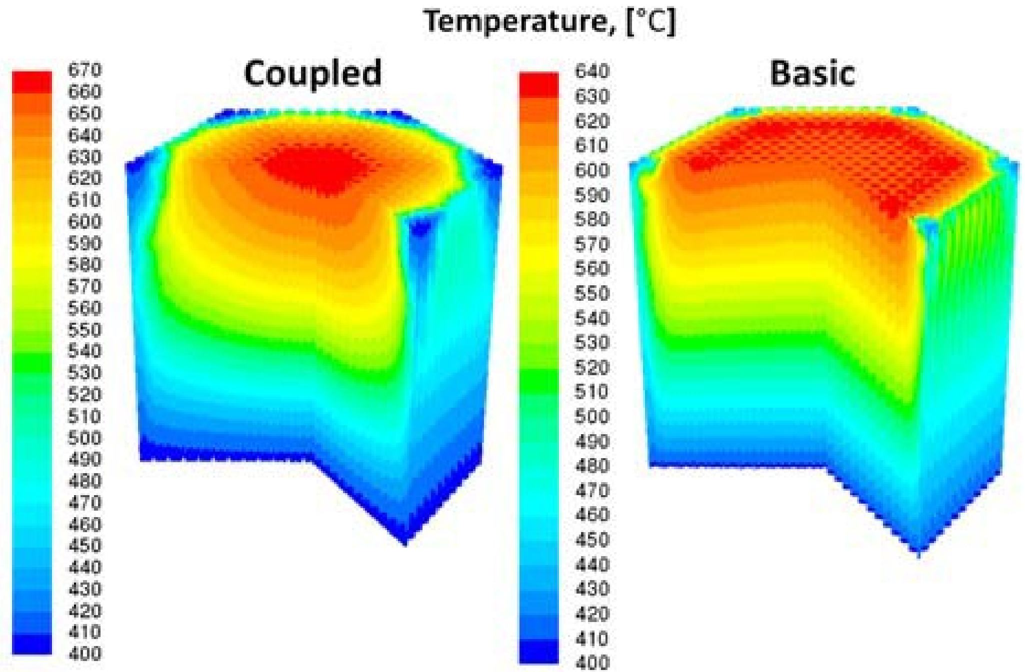
- ELECTRA (European Lead-cooled Training Reactor) concept was investigated.
- Two different geometries for neutronic and thermal-hydraulic parts
- Coupling provided by dedicated script exetucing the codes
- Volume of the fuel divided into small volumes, thus creating matrix of volumes





Geometries for neutronic and CFD parts (Cetnar 2014)

MCB & FLUENT



Temperature, [°C]
Coupled
Basic
670
660
650
640
630
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
430
420
410
400
640
630
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
430
420
410
400

Summary

- Coupling of neutronic and thermal-hydraulic calculations allows to obtain more accurate results compared to separate calculations.
- Coupling is provided by information exchange between specific codes or solvers.
- It can be made internally using specific features of the codes or externally by a script executing codes and fixing data format.
- The MCB code includes several features allowing to accurately simulate entire reactor operating cycle.
- The OpenFOAM code is a very flexible tool that can have many applications and consider complex phenomenons.
- In future external coupling of the MCB and OpenFOAM will be provided.

Literature

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6. Tuominen R., et al.: *Coupling Serpent and OpenFOAM for neutronics - CFD multi-physics calculations*. VTT Technical Research Centre of Finland Ltd, Espoo, 2016

Thank you for attention

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