NTEC 2014	1 / 27	Lecture CFD-1

CFD in nuclear thermal hydraulics

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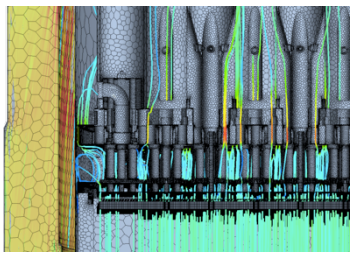
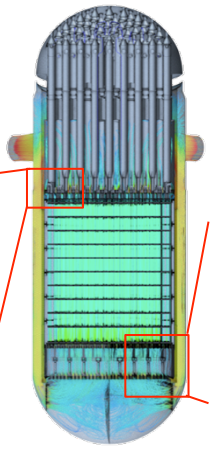
NTEC 2014	2 / 27	Nuclear applications

- CFD in nuclear industry
- CASL project
- CFD + neutronics
- Pressure drop in fuel bundle
- PSBT International Benchmark on boiling in rod bundle
- Pebble bed reactor
- Spent fuel transport and storage

NTEC 2014	3 / 27	CFD in nuclear industry

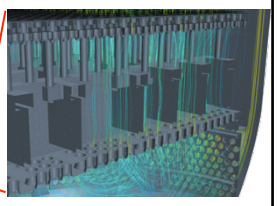
- Size of CFD model:
  - 1 billion cells => frontier
  - 100 million cells => large
  - 10 million cells => average
  - 1 million cells => small





AP1000 PWR

virtual simulator



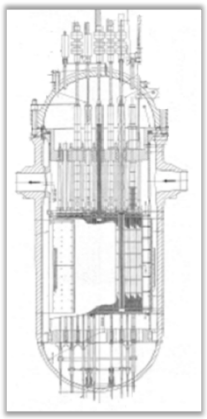
Zeses Karoutas et al. Westinghouse Electric Company

Top Fuel 2010, Orlando, Florida, September 26-29, 2010

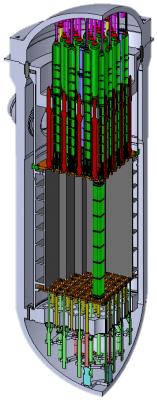
Westinghouse

NTEC 2014	4 / 27	CASL: The Consortium for Advanced Simulation of Light Water Reactors

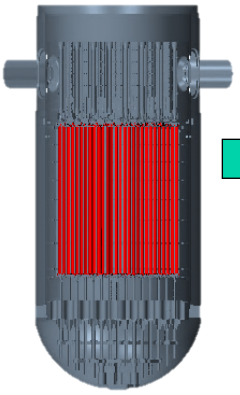
- A DOE Energy Innovation Hub for Modeling & Simulation of Nuclear Reactors
- 4-Loop Westinghouse PWR Multi-Physics Model Development



Drawings



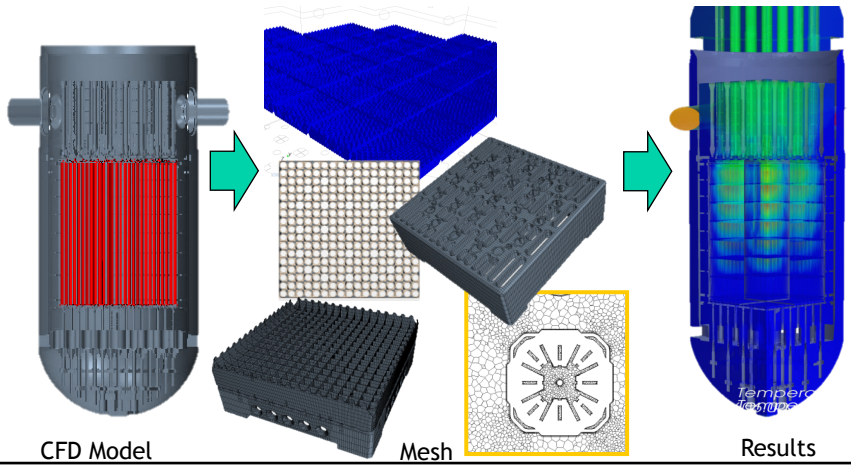
CAD Model



CFD Model

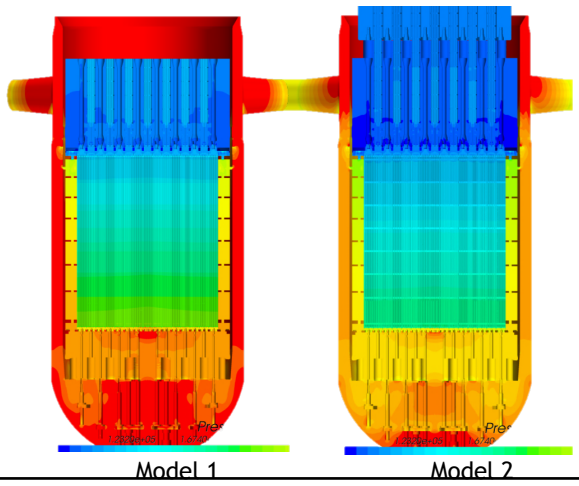
NTEC 2014	5 / 27	4-Loop Westinghouse PWR Multi-Physics Model Development

RPV ID 173", 193/4 Fuel Assemblies,13,944 fuel rods (fuel pellets, helium gap), 434 spacers, 148,224 mixing vanes; 1.2 billion cells



NTEC 2014	6 / 27	A "Typical" Multi-Scale Problem

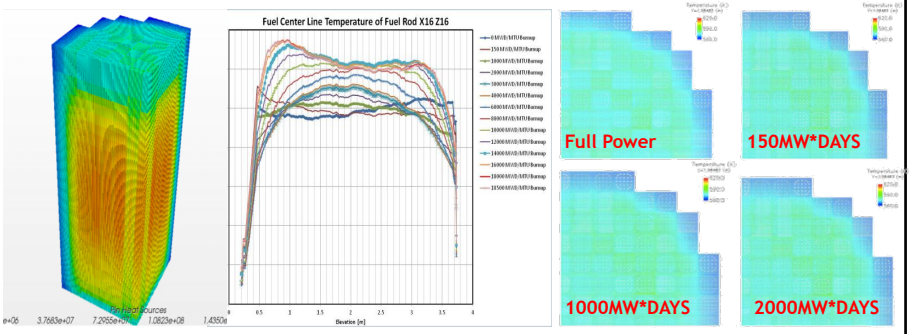
Full-core performance is affected by localized phenomena



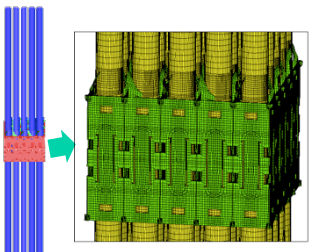
NTEC 2014	7 / 27	Thermal Hydraulics & Neutronic Coupling

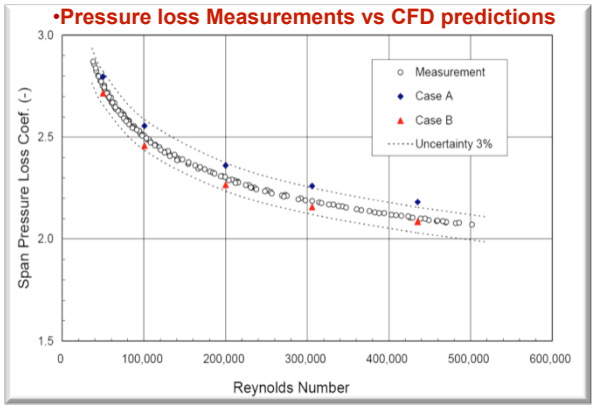
- CFD + Neutronic full depletion cycle simulation: 14 state points
- Total time required for a complete depletion cycle: 44 hours on 1028 cores.

ANC power



NTEC 2014	8 / 27	Pressure Drops Evaluation



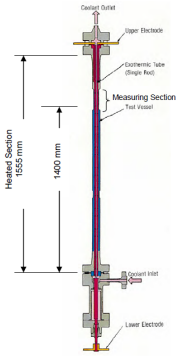


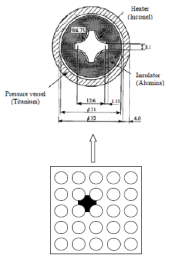
MITSUBISHI HEAVY INDUSTRIES, LTD.

•K. Ikeda et al. "Study Of Spacer Grid Span Pressure Loss Under High Reynolds Number Flow Condition" - Proceedings of ICONE17

•CASE B = Baglietto, E., 2006, Anisotropic Turbulence Modeling for Accurate Rod Bundle Simulations, ICONE14

NTEC 2014	9 / 27	Boiling: PSBT International Benchmark





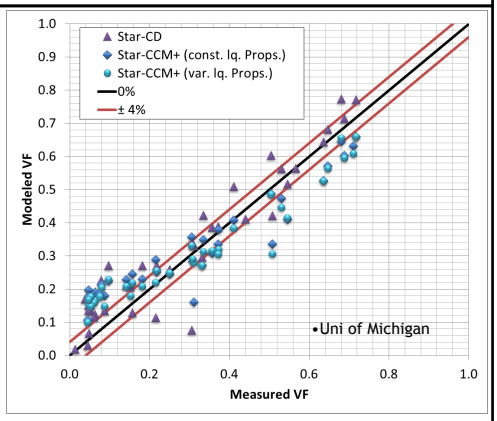
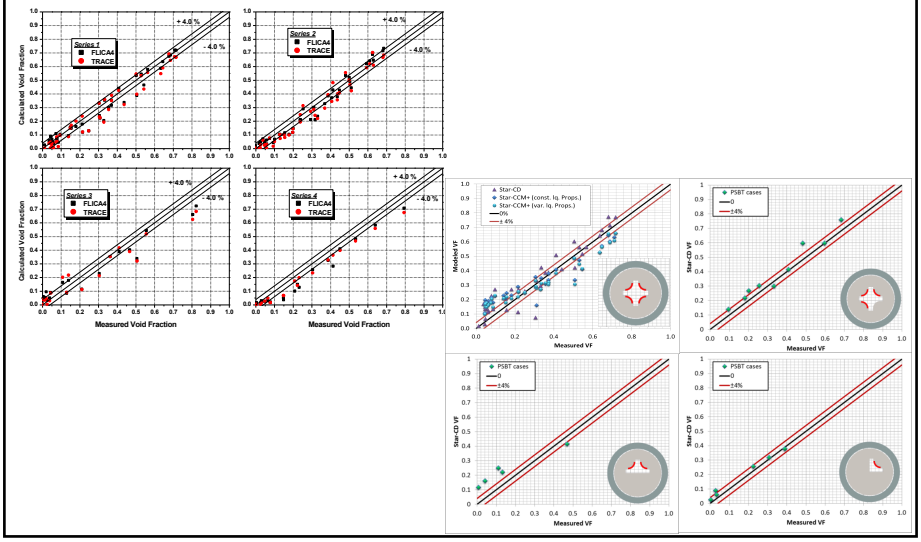


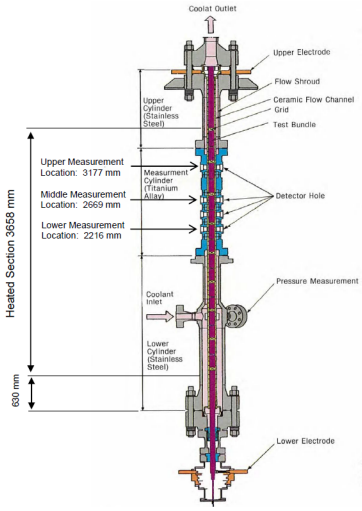
Table 2.2.1 Range of NUPEC PWR Test Facility Operating Conditions

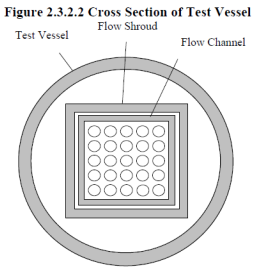
Quantity	Range
Pressure	4.9 – 16.6 MPa
Mass Velocity	550 – 4150 kg/m^{2}s
Inlet Coolant Temperature	140 – 345 °C

NTEC 2014	10 / 27	PSBT - Comparison with sub-channel codes

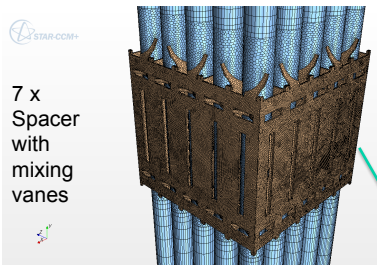


NTEC 2014	11 / 27	PSBT International benchmark - NUPEC rod bundle test section

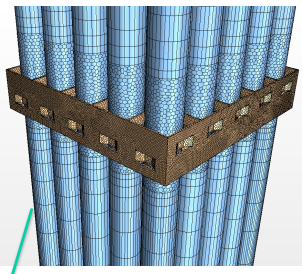




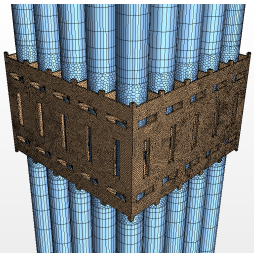
NTEC 2014	12 / 27	PSBT International benchmark 5x5 bundle



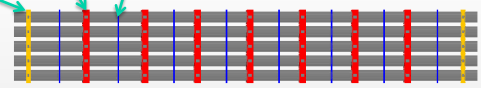
7 x Spacer with mixing vanes



8 x Simple spacer

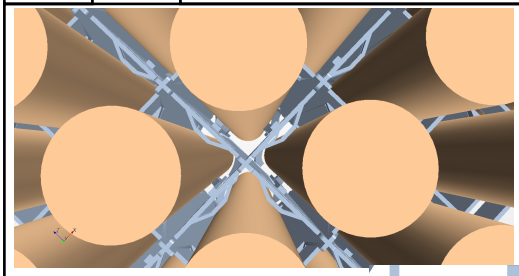


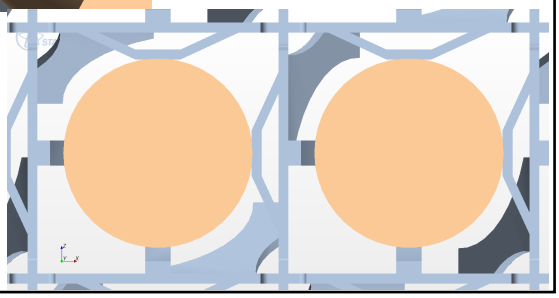
2 x Spacer without mixing vanes



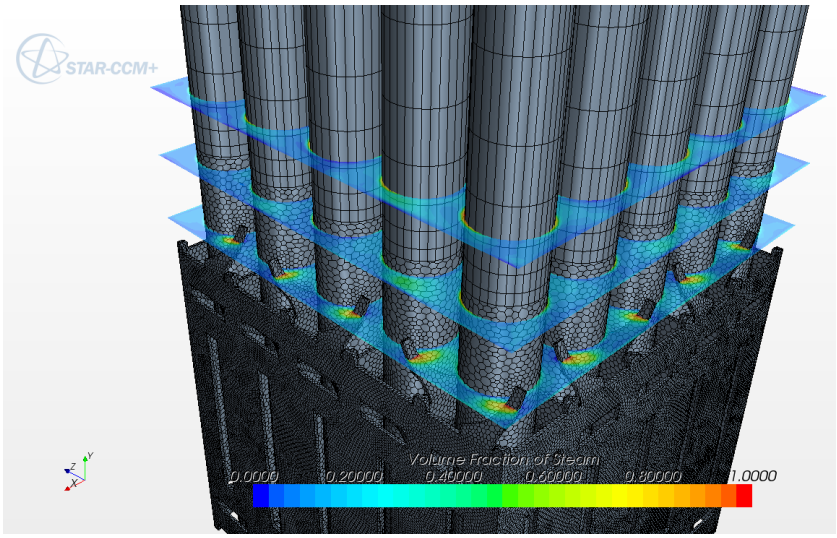
All rods and spacers in bundle are modelled.
Cell count: 17,950,126

NTEC 2014	13 / 27	Contacts between rods and spacers

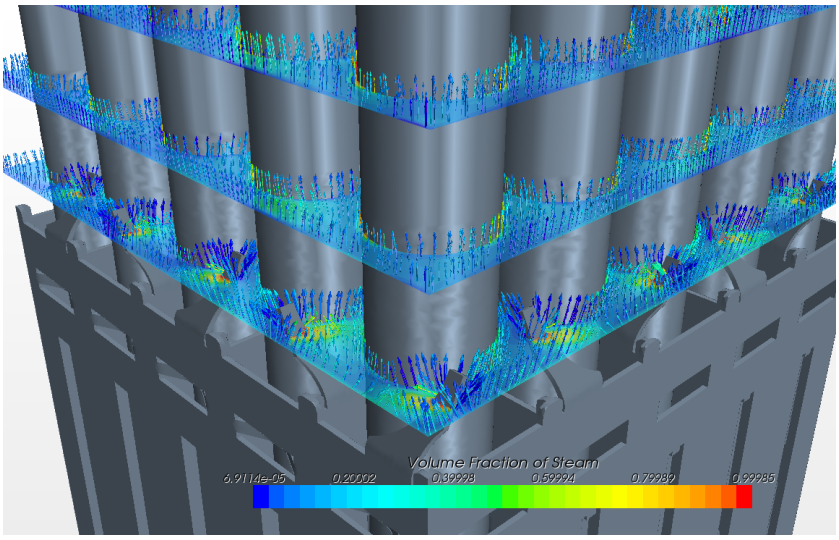




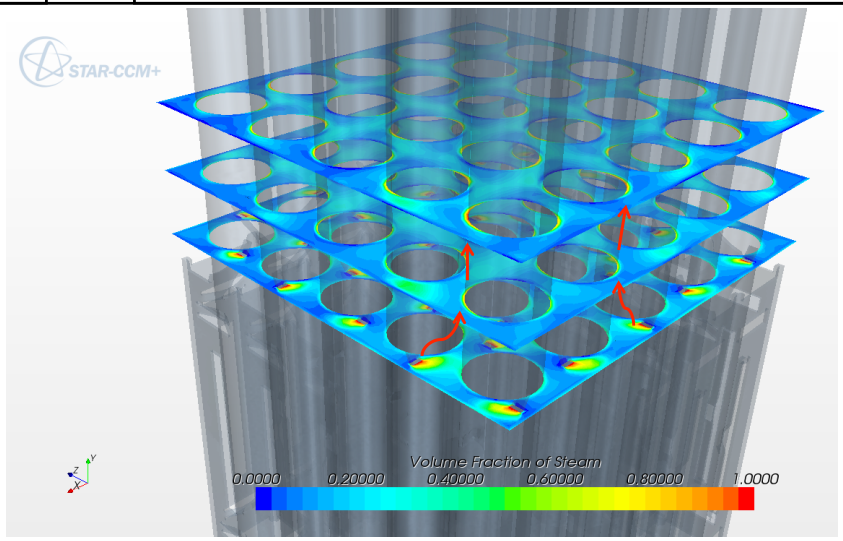
NTEC 2014	14 / 27	Boiling flow in PSBT 5x5 bundle



NTEC 2014	15 / 27	Boiling flow in PSBT 5x5 bundle

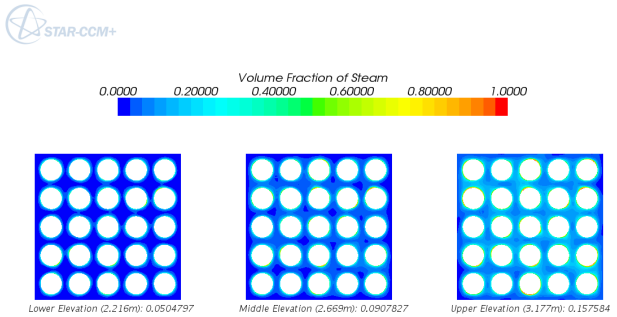


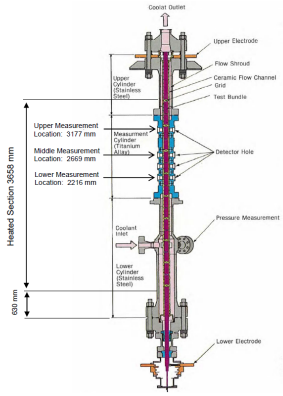
NTEC 2014	16 / 27	Boiling flow in PSBT 5x5 bundle



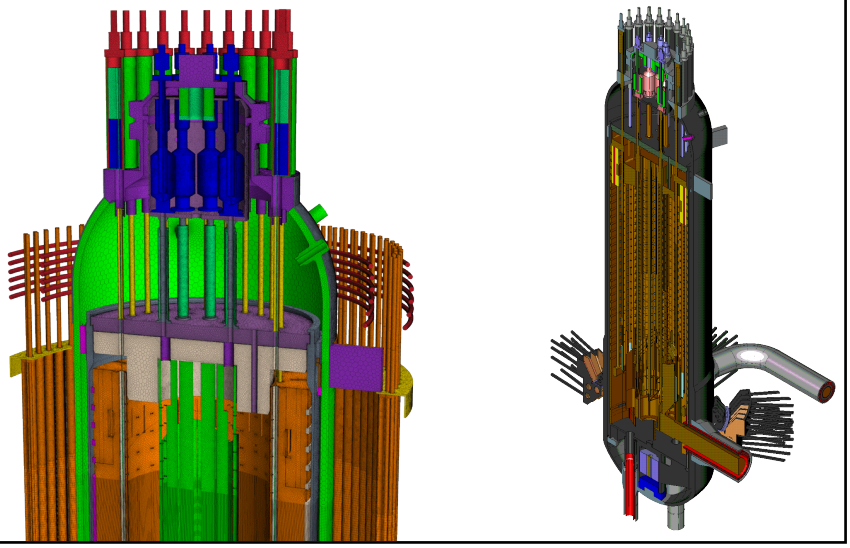
NTEC 2014	17 / 27	Void fraction at measurement location

- Void fraction averaged over the 4 central sub-channels:
  - Experiment: 0.18
  - STAR-CCM+: 0.16 (12% lower than experiment)

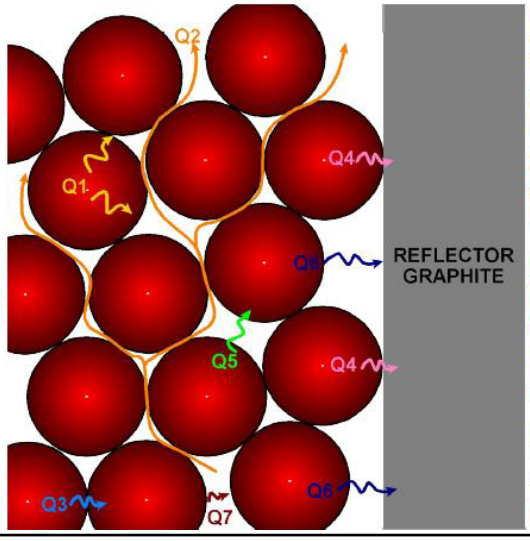




NTEC 2014	18 / 27	CFD model of PBMR



NTEC 2014	19 / 27	Modes of heat transfer in a pebble bed



Q1: Conduction from the centre of the pebble to the surface

Q2: Convection from the pebble surface to the gas

Q3: Point contact conduction between the pebble surfaces that are in contact with one another

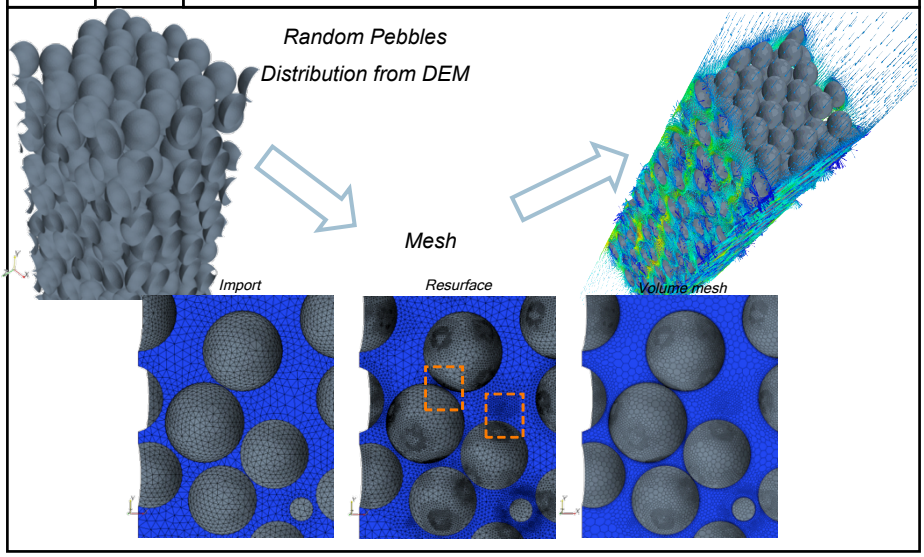
Q4: Point contact conduction between the pebble surfaces that are in contact with the reflector

Q5: Thermal radiation between the pebble surfaces

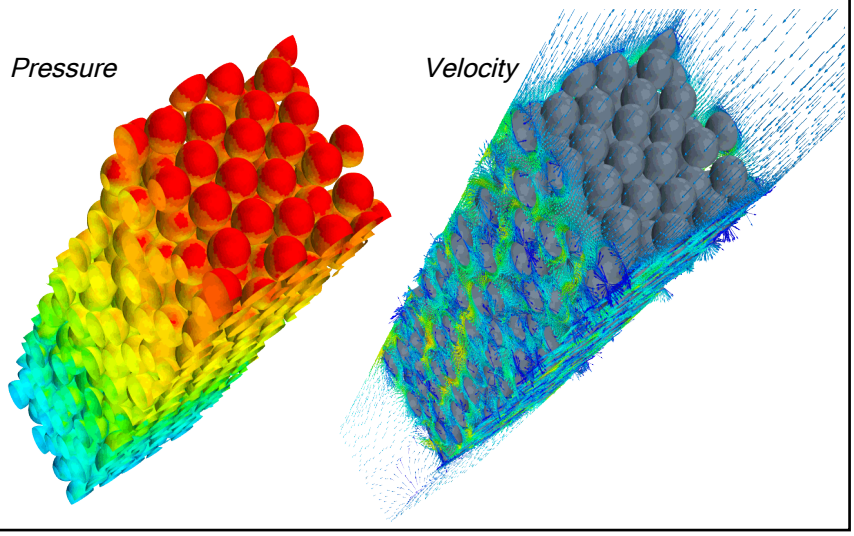
Q6: Thermal radiation between the pebble surfaces and the reflector

Q7: Conduction in the gas

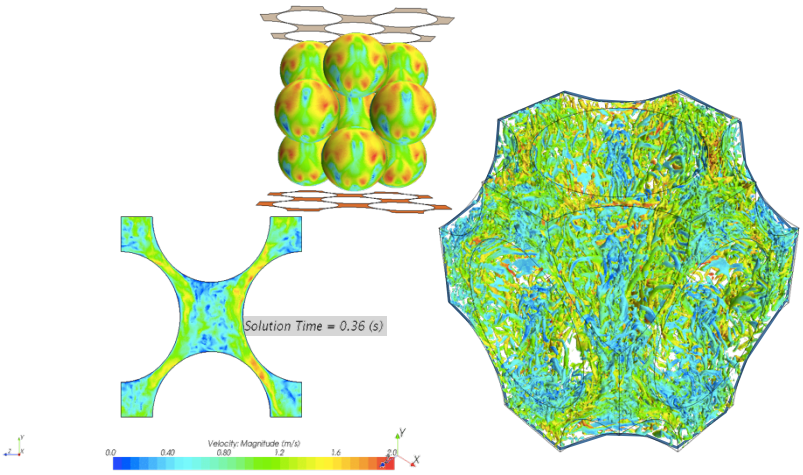
NTEC 2014	20 / 27	Detailed modelling of pebble bed



NTEC 2014	21 / 27	Pressure and flow distributions in pebble bed

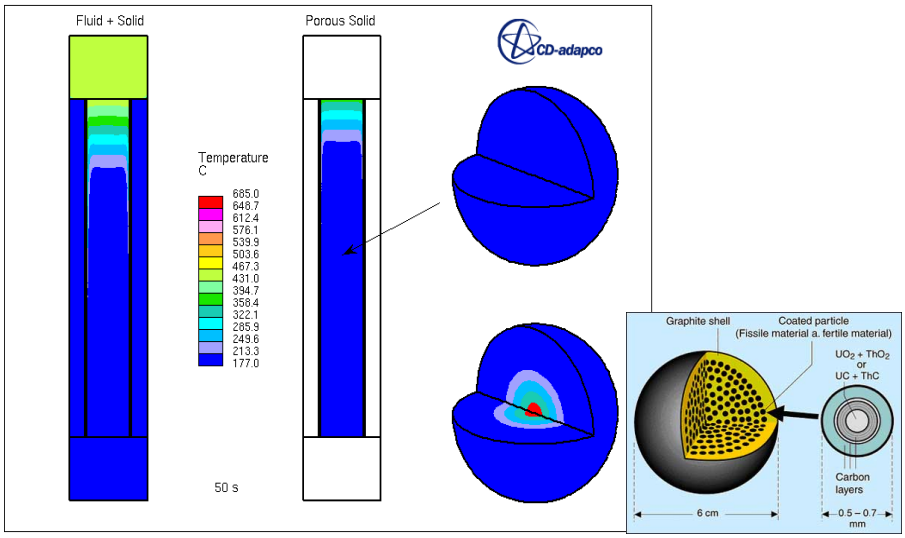


NTEC 2014	22 / 27	Detailed modelling of flow between pebbles

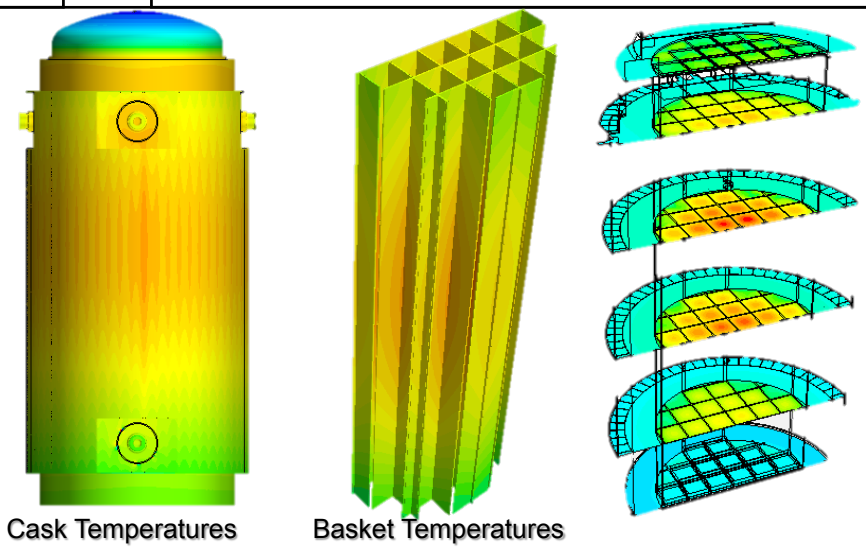


A. Shams, F. Roelofs, E.M.J. Komen and E. Baglietto - CALIBRATION OF A PEBBLE BED CONFIGURATION FOR DIRECT NUMERICAL SIMULATION – NURETH14

NTEC 2014	23 / 27	Multi-scale modelling of conjugate heat transfer in pebble bed reactor



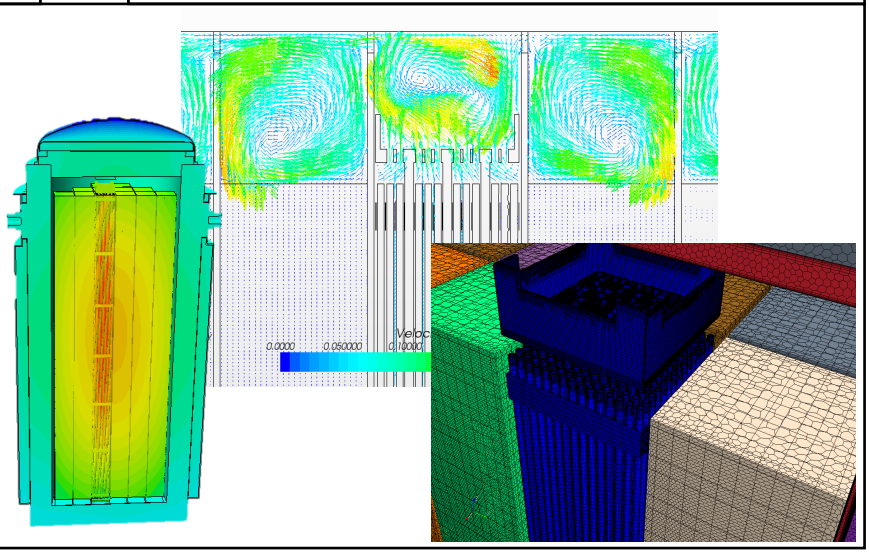
NTEC 2014	24 / 27	Transportation Cast



Cask Temperatures

Basket Temperatures

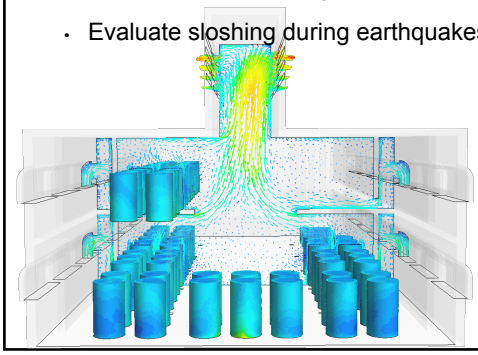
NTEC 2014	25 / 27	Modeling “Full Detail” of Fuel

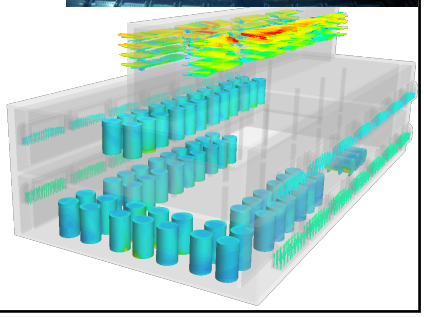


NTEC 2014	26 / 27	Interim Storage Management

Model complete pool detail

- Evaluate maximum rod temperature
- Optimize pool loading
- Evaluate influence of geometrical distortion
- Evaluate sloshing during earthquakes





NTEC 2014	27 / 27	**Summary**

- CFD in nuclear industry
- CASL project
- CFD + neutronics
- Pressure drop in fuel bundle
- PSBT International Benchmark on boiling in rod bundle
- Pebble bed reactor
- Spent fuel transport and storage