NRG’s Thermal Hydraulic Expertise for Advanced Reactors

Nuclear Innovation Conference

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Contents

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Introduction

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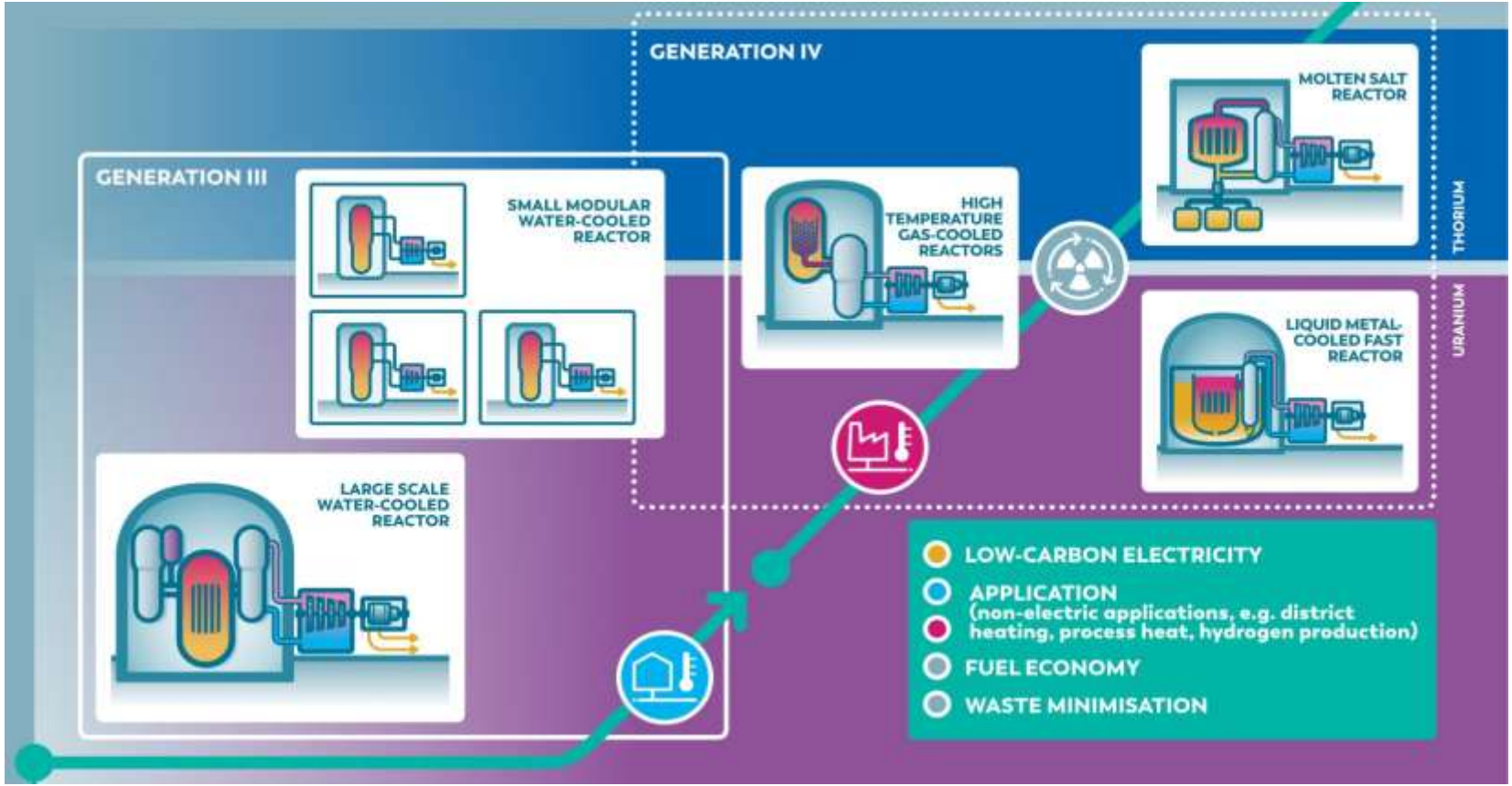
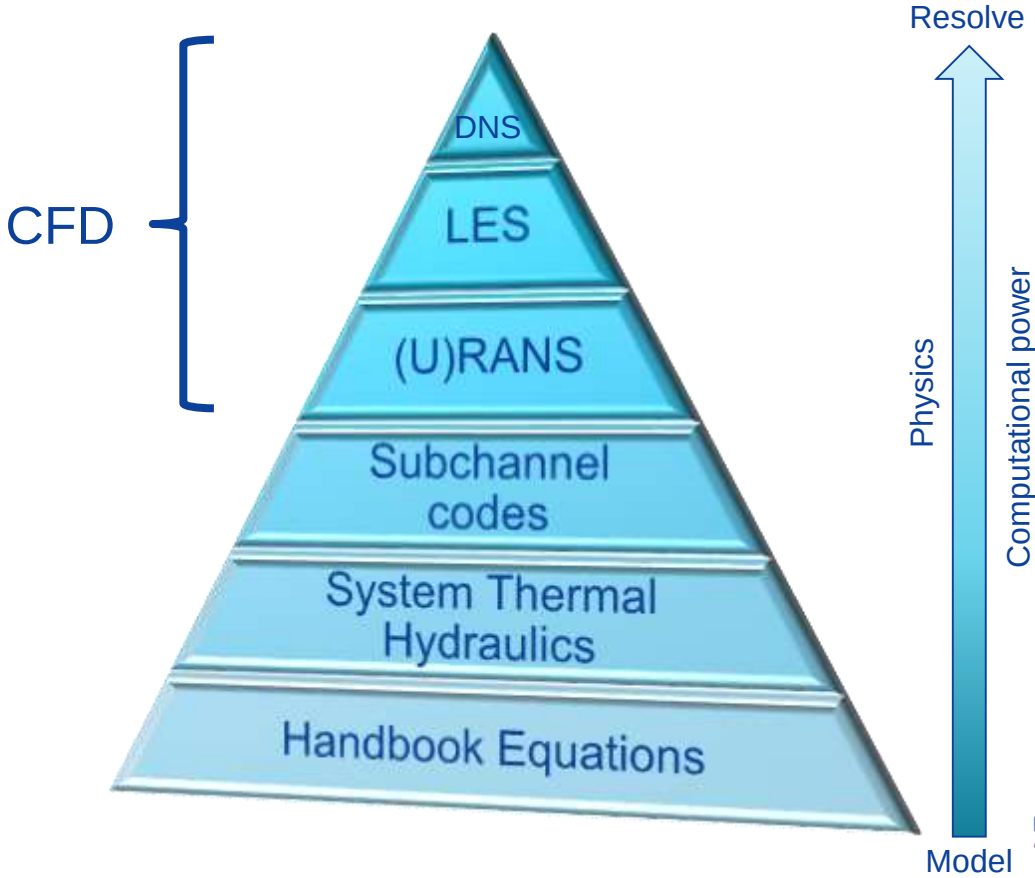
Introduction: Reactors



Introduction: Simulation Methods

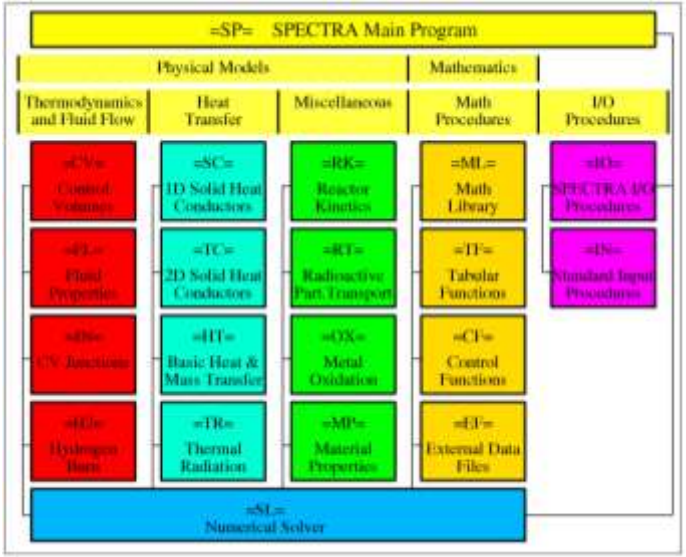
- Simulation tools
  - Various tools for each level
  - Open source vs. Commercial
  - CFD:
    - OpenFOAM
    - STAR CCM+
    - Fluent
    - CFX
    - NEK5000
- Mult-scale
  - Coupling tools between levels, e.g. STH and CFD
- Multi-physics
  - Coupling thermal hydraulics tools with neutronics and/or structural mechanics



Introduction: SPECTRA Code

Sophisticated Plant Evaluation Code for
Thermal hydraulic Response Assessment

- Developed at NRG for conventional and advanced reactor safety analysis.
- Flexibility of the code allows application to various reactor types: LWR, HTR, LMFR, MSR
- Euler-type solver for two-phase, non-equilibrium conservation equations.
- Point and nodal kinetics model, with isotope transformation.
- Computes important isotope concentrations and radioactive particle transport.
- Simultaneous simulation of multiple fluids (e.g. primary & secondary) through coupling multiple SPECTRA models



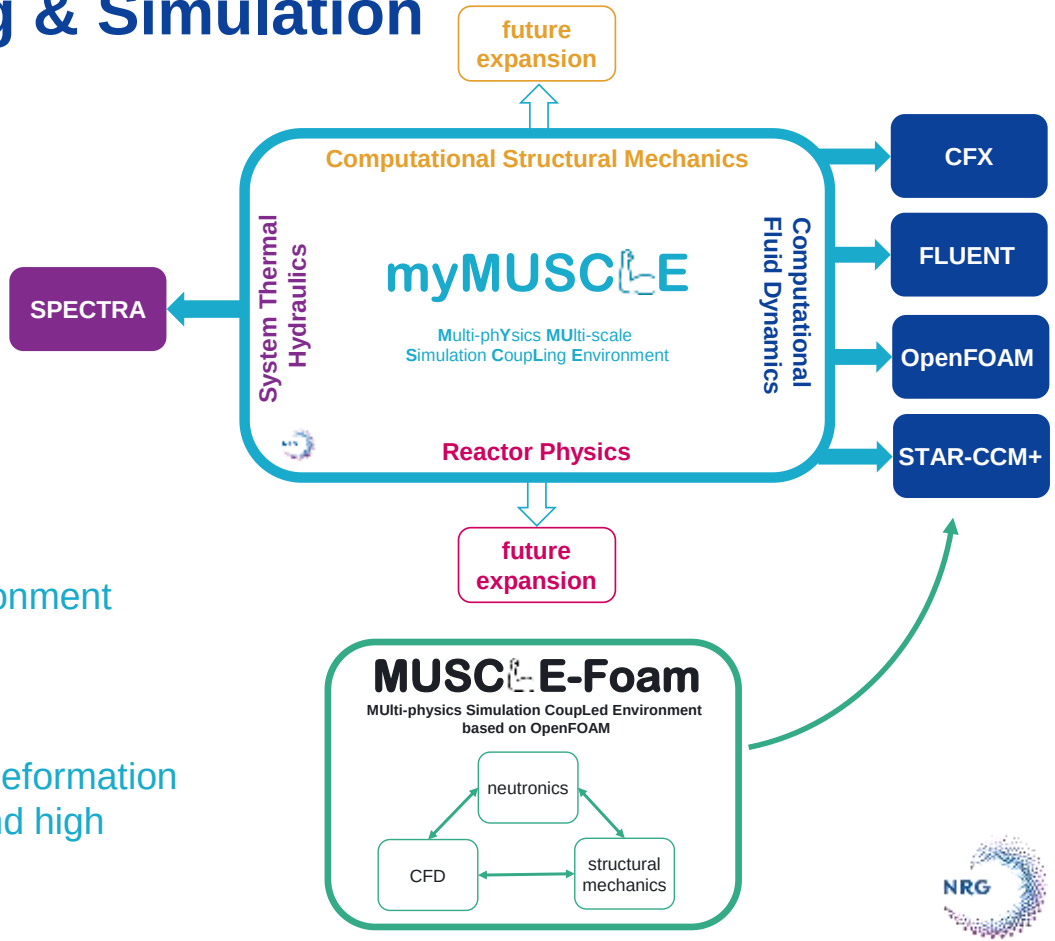
Introduction: Modelling & Simulation

myMUSCLE
multi-physics MUlti-scale
Simulation CoupLing Environment

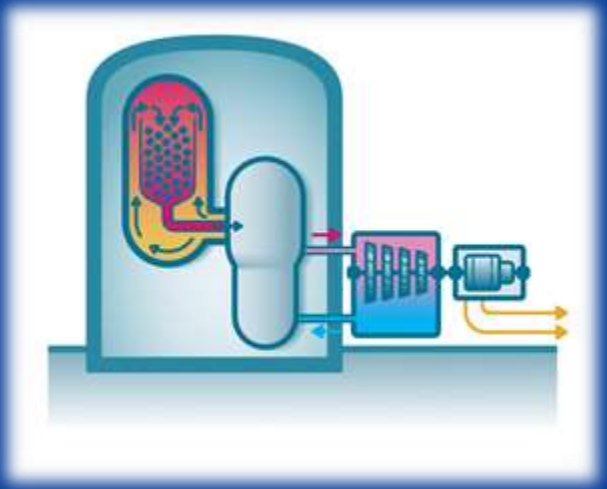
- Single coupling tool
- Improved quality control
- Arrange communication
- Coupling algorithms

MUSCLE-Foam
MUlti-physics Simulation CoupLed Environment
based on openFOAM

- Diffusion, SP3, Discrete ordinate
- Arbitrary Lagrangian Eulerian mesh deformation for fluid structure interaction at low and high Mach numbers
- Validation in progress



High Temperature Reactors



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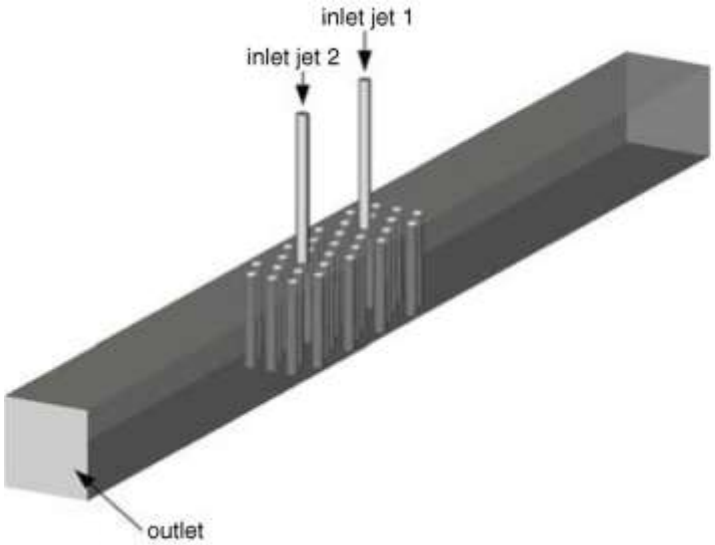
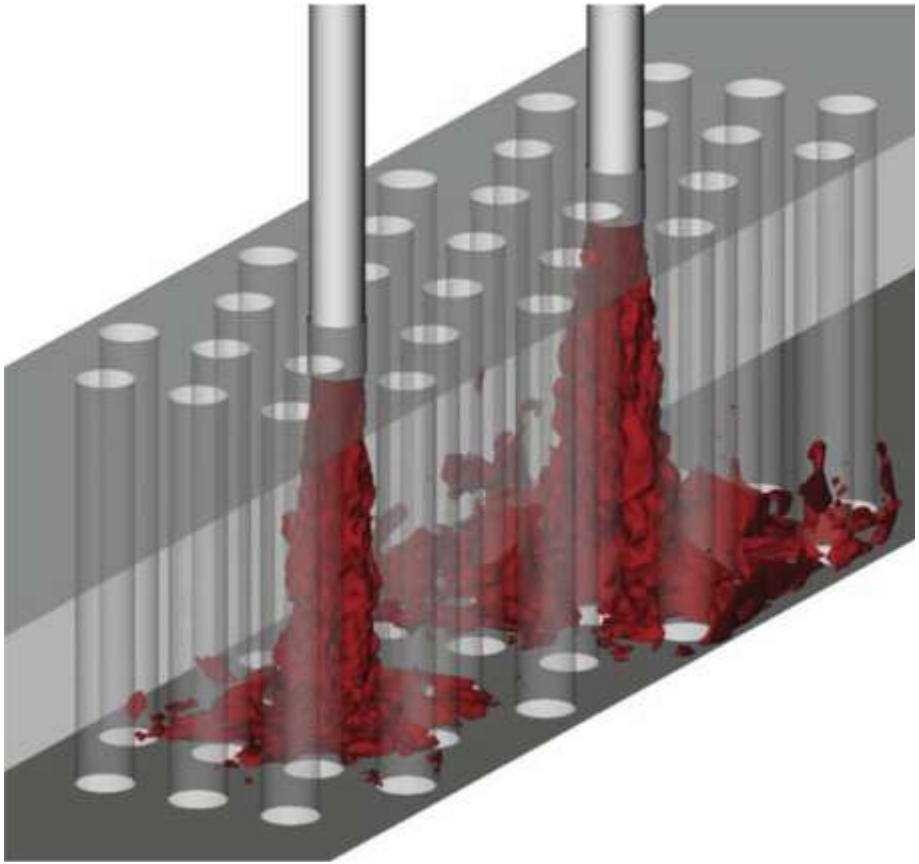
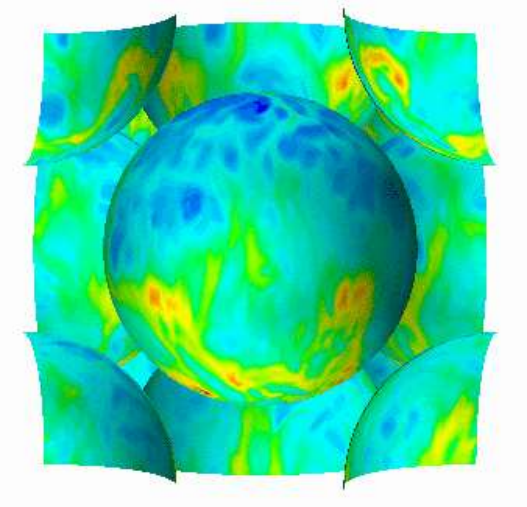
HTR: Core Outlet Plenum

- Simulation of core outlet plenum experiment at TAMU
- Rectangular channel with vertical rods
- Assessment of various steady-state and transient CFD approaches

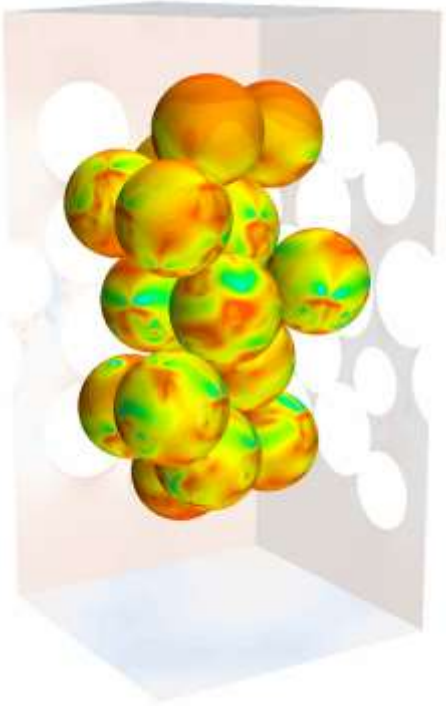




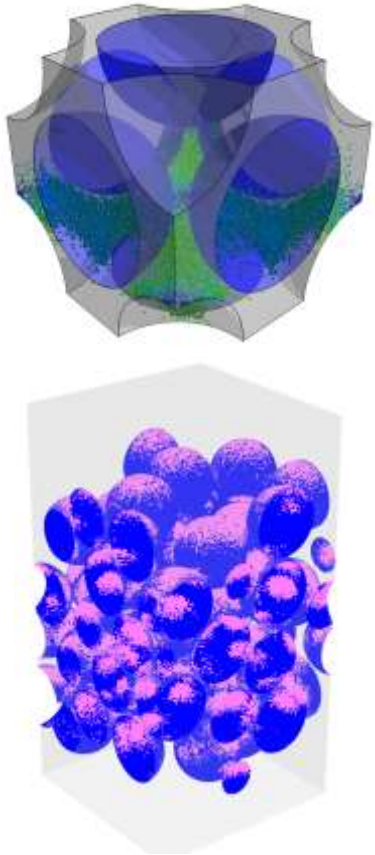
HTR: Pebbles



Single pebble domain

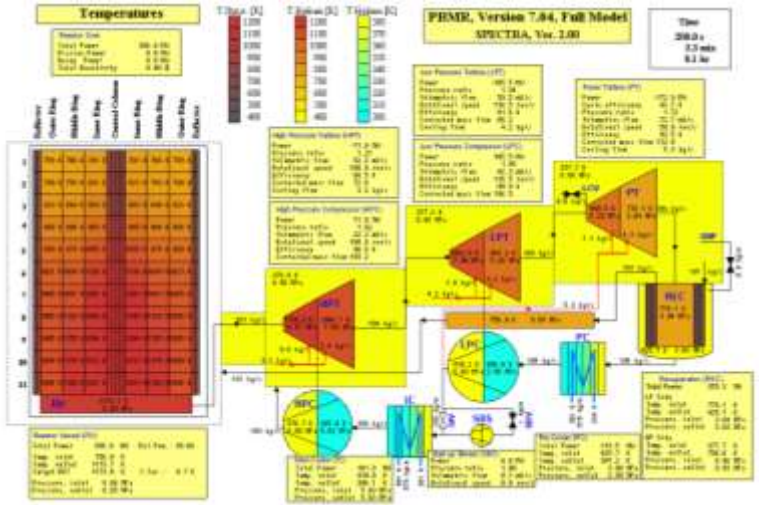


Limited size pebble bed

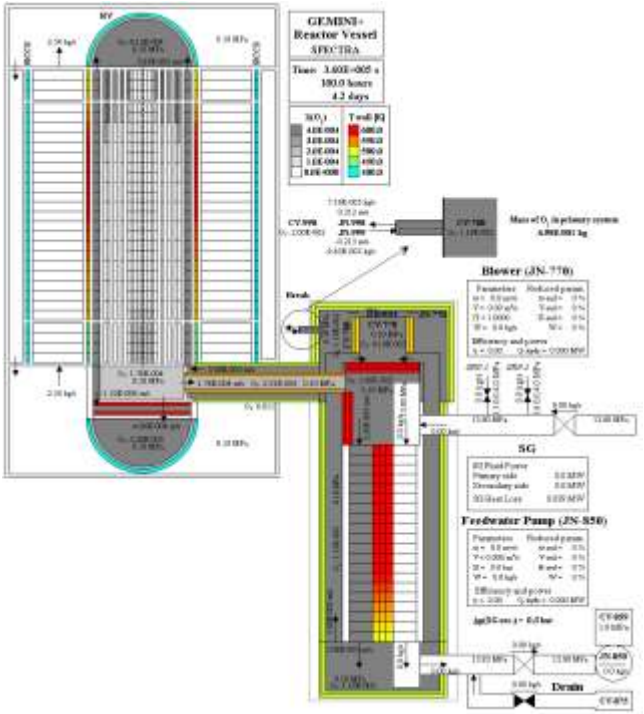


Graphite
Dust Transport

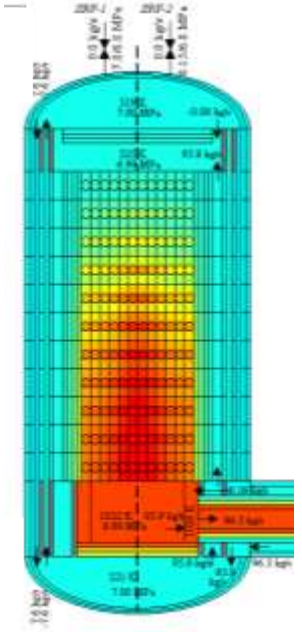
HTR: System Thermal Hydraulics



PBMR:
NRG responsible for independent system safety analyses

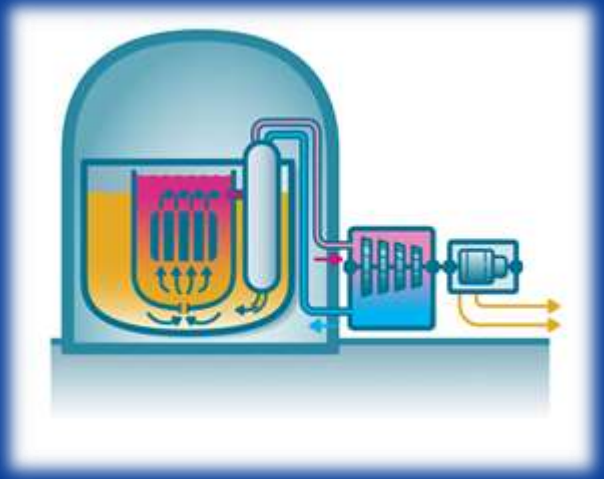


GEMINI (EU project):
Safety Analyses



HTR-PM:
Independent safety analyses

Liquid Metal Fast Reactors



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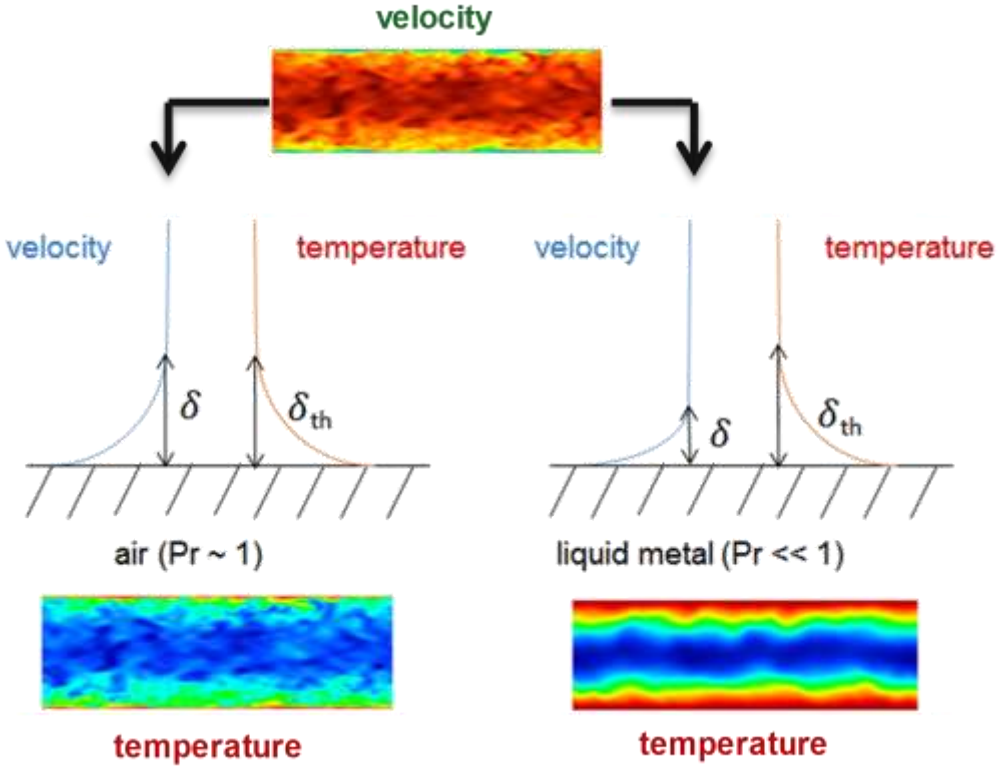
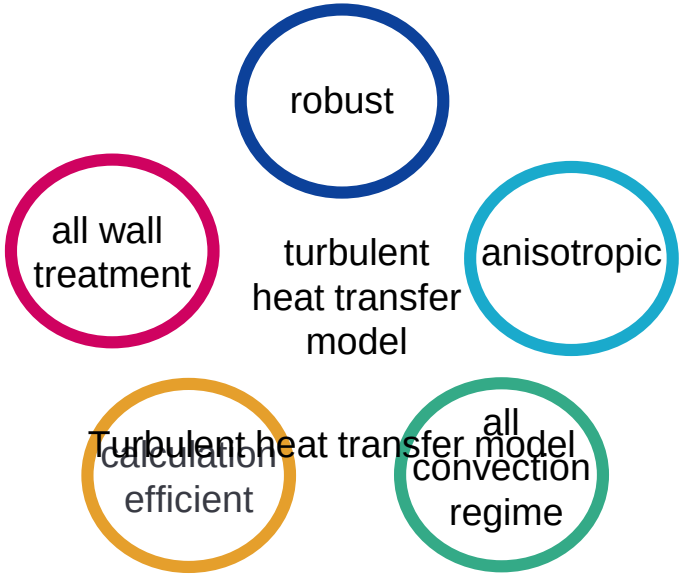
LMFR: Turbulent Heat Flux Model Development

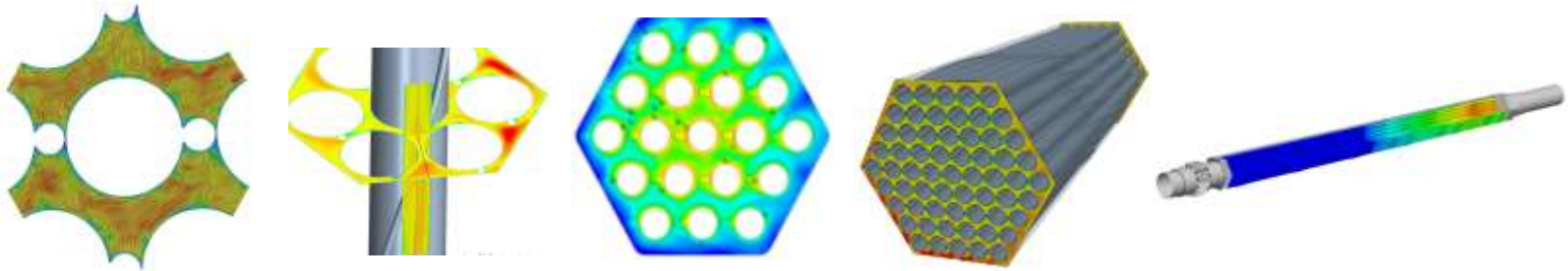


- High thermal conductivity
- Requires advanced turbulent heat transfer models



LMFR: Core Thermal Hydraulics

Wire Wraps



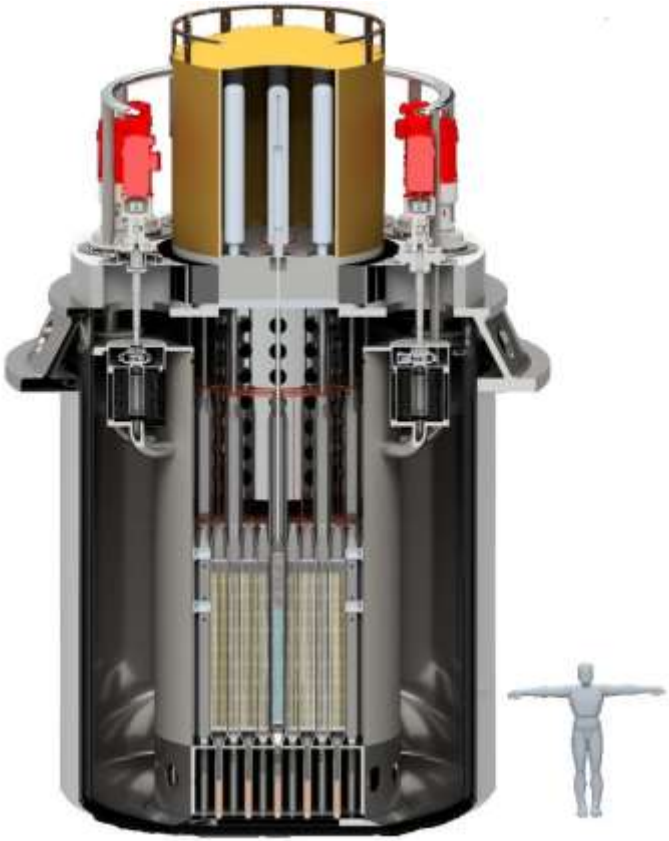
Increasing number of modelled pins

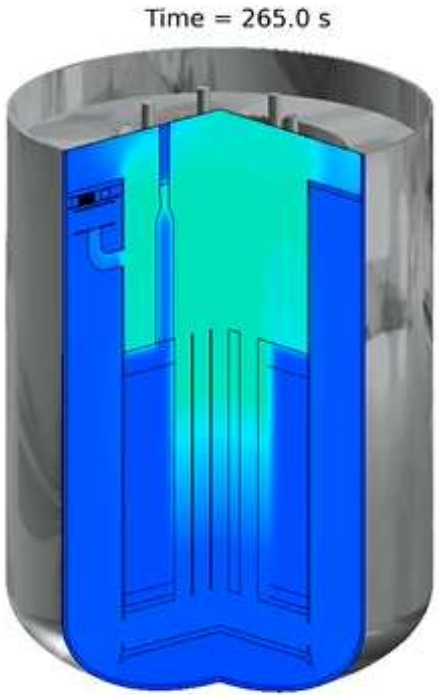
Grid Spacers

Ongoing and future: inter-wrapper flow, blockages & deformed assemblies

LMFR: Pool Thermal Hydraulics

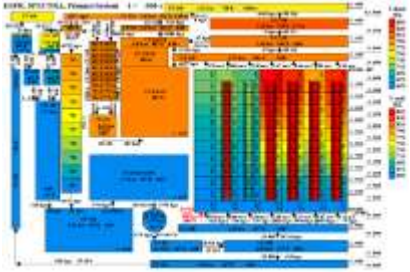
- Modelling strategy for various components:
  - Cover gas
  - Internals
  - Heat exchangers
  - Pumps
  - Core
  - Liquid metal
- Experimental validation:
  - CIRCE
  - ESCAPE
- Application
  - SEALER designs
  - ALFRED

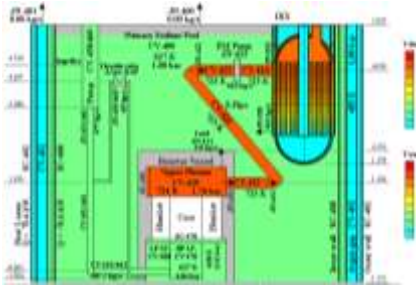




Na

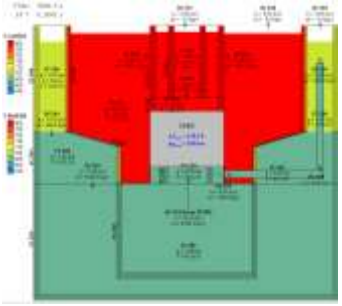
ESFR

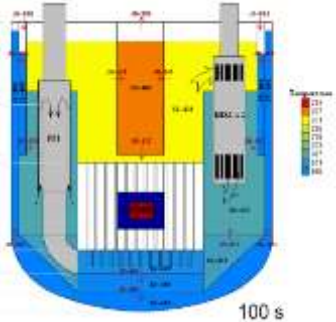




EBR-II

ASTRID

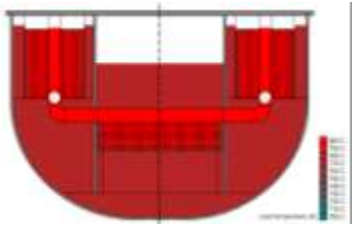




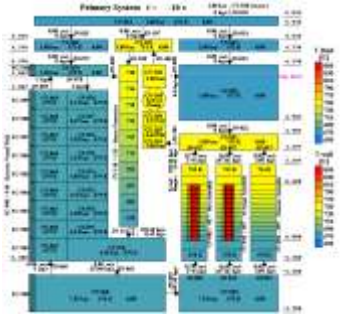
Phénix

FFTF

Pb (Bi)

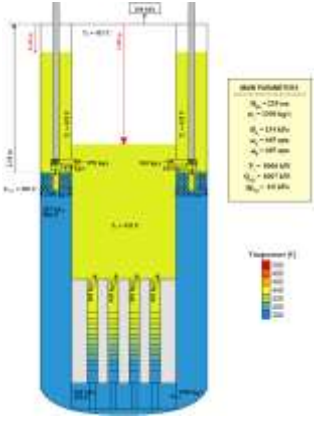


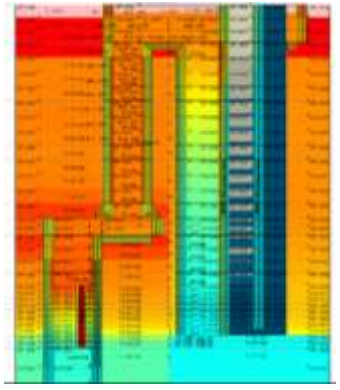
ELSY



ALFRED

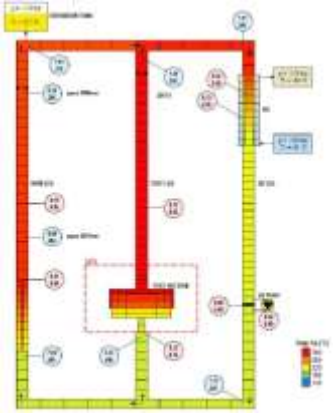
SEALER-Arctic



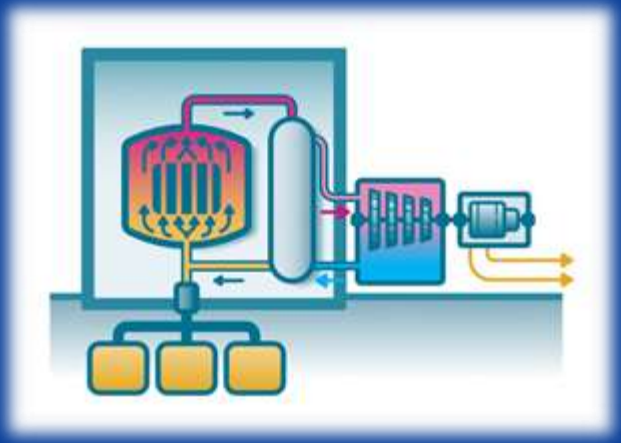


CIRCE

TALL-3D



Molten Salt Reactors



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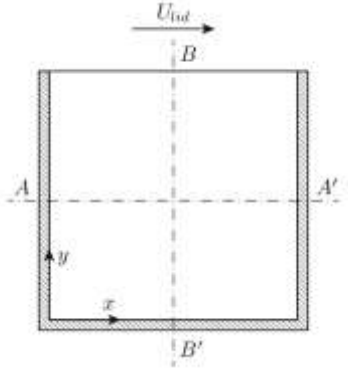
MSR: 3D Multi-physics

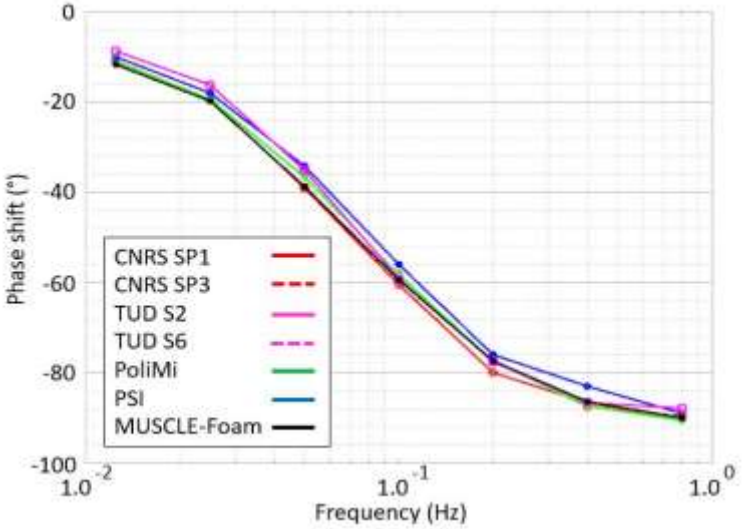
Verification of MUSCLE-Foam with difusion solver:
Lid-driven cavity benchmark

- Single physics
  - Thermal hydraulics
  - Neutronics
- Coupled physics
  - Circulating fuel (fixed velocity field)
  - Power coupling (fixed velocity field)
  - Buoyancy flow (fixed lid)
  - Full coupling
  - Transient

In progress: a 3D CFD-based model of MSRE



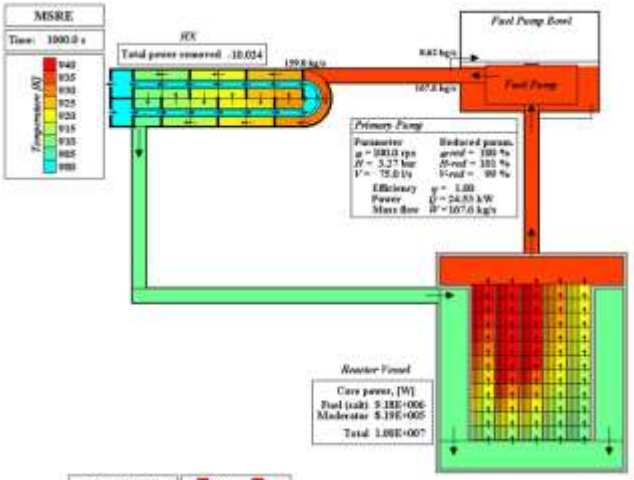
Tiberga et al. (2020)

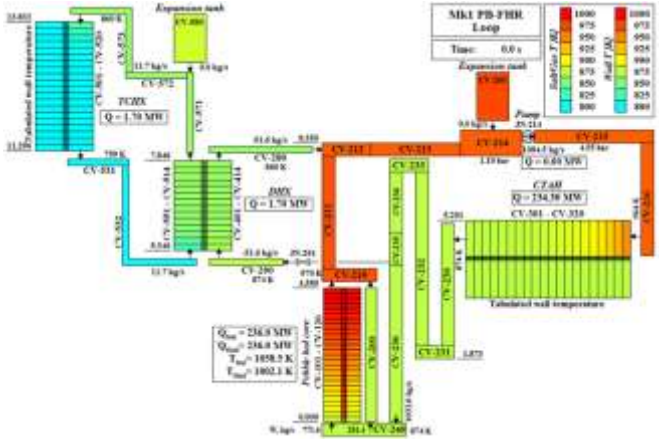


MSR: System Thermal Hydraulics

Molten salt model development
- delayed neutron precursor drift
- heat removal by natural circulation
- fission product transport in (fueled) molten salt reactors
- noble gas and noble metal behavior
- noble metal extraction
- chromium leaching and deposition

Comparison and validation (whenever possible)
- MSRE
- Mk1-PB-FHR





Conclusive Remarks

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Summary & Outlook

Thermal hydraulic simulation activities at NRG cover:

- Wide range of applications:
  - Improve turbulent heat flux modelling
  - Core thermal hydraulics
  - Pool thermal hydraulics
  - System thermal hydraulics
  - Multi-scale simulations
  - Multi-physics simulations

- Outlook
  - Increasing complexity
    (Applications, size, combination of physics, turbulence)
  - Continuous validation efforts
    (Requires tight link with well performed experiments and additionally high resolution simulations)
  - Further development and validation of myMuscle and MUSCLE-Foam

Questions?

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