Coupling between dynamics Monte Carlo neutron transport and thermal-hydraulics

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Field of reactor physics

- Besides of deterministic codes Monte-Carlo codes are becoming more and more common
- Dynamic Monte-Carlo (DMC) codes solve the integral form of Boltzmann equation
- Can provide very accurate calculations
- Becoming an essential part of reactor safety calculations

Monte-Carlo particle transport

Analog Monte-Carlo

- Real physical phenomena
- Variance is only function of the particle population
- Need to simulate large amount of particles
- Multiplying system
- Computation time is governed by the number of particles

Non-analog Monte-Carlo

- Do not follow the real physics
- Particles have weights
- Distorted probability densities of the events
- Variance reduction techniques (Russian roulette, Implicit capture, Splitting, etc...)
- Population is controlled artificially
- Computation time can be saved

GUARDYAN

GUARDYAN: GPU Assisted Reactor Dynamic Analysis

- Developed at Institute of Nuclear Techniques of Budapest University of Technology and Economics
- Direct time dependence
- Continuous energy handling
- GPU specific code from the beginning
- Accepts geometry descriptions of cells bounded by second order surfaces
- Variance reduction techniques (Implicit capture, Combing)
- Uses double precision arithmetic

Thermal-hydraulics coupling

SUBCHANFLOW thermal-hydraulics sub-channel code:

- Basic conservation equations (Energy, Momentum, Mass)
- Heat conduction equation (Finite volume method)
- Empirical correlations (Pressure drop, Void generation, Heat transfer)
- Modelling light water reactors
- The thermal-hydraulic calculations are executed separately for each sub-channel

Coupling scheme

Semi implicit Operator Splitting Method (OSSI):
Fuel temperature T_f, coolant temperature T_c, and coolant density ρ data of the previous time step $(i-1)$ is used for calculation (F_N) of the node-wise power release:

$$P^k = F_N\left(T_f^{i-1}, T_c^{i-1}, \rho^{i-1}\right) \tag{1}$$

The thermal-hydraulics module returns (F_{TH}) the new temperature and density data:

$$\left[T_f^i, T_c^i, \rho^i\right] = F_{TH}\left(P^k\right) \tag{2}$$

Coupling scheme

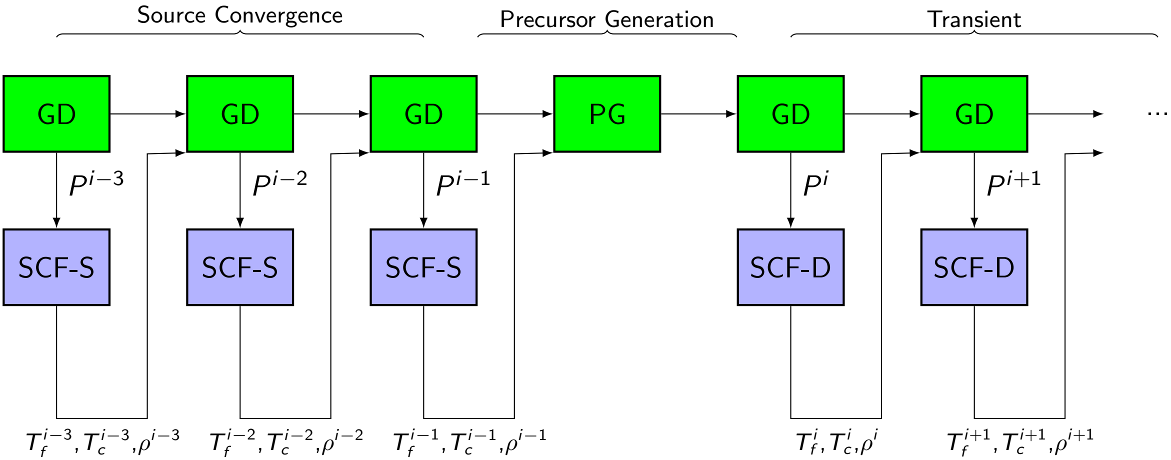


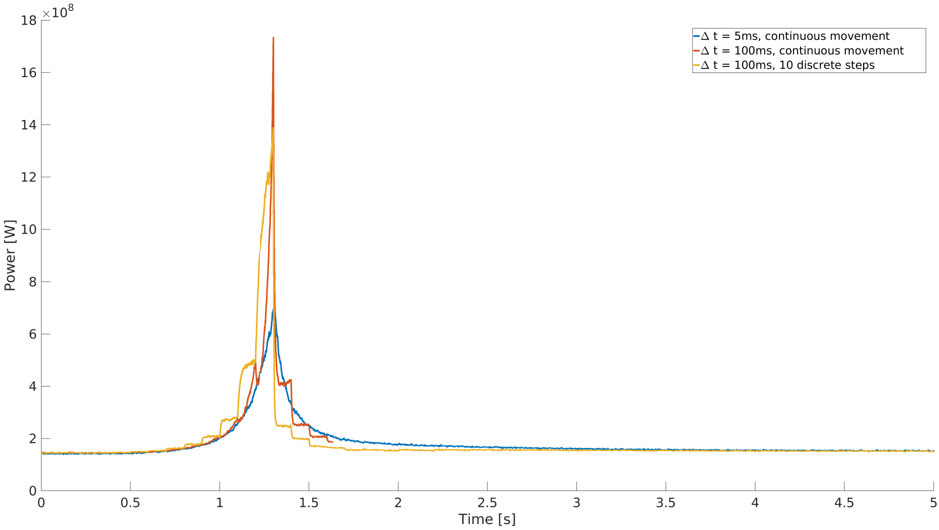
Figure: Dynamic coupling scheme.

Transient simulation

Simplified core model of Three Mile Island (TMI) reactor:

- Benchmark calculation
- 40 cm control rods moving transient
- Transient time: 5 sec
- Number of simulated neutrons: 4.6 million
- Used memory below 20 GB

Transient simulation



Comparison of the reactor power results

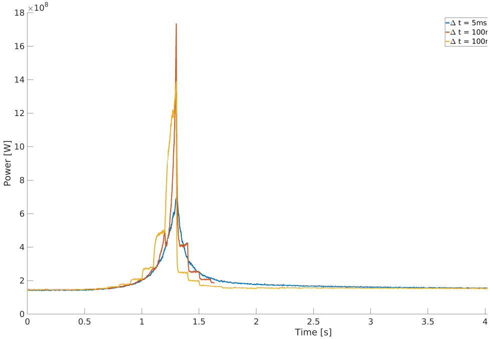


Figure: GUARDYAN

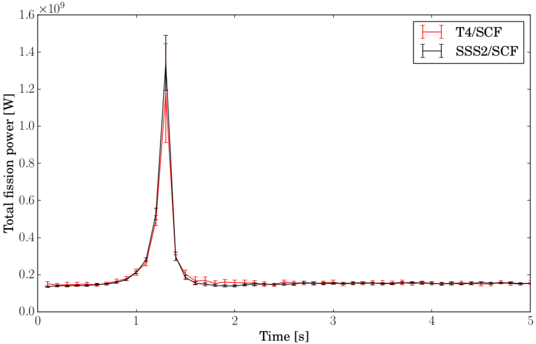


Figure: TRIPOLI and SERPENT

Comparison of the average fuel temperature results

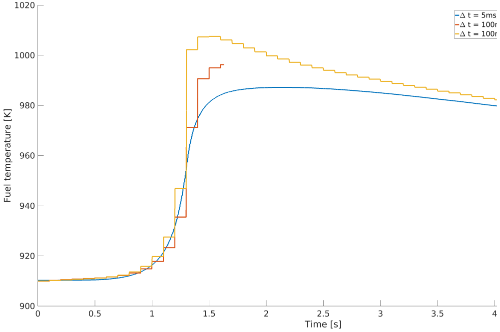


Figure: GUARDYAN

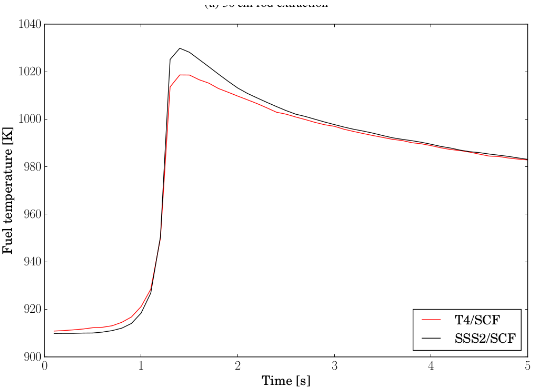


Figure: TRIPOLI and SERPENT

Used GPU hardwares

Features	RTX 3090	RTX A6000
Number of CUDA cores	5248	10752
Memory size	24 GB	48 GB
Double Precision Performance (TFLOPS)	0.45	-
L2 cache	6MB	-

Computational times

Cases	**RTX 3090**	**RTX A6000**
GUARDYAN continuous move	462 h	-
GUARDYAN discrete move	-	488 h
SUBCHANFLOW 0.1 s coupling time step	45 min	45 min
SUBCHANFLOW 5 ms coupling time step	8.8 h	8.8 h

Steady state simulation

Paks Nuclear Power Plant Block 4:

- Steady state simulation
- Coupling time step: 5ms
- 15 inactive cycle was enough for convergence
- Number of simulated neutrons: 4.19 million
- Simulation took 90 h in a RTX A6000 card
- Used memory: 30 GB

Thank you for your attention!

Transient simulation

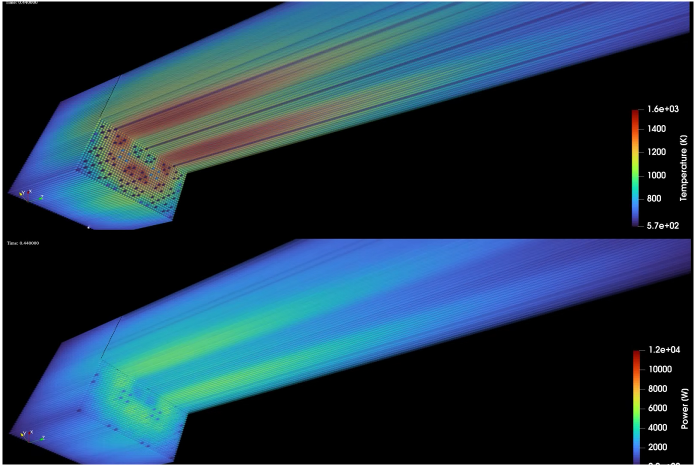


Figure: GUARDYAN-SUBCHANFLOW coupling