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Multi-scale multi-physics modelling for nuclear and other fields

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Applied Modelling and Computation Group

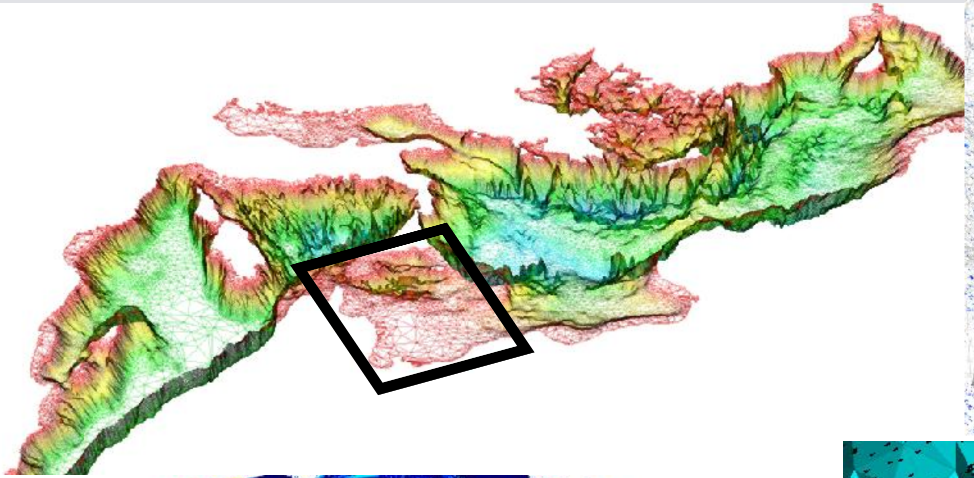
MULTIPHYSICS 2015

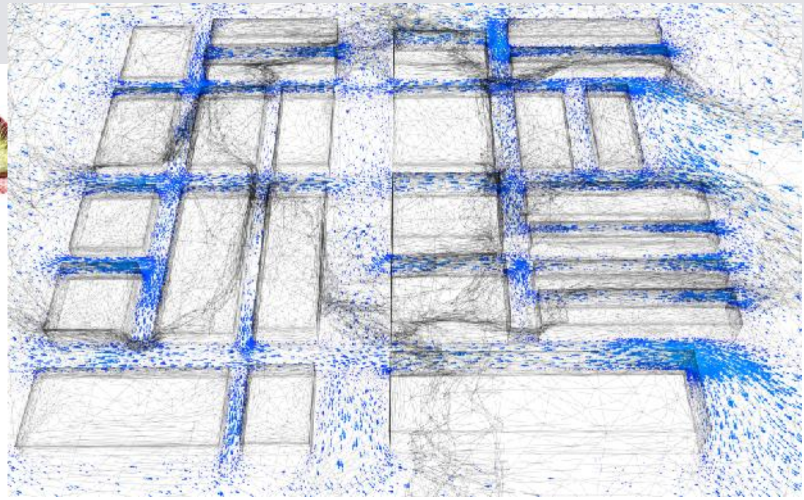
DEPARTMENT OF
EARTH SCIENCE AND ENGINEERING

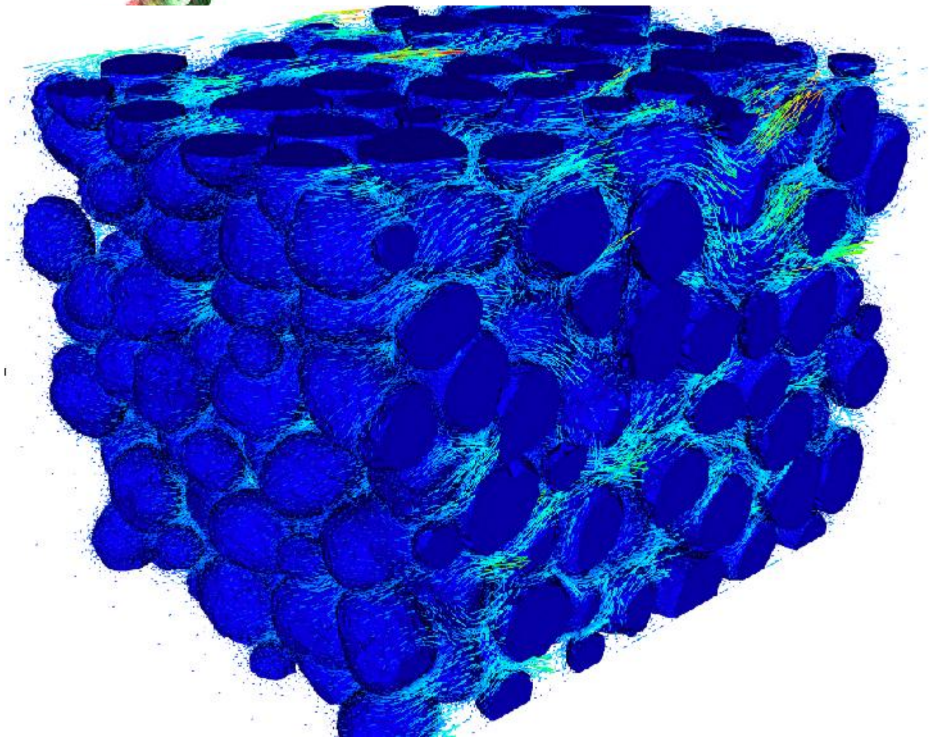
Presentation outline

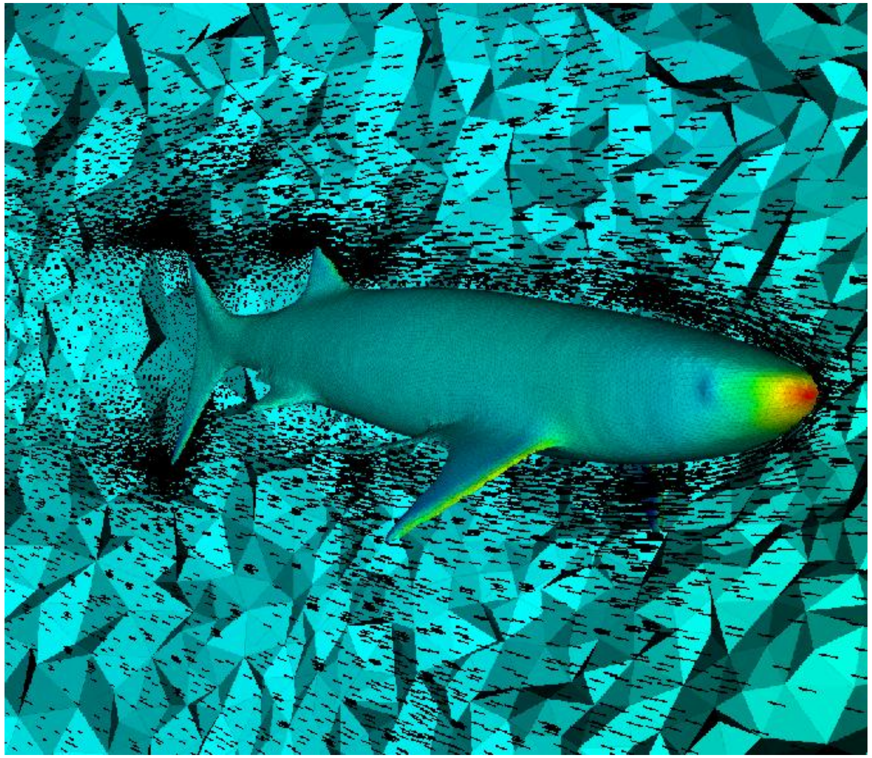
- Multi-scale adaptivity
- Fluids modelling
- Solids modelling
- Coupled solids-fluids modelling
- Radiation transport modelling
- Coupled radiation transport multi-phase fluid flow
- Rapid modelling

A Quick Review of the Numerical Technology









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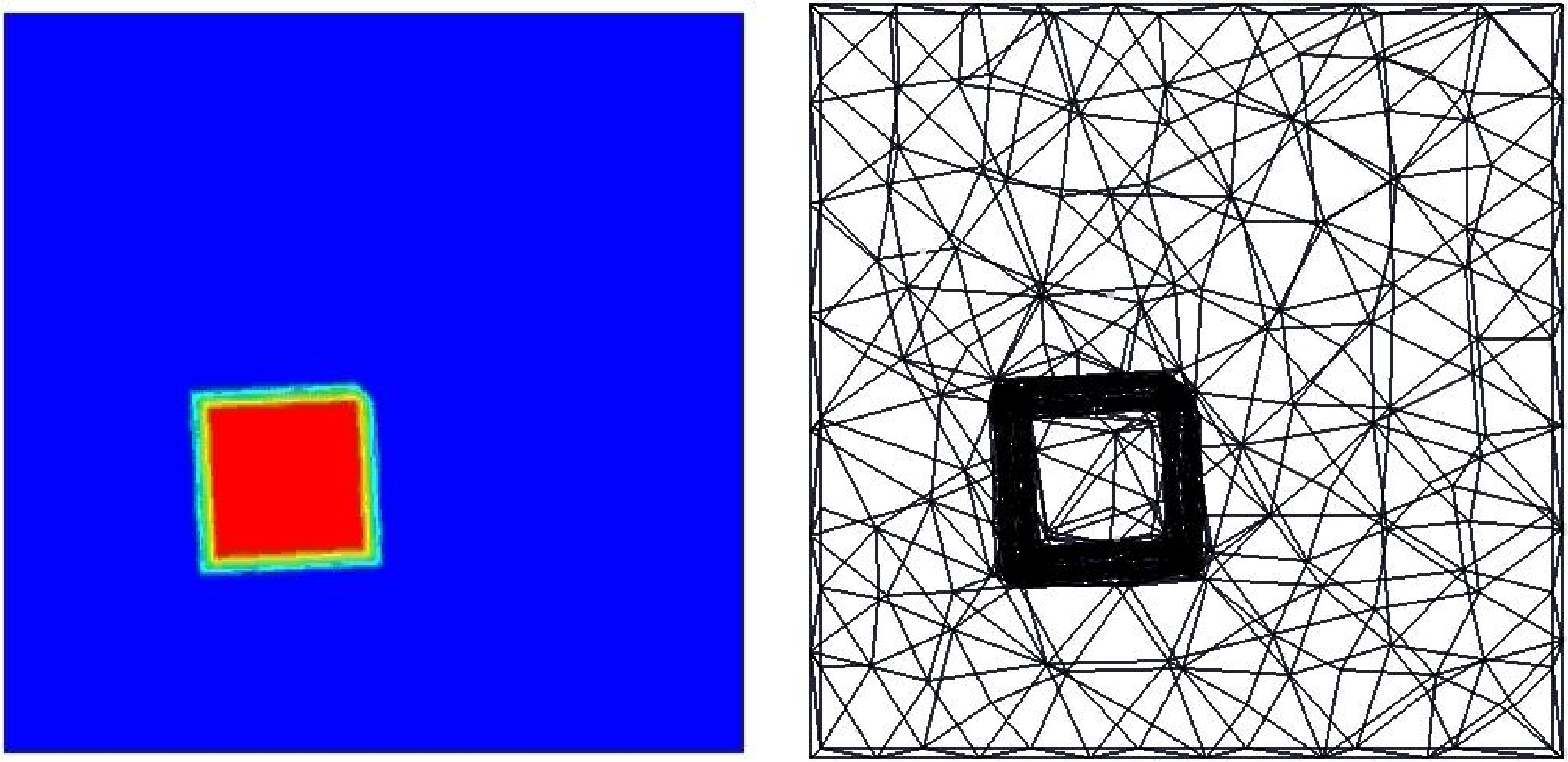
Moving and adaptive meshes



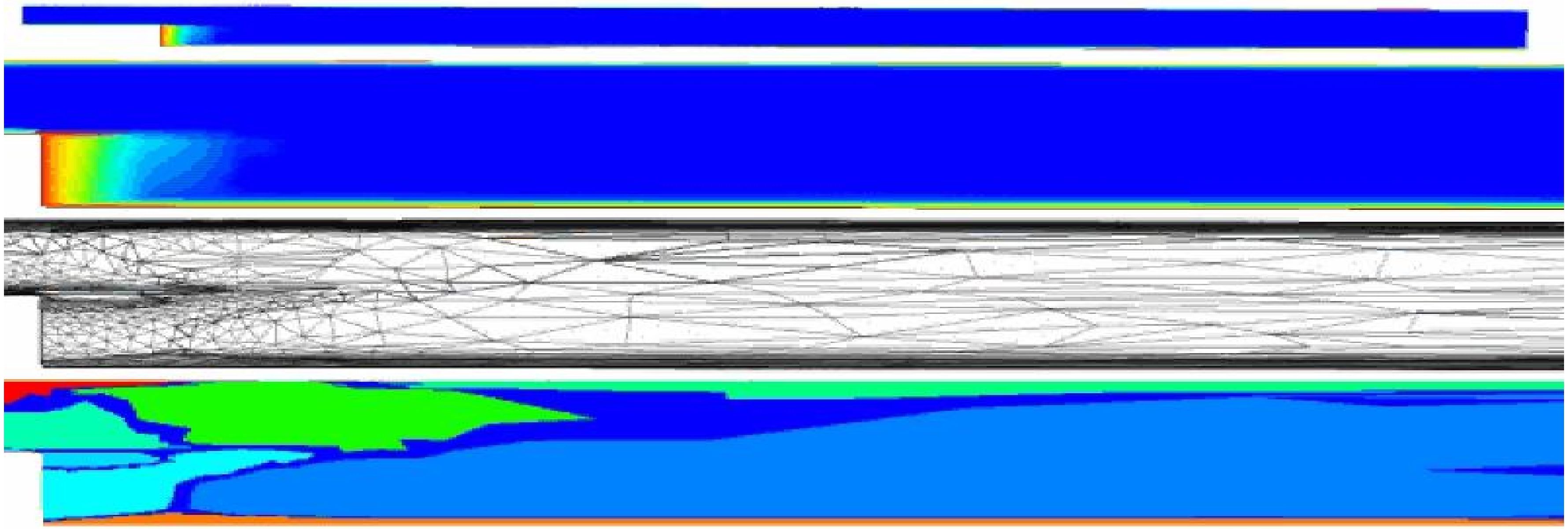
Node movement for interface tracking

CFD Modelling

Mesh Adaptivity and Domain Decomposition

Flow past a backward facing step – a classical CFD problem for motivation and validation

Movie below shows the entire domain, and then zooms of a tracer field, the adapting mesh, and the adapting load-balanced domain decomposition



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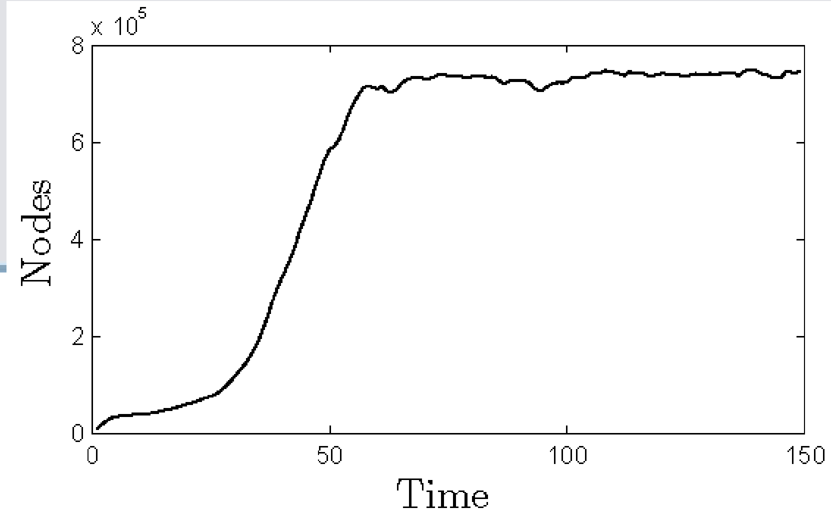
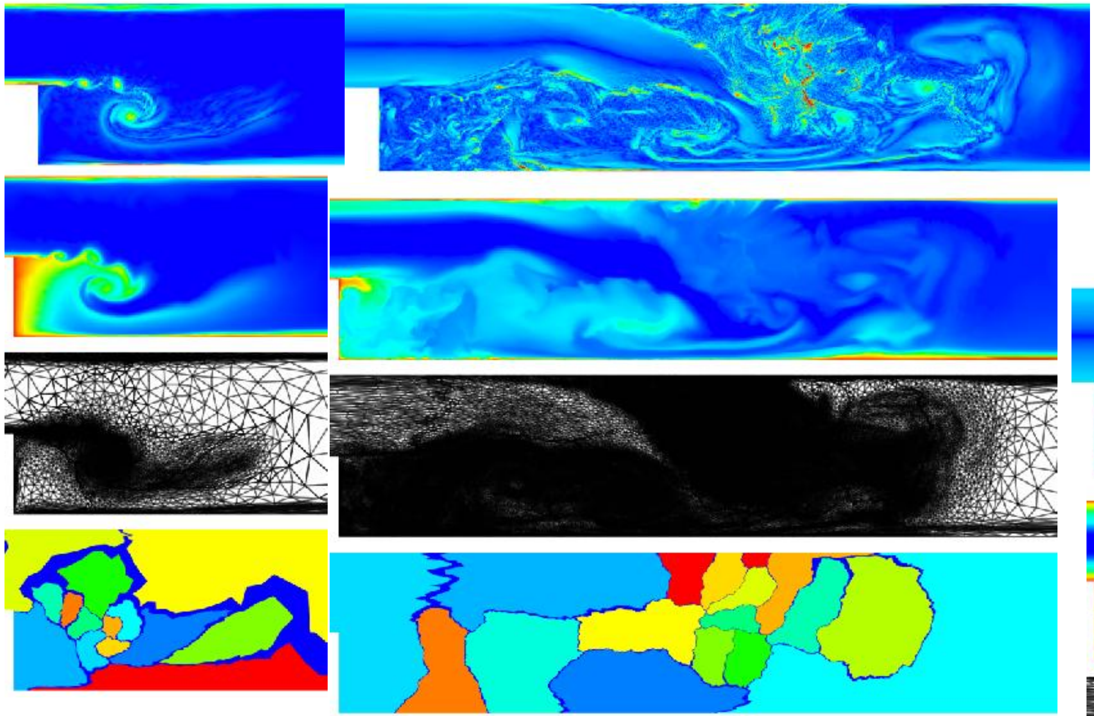
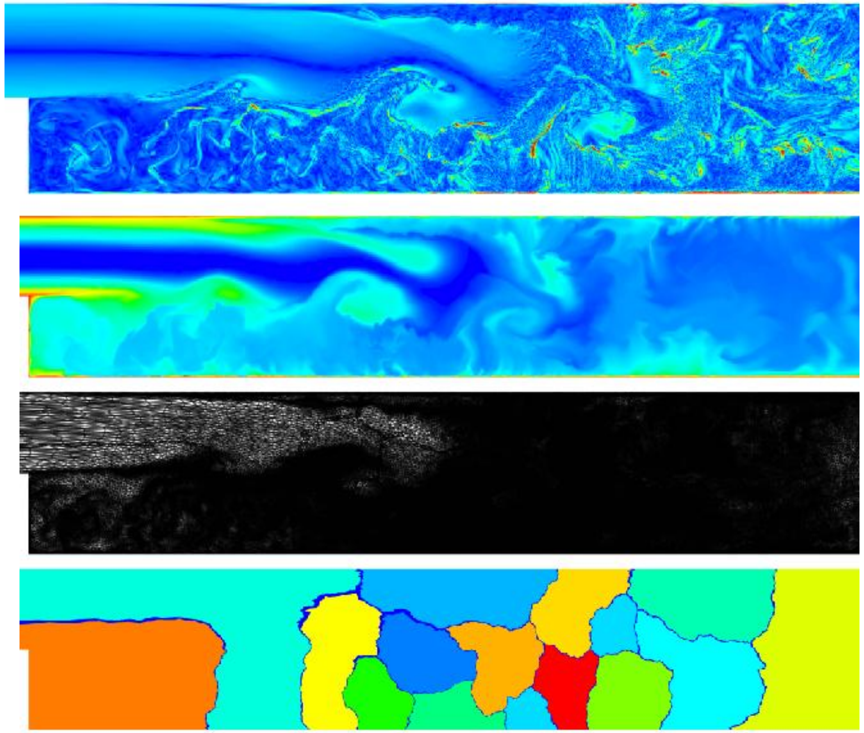
CFD Modelling

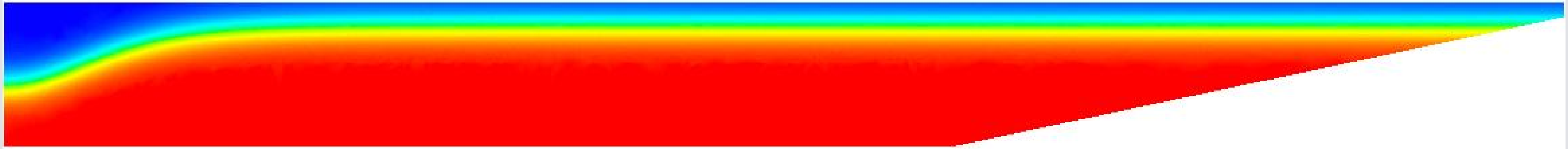
Mesh Adaptivity and Domain Decomposition

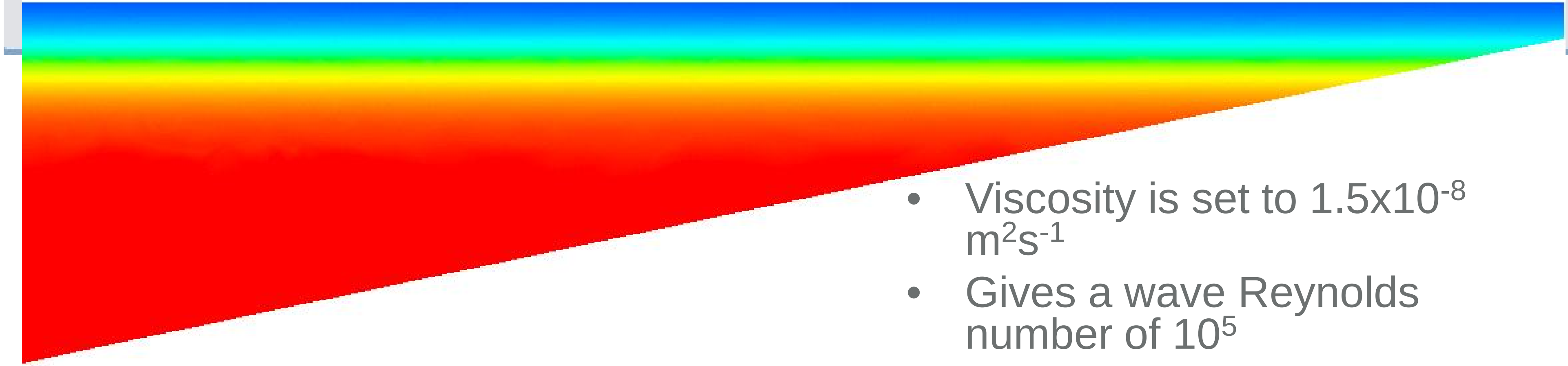




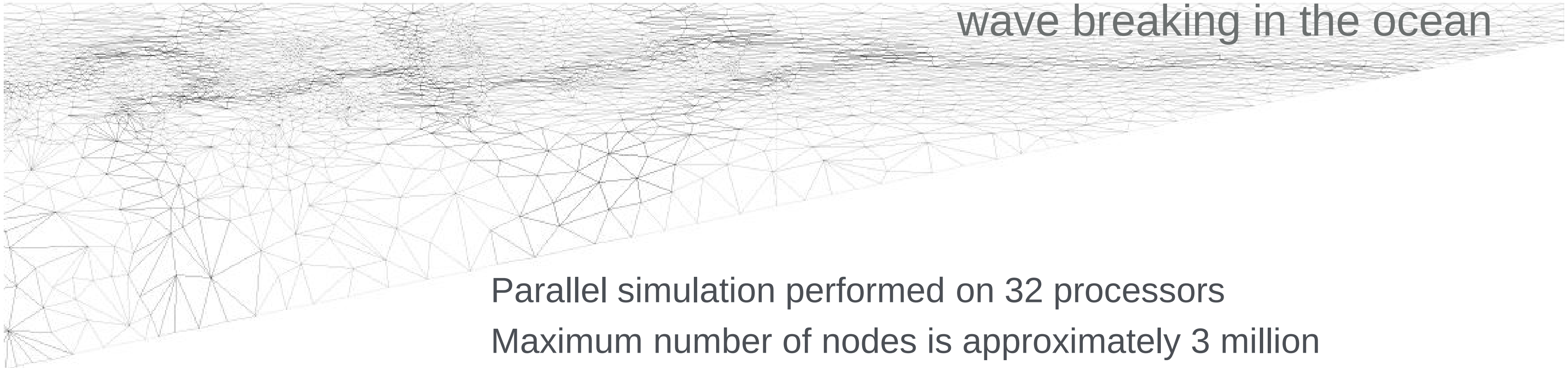


Lower frame shows the domain decomposition which has been optimised to balance the load based on number of nodes and minimised edge cut





- Viscosity is set to 1.5×10^{-8} m^2s^{-1}
- Gives a wave Reynolds number of 10^5
- More indicative of an internal wave breaking in the ocean



Parallel simulation performed on 32 processors

Maximum number of nodes is approximately 3 million

Smallest element has edge lengths of 10^{-5} m

Would require more than 1 billion nodes if run on a uniform mesh with those edge lengths everywhere

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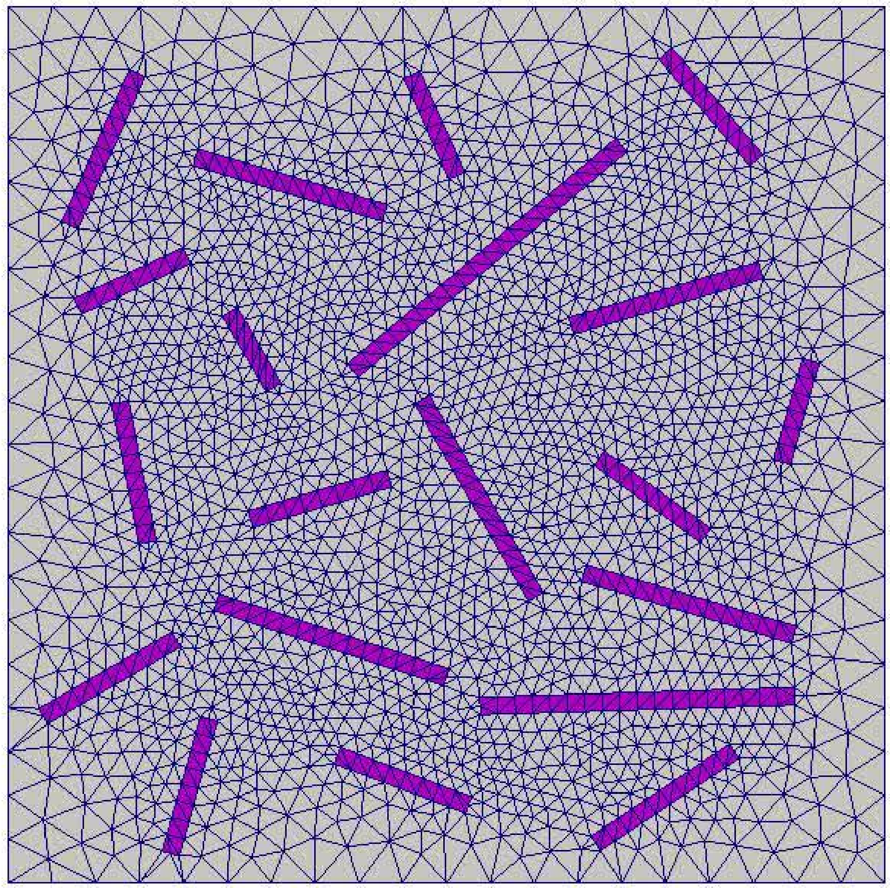
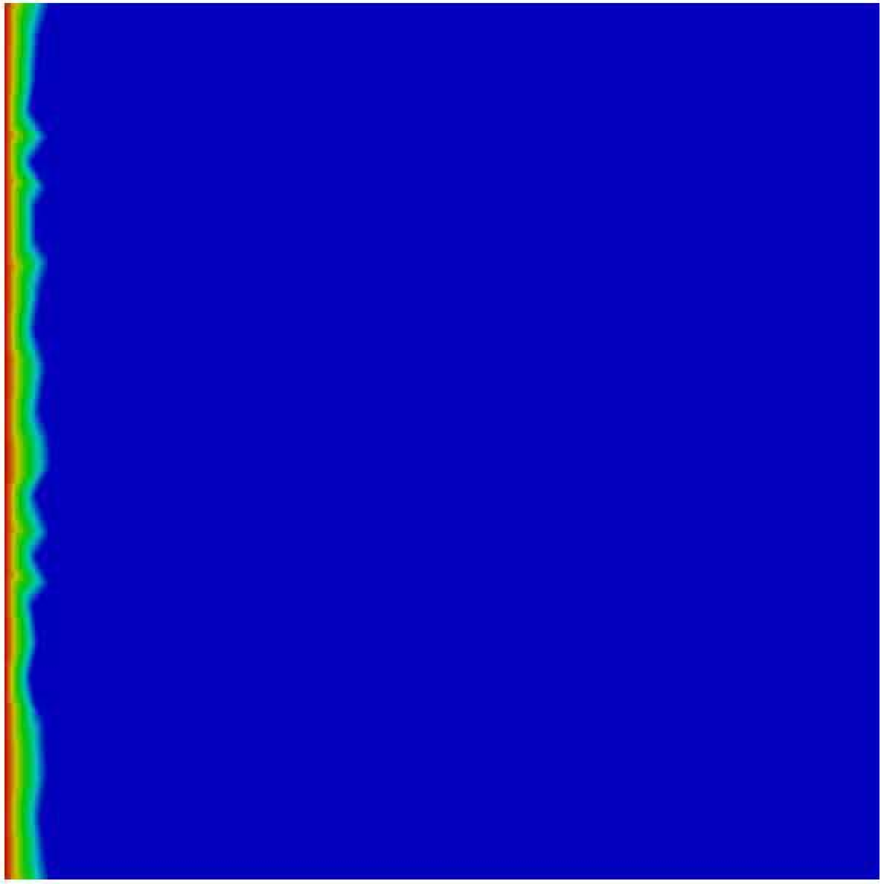
Modelling with fractures





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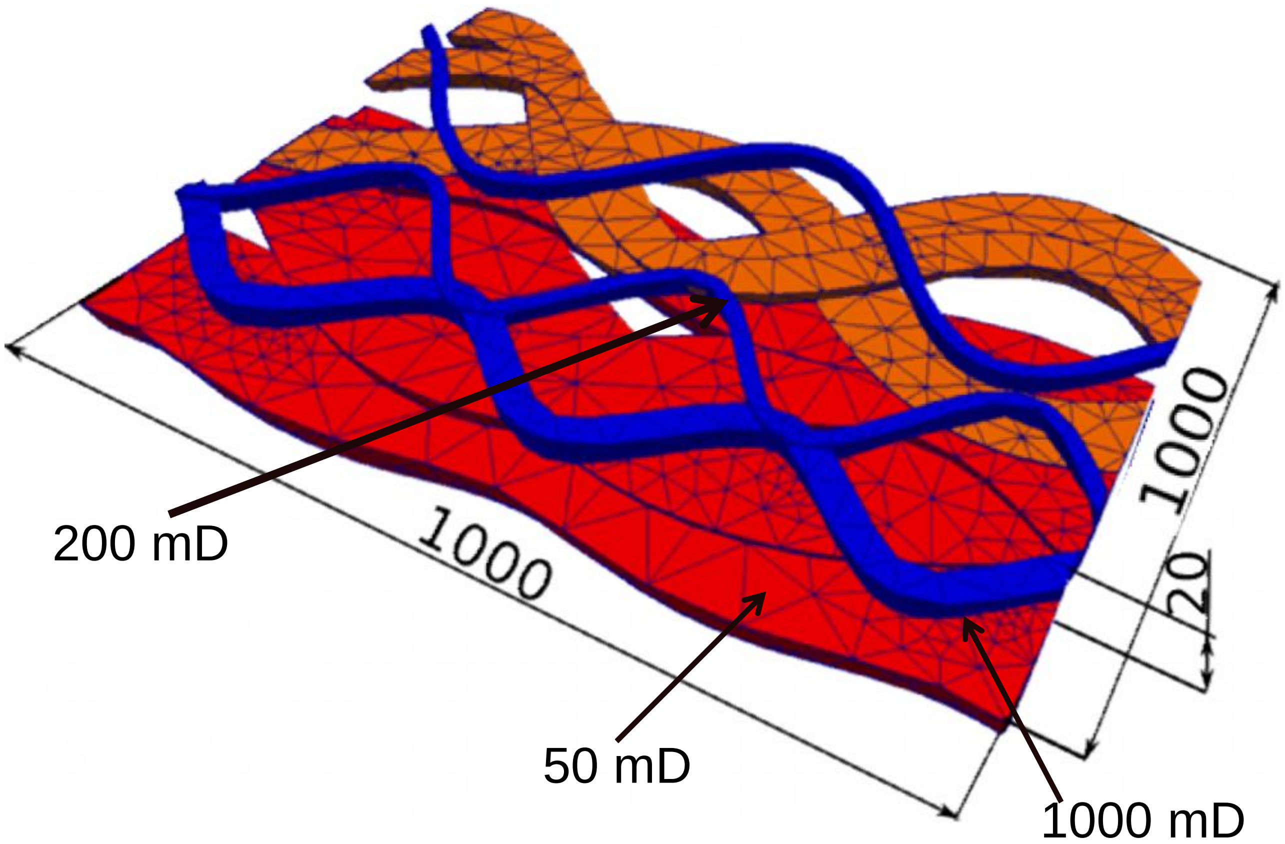
Test cases: Fluvial channels



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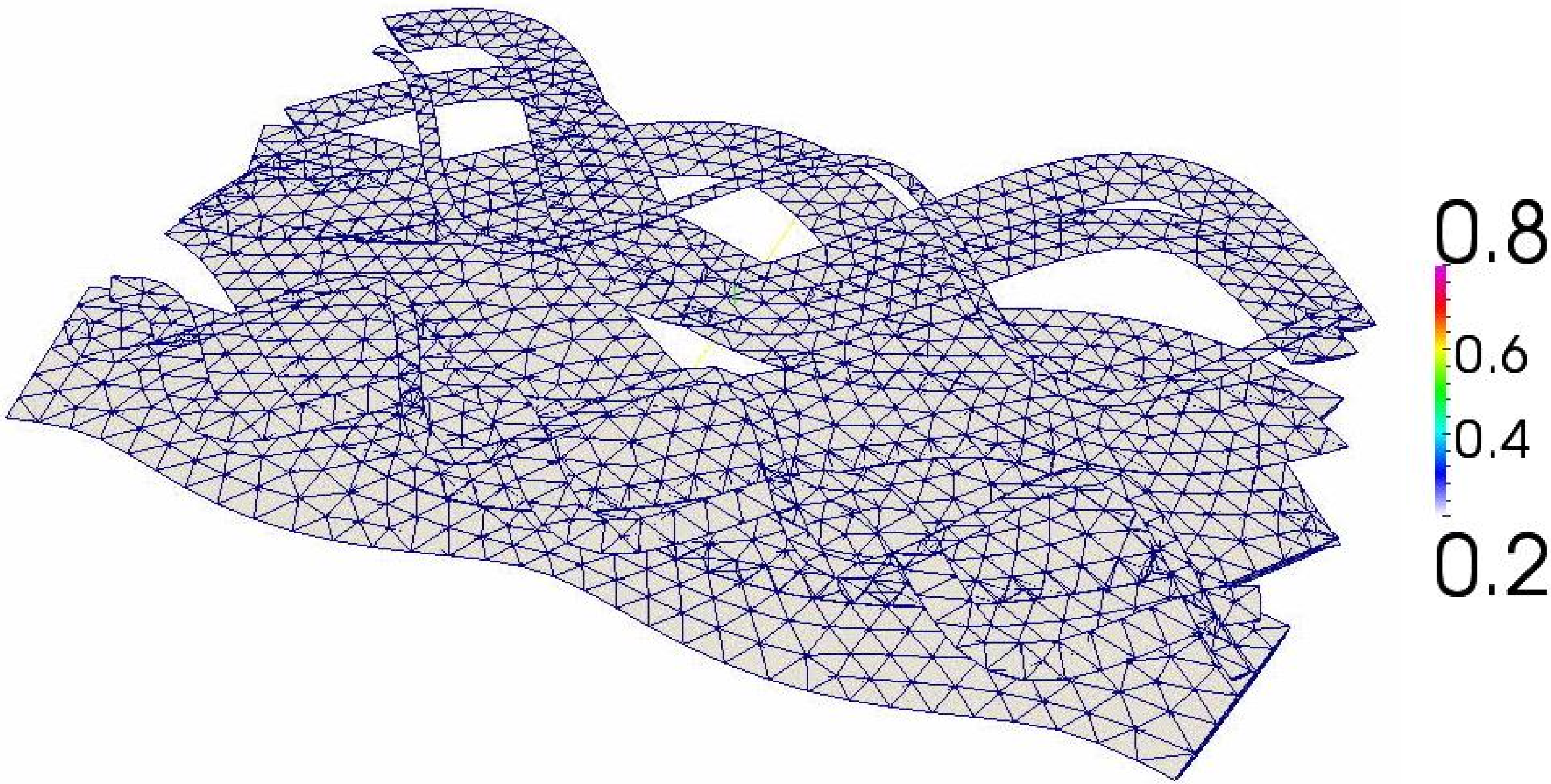
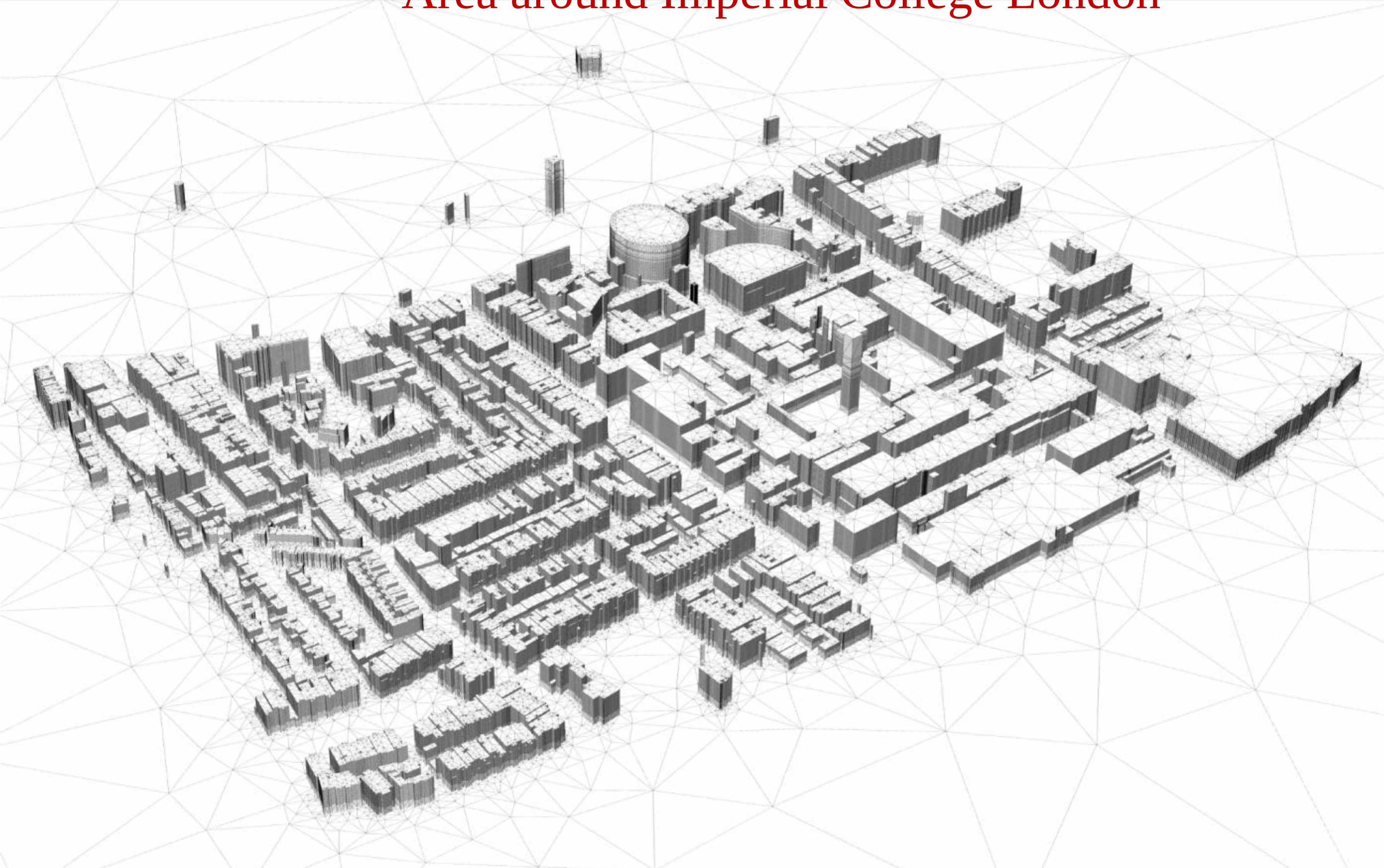
Test cases: Fluvial channels with Kv/Kh = 0.01



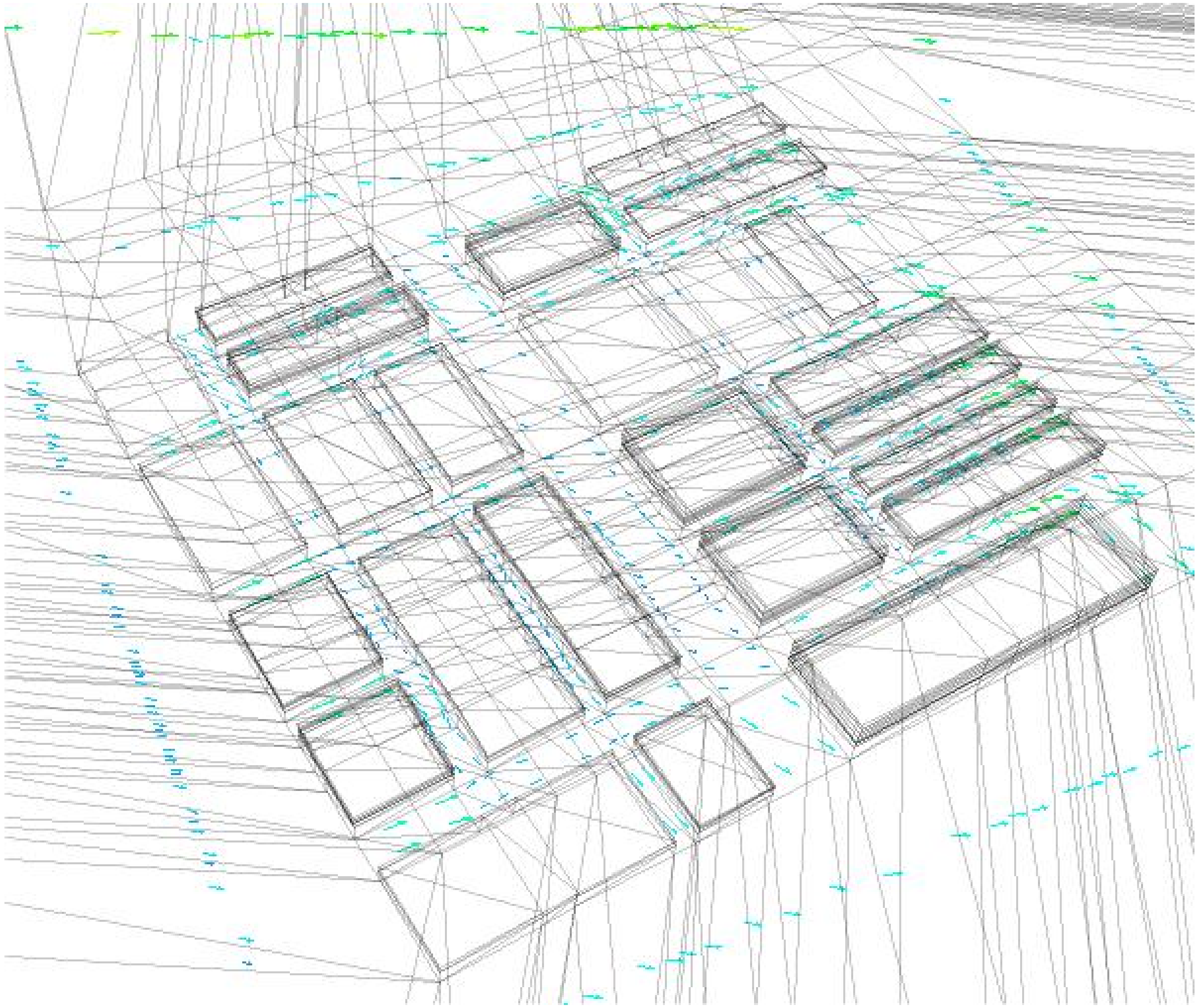
Generation of Urban Geometry using Urban-Terreno

Area around Imperial College London



Environmental Modelling

24 Building Case (600000 Nodes): 20 Processors



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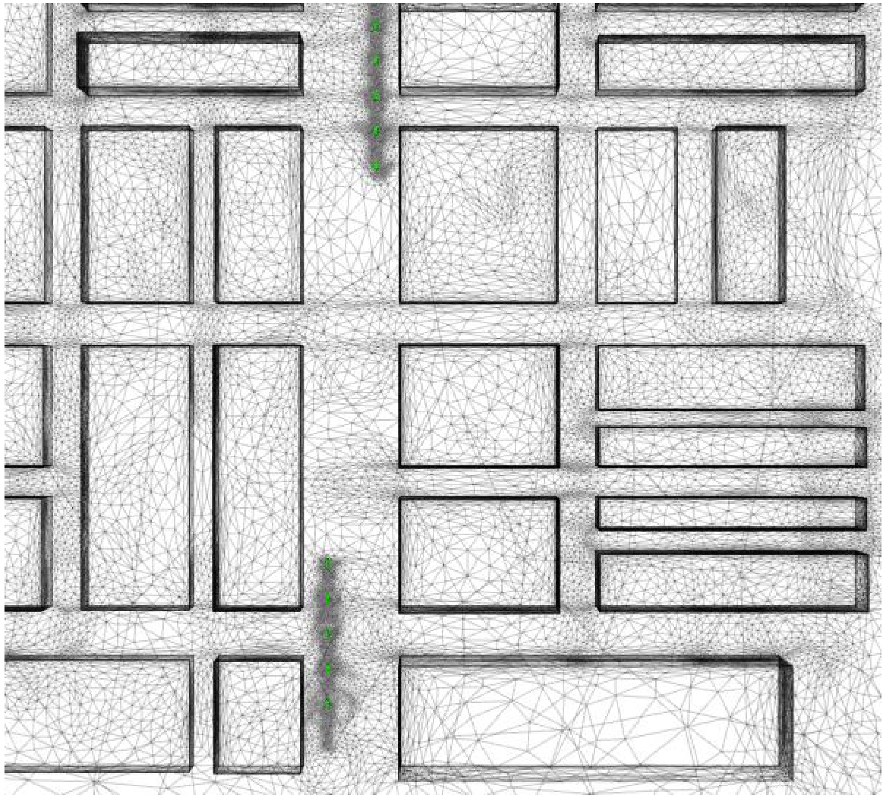
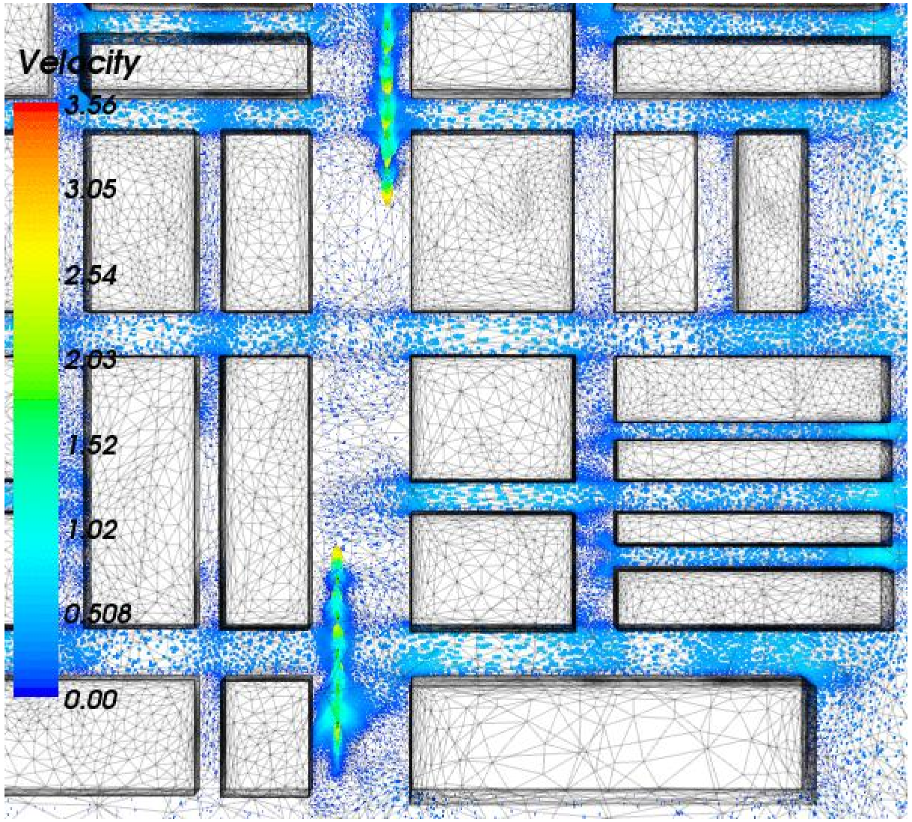
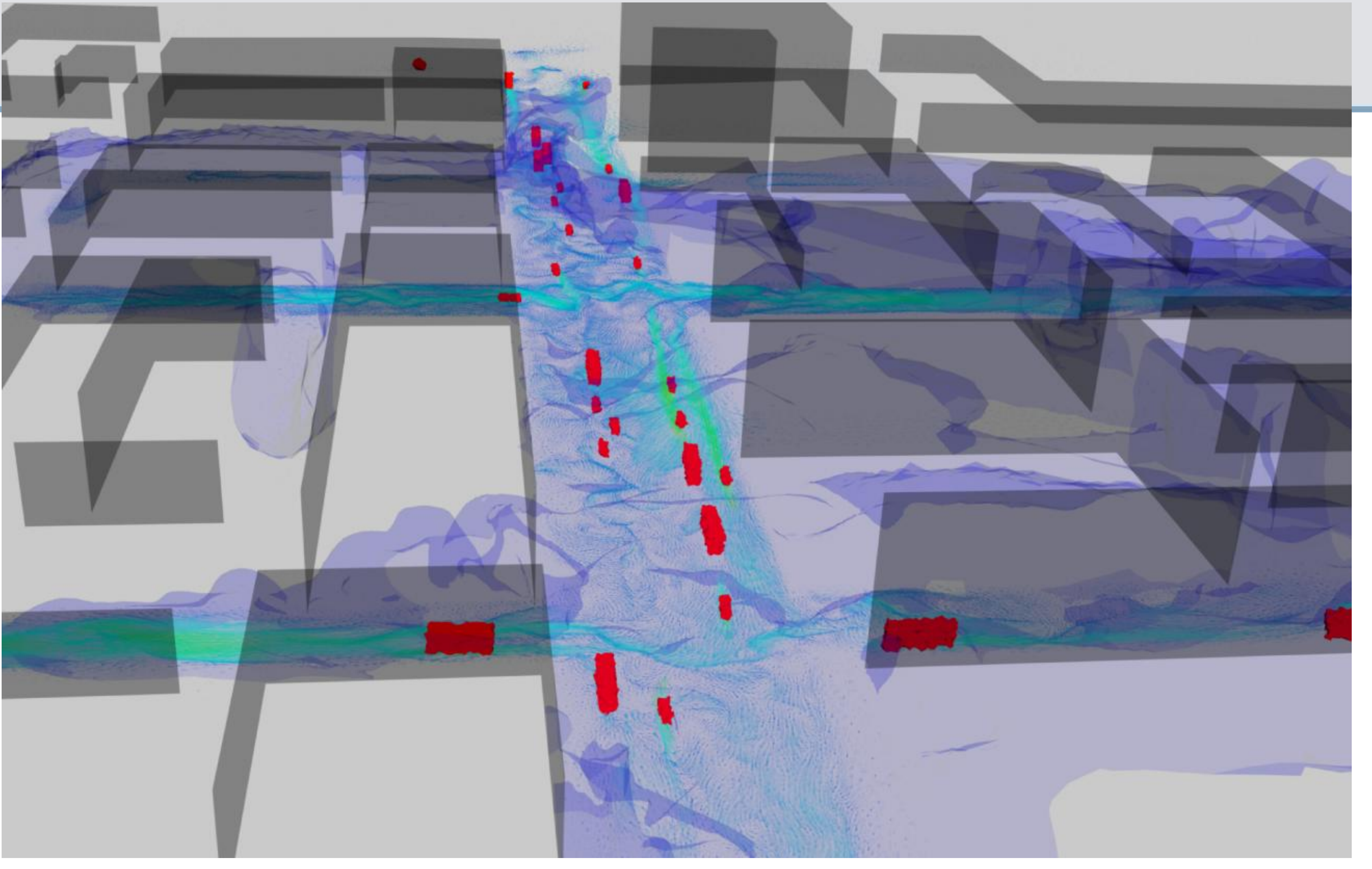
Environmental Modelling

Moving Vehicles and Scalar Dispersions in Street Canyons





LES flow with traffic modelling



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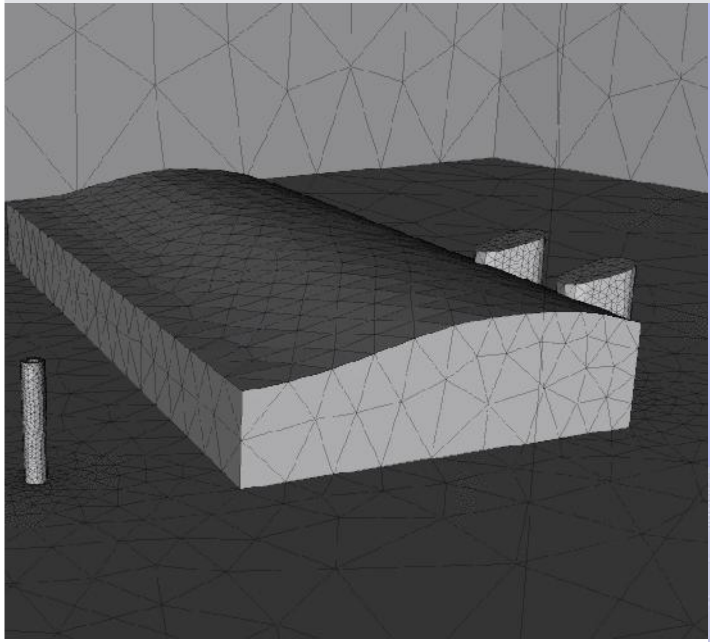
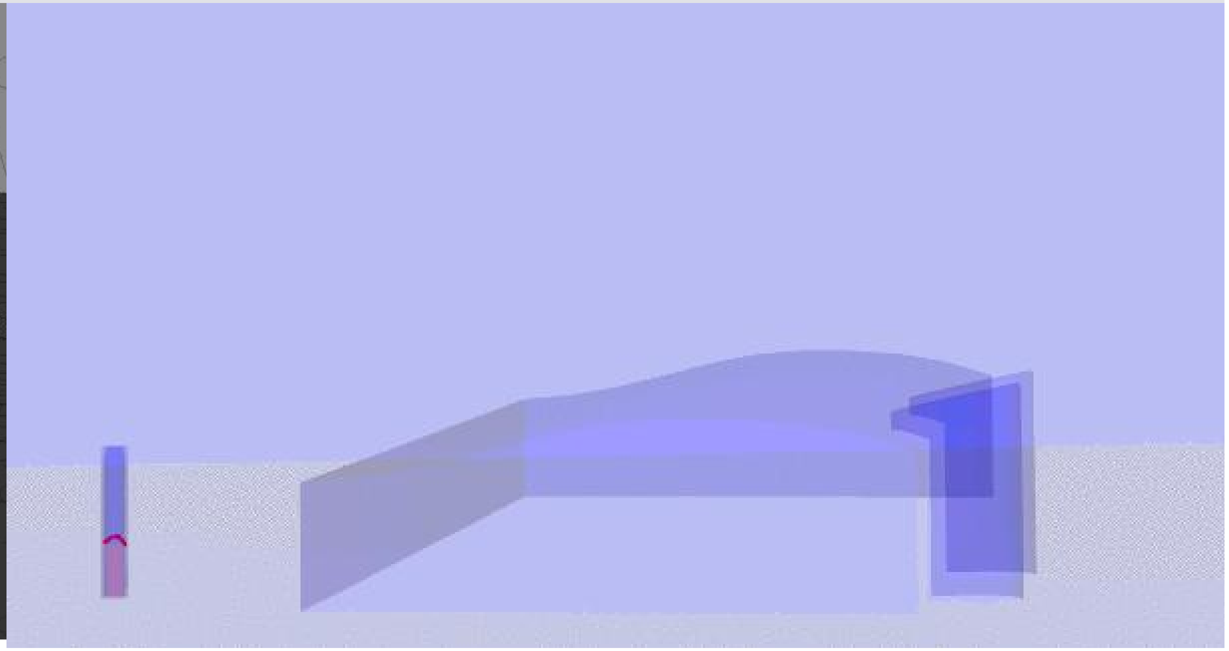
Environmental Modelling

Modelling Gas Dispersion around an Industrial Site





- Neutral atmospheric conditions are assumed
- Mechanical turbulence is added to the incident wind profile to enhance realism
  - Physical analogue to terrain roughness effects
  - Similar to approach used in wind tunnel experiments
- Incident wind adjusted to give an approximate wind velocity of 4-6m/s at the tower to match instrument readings
- The iso-surface (left) and contour (right) indicate the 1/200th concentration level relative to the exit flue gas concentration
- Clearly the plume strongly impacts the building and surrounding area

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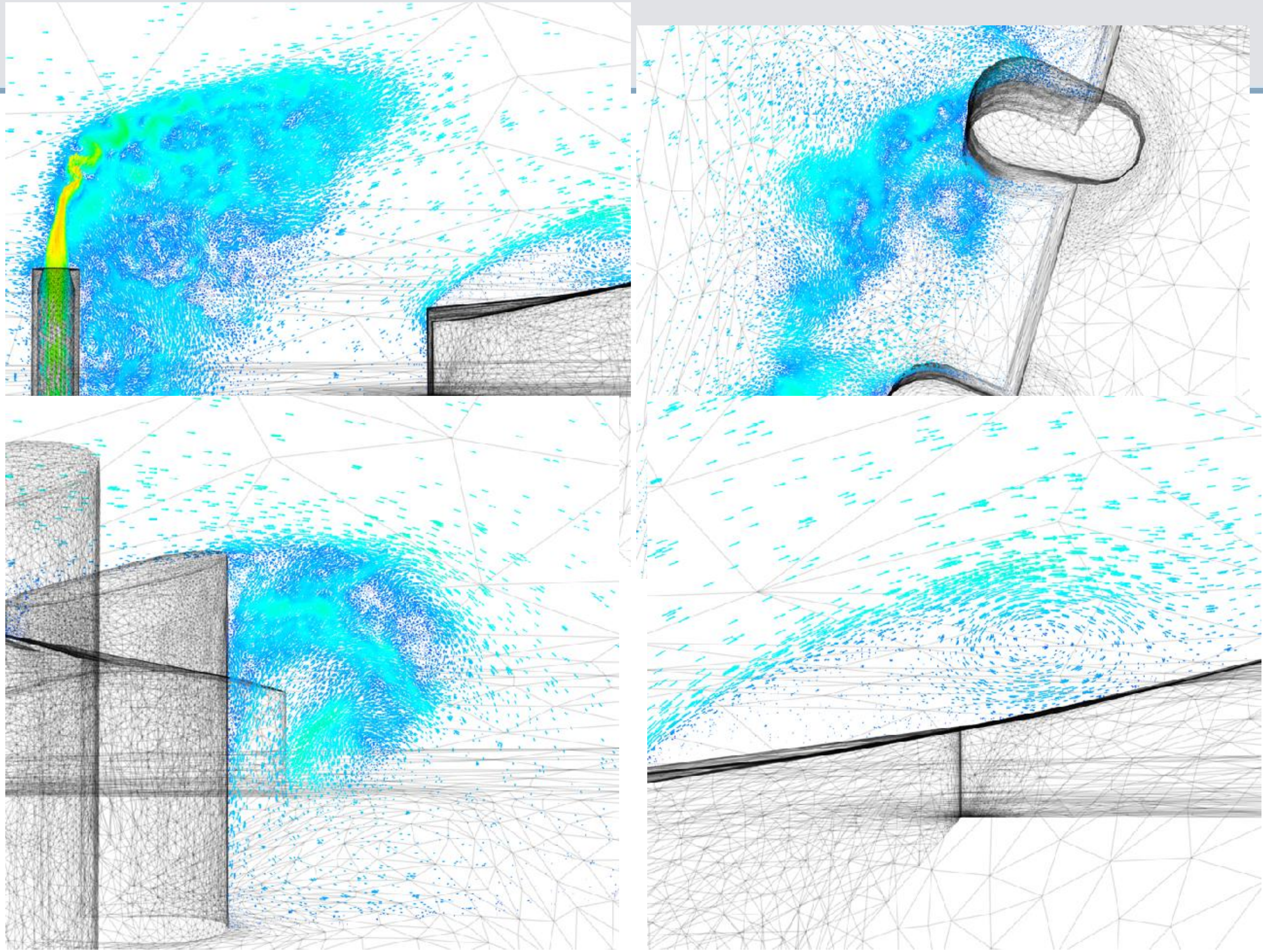
Environmental Modelling

Modelling Gas Dispersion around an Industrial Site



Environmental Modelling

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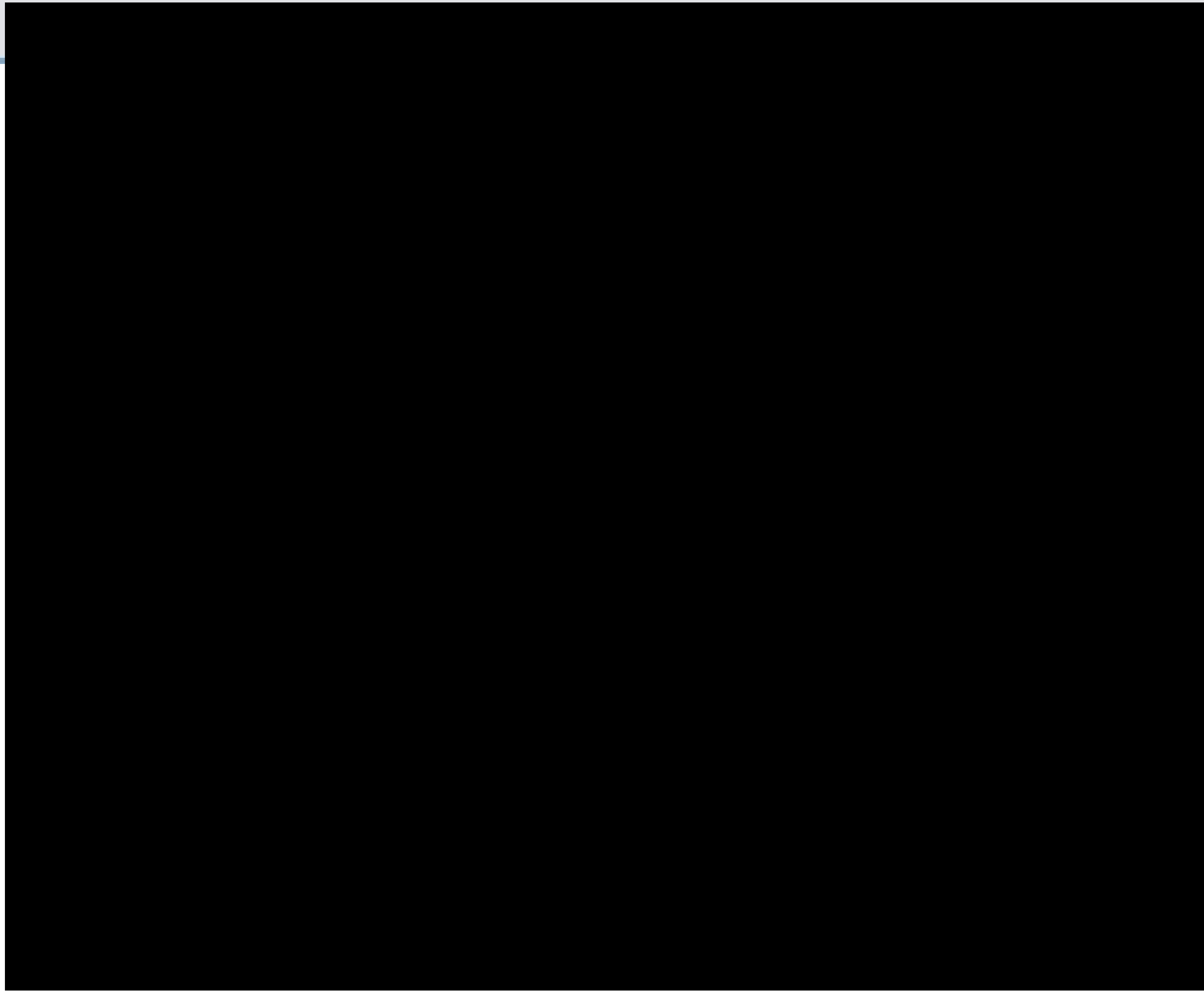

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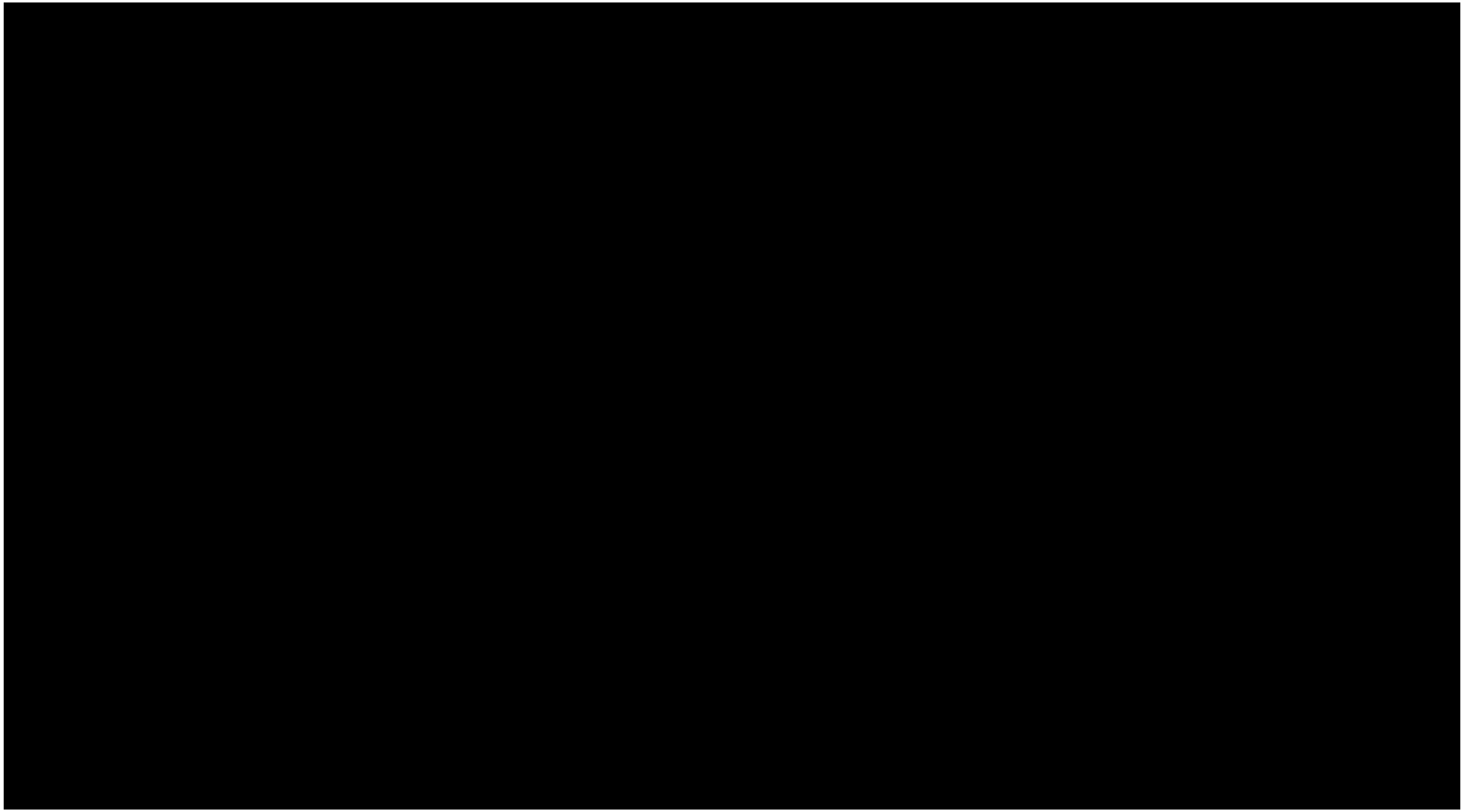
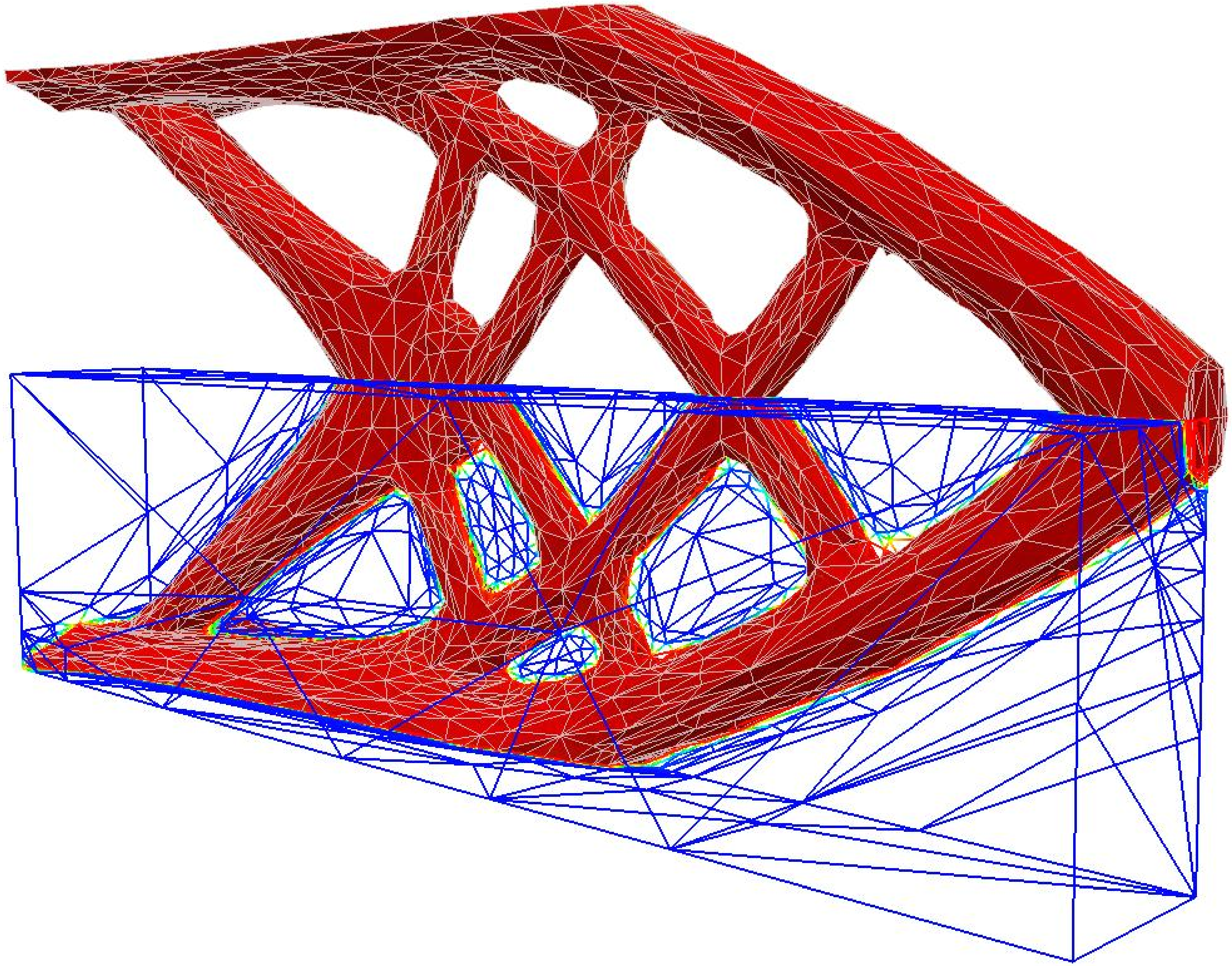
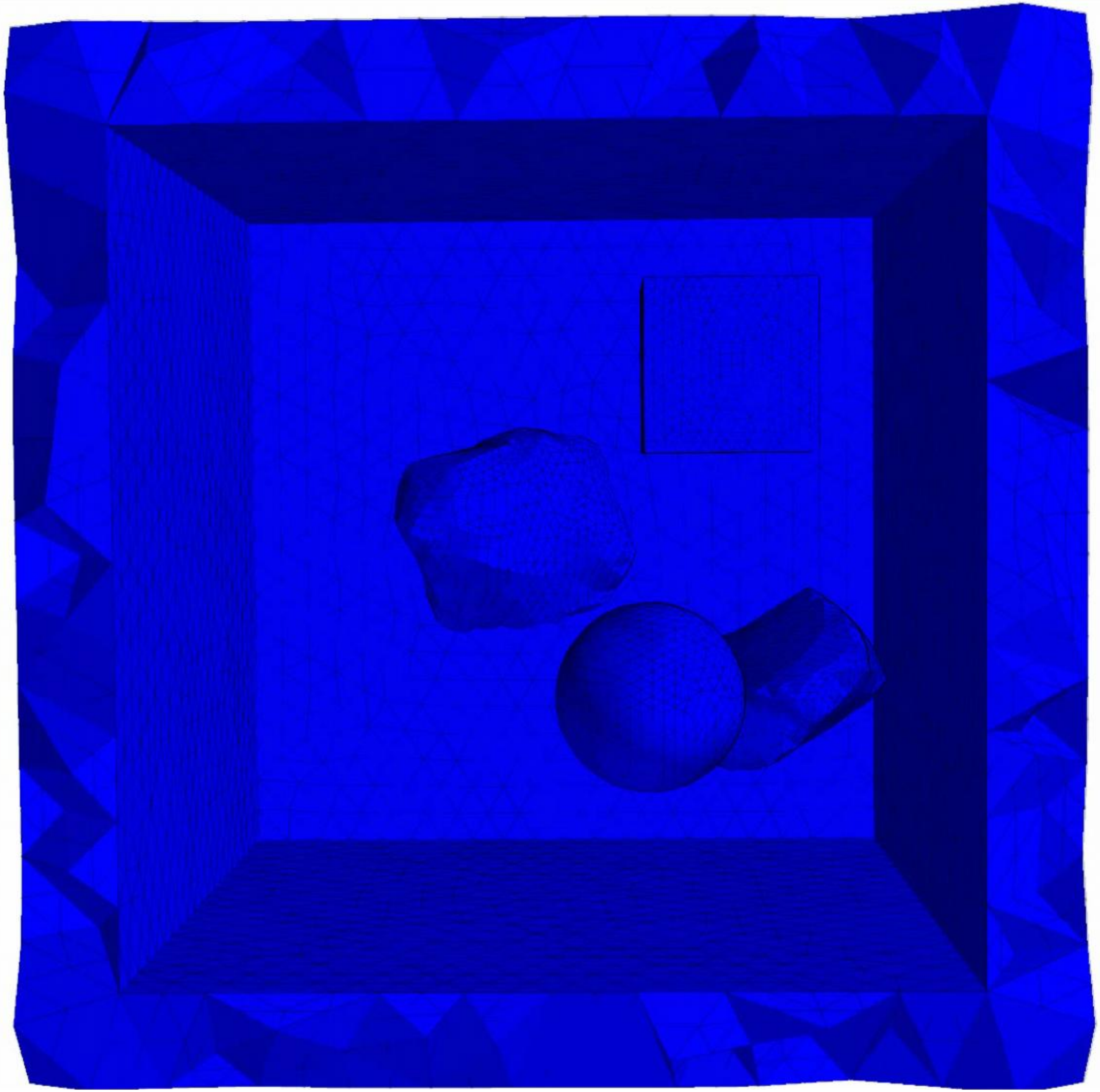
Environmental Modelling

Modelling of cloud formation

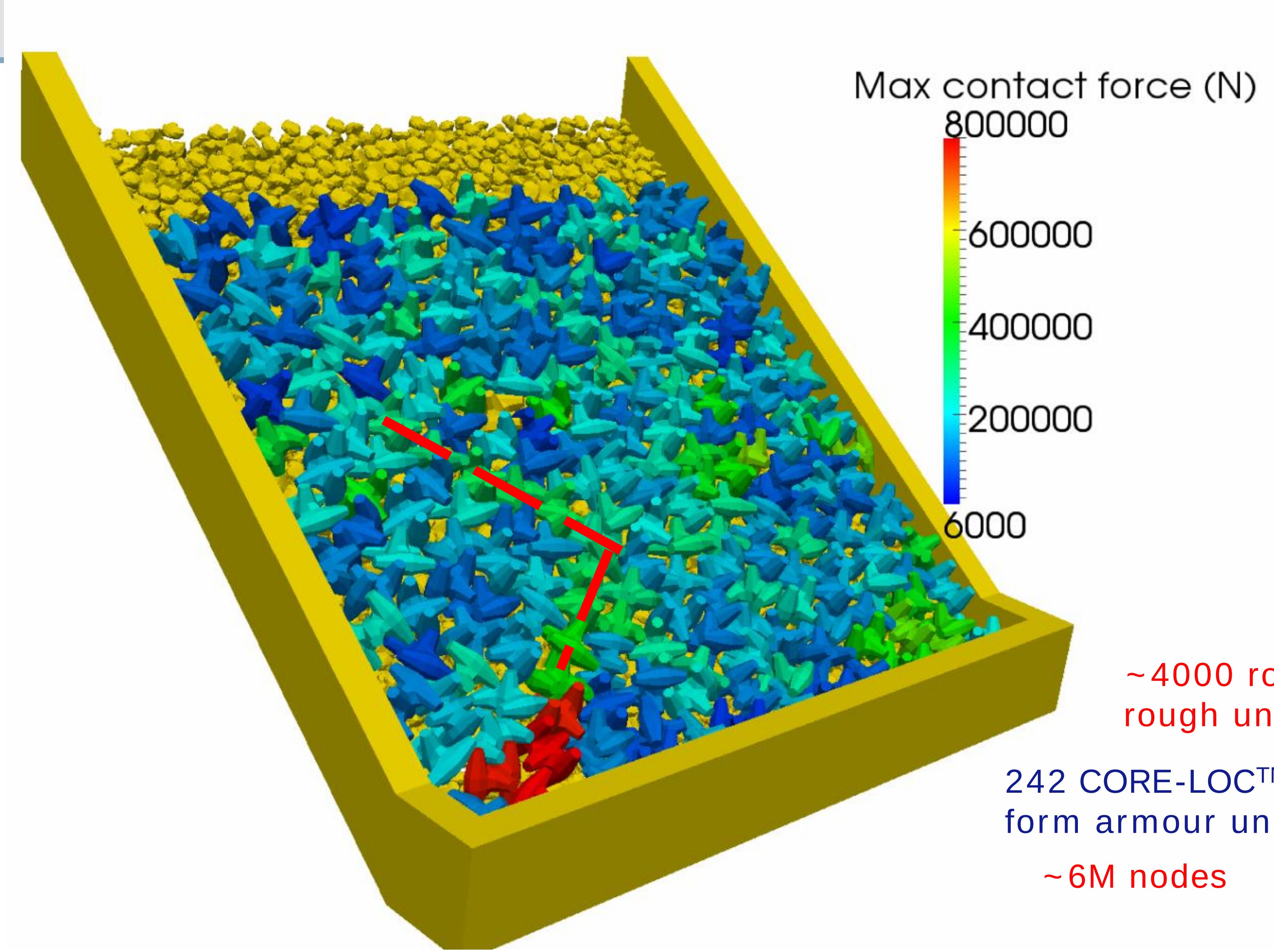


Solids modelling:
Optimized structures with mesh – solid structure shown





Application to Coastal Structures

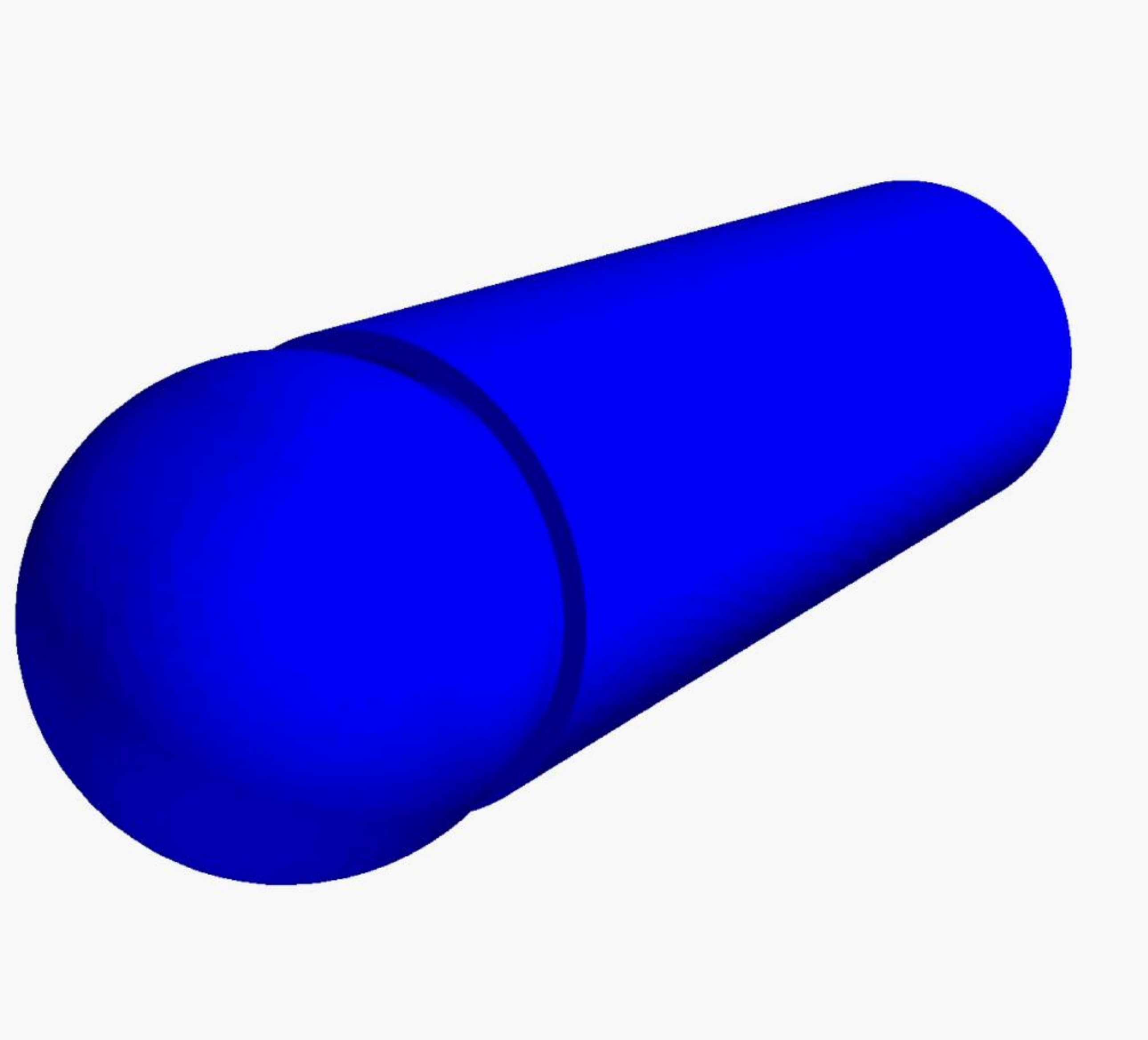


~4000 rocks form rough underlayer

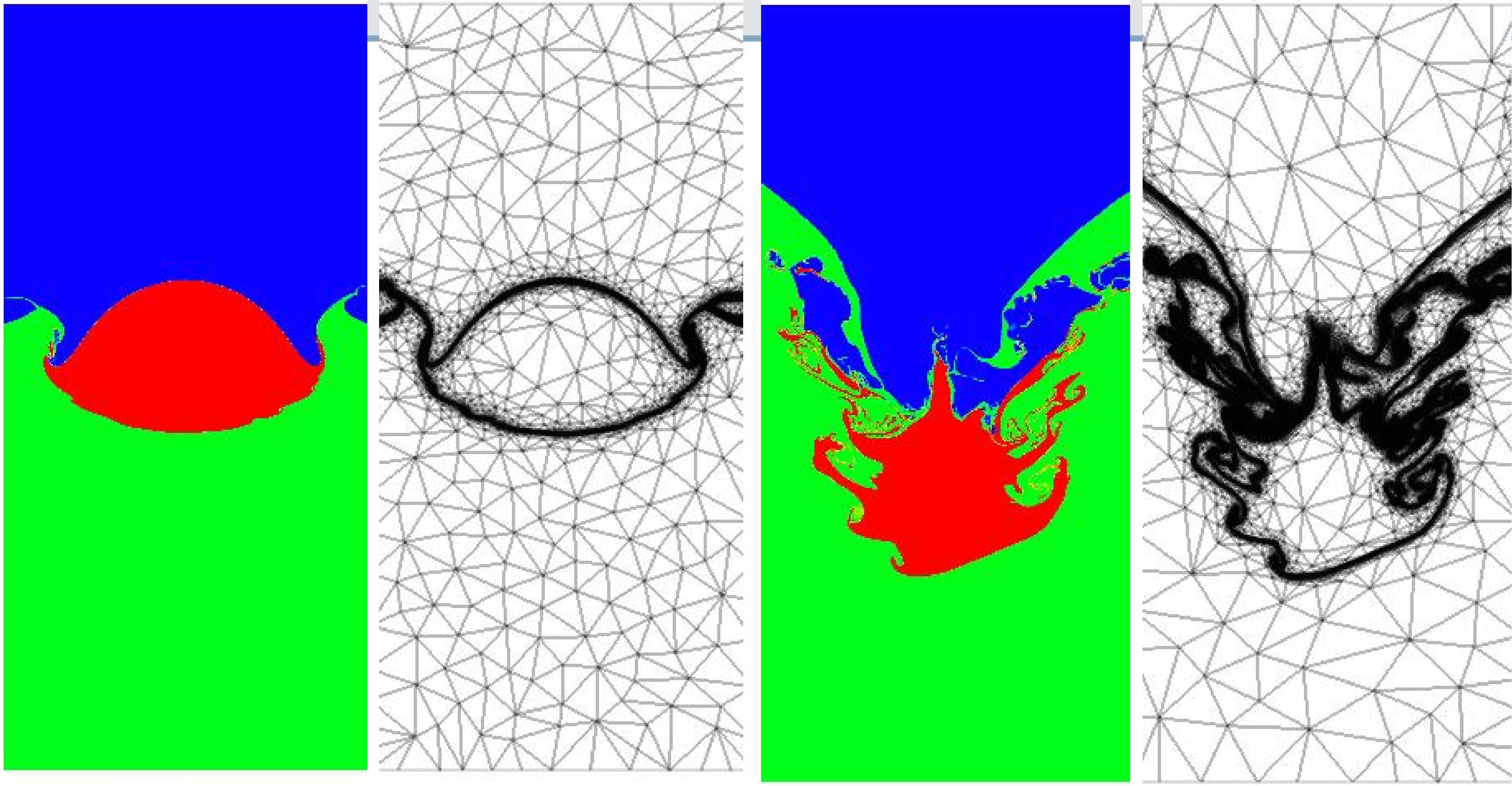
242 CORE-LOC™ units form armour unit layer

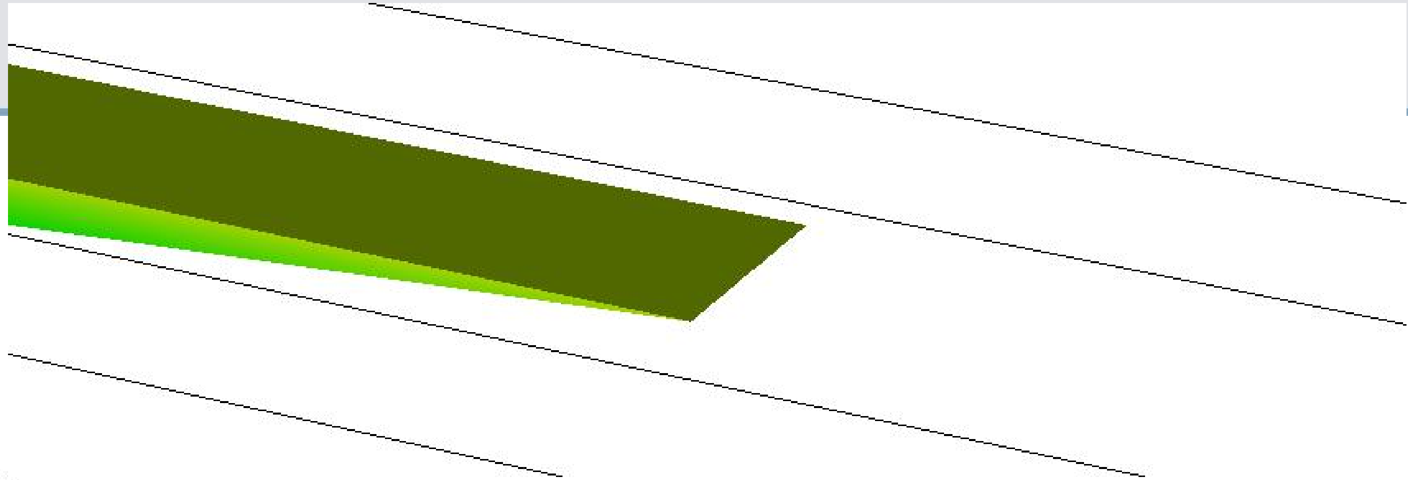
~6M nodes

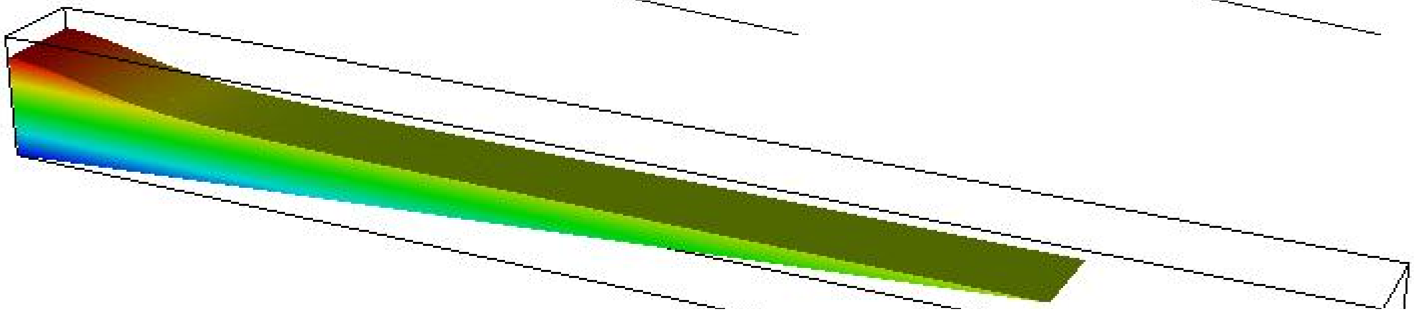
FEMDEM: Large Finite Strain Capability

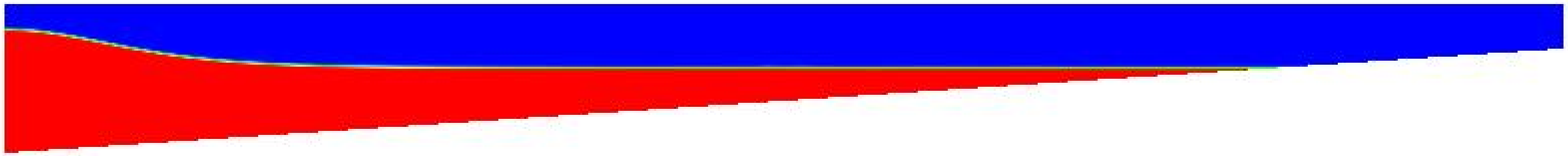


Interface tracking – 3 materials

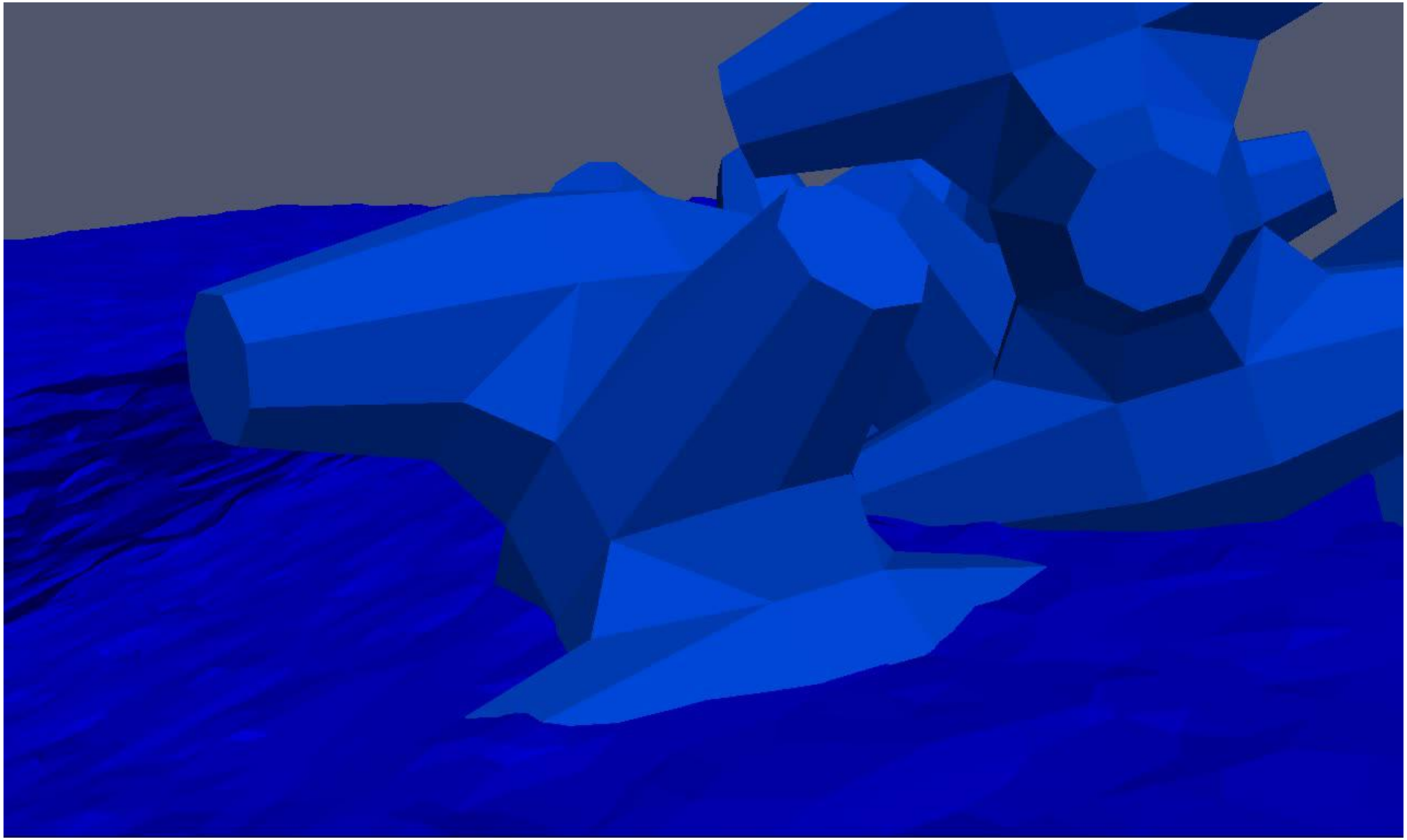




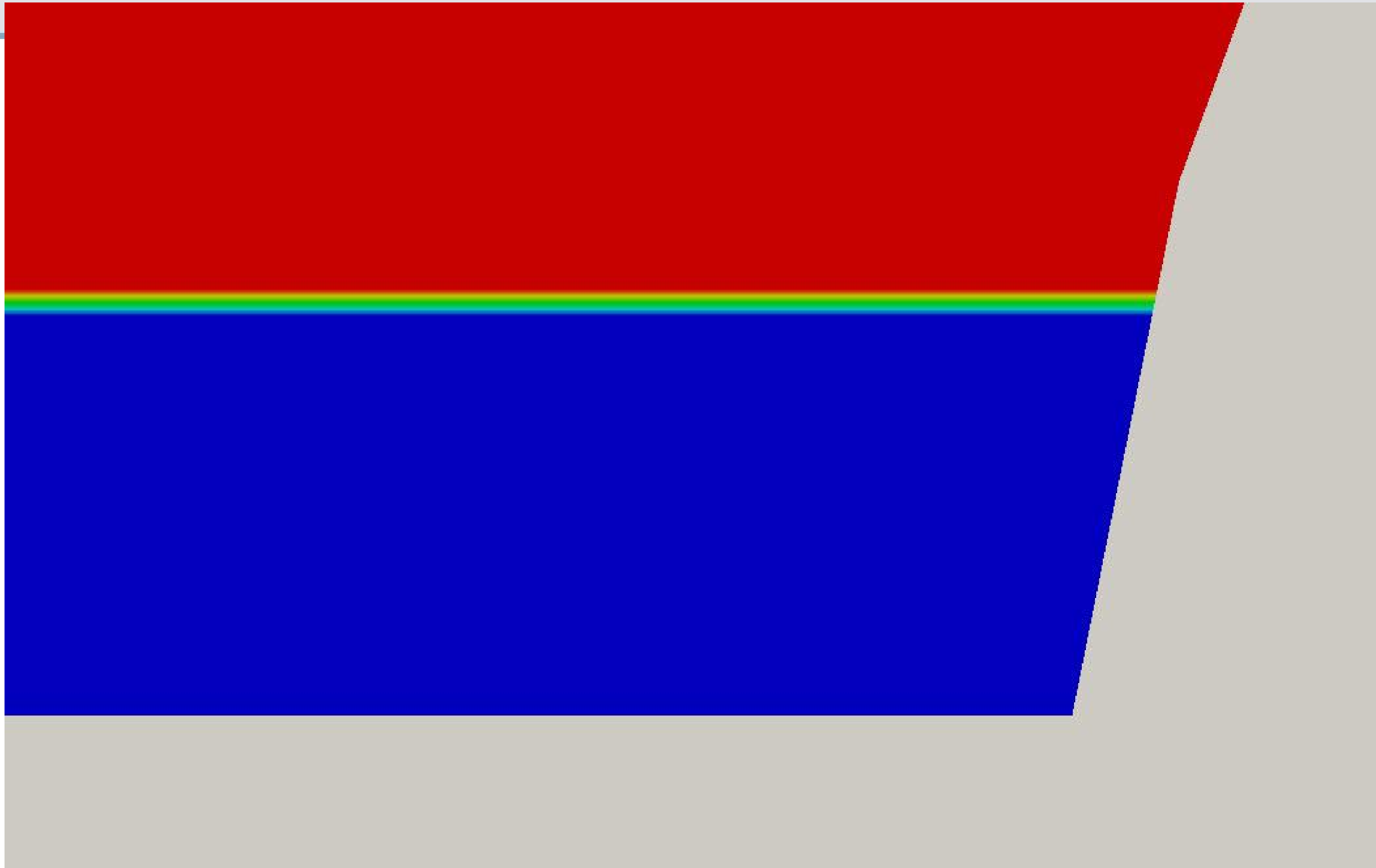




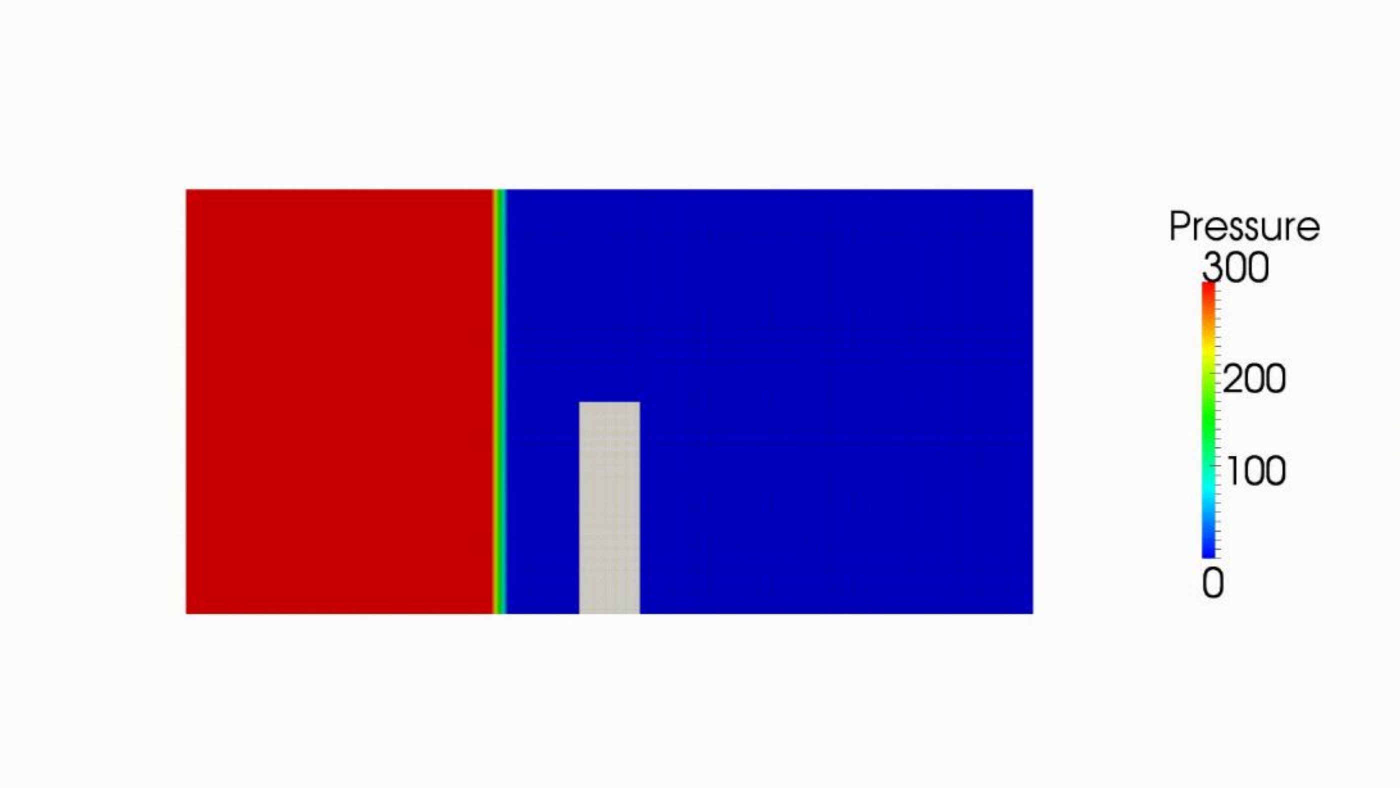
Coastal protection



Rock slide into water – volume fraction of air/water



The clamped beam simulation

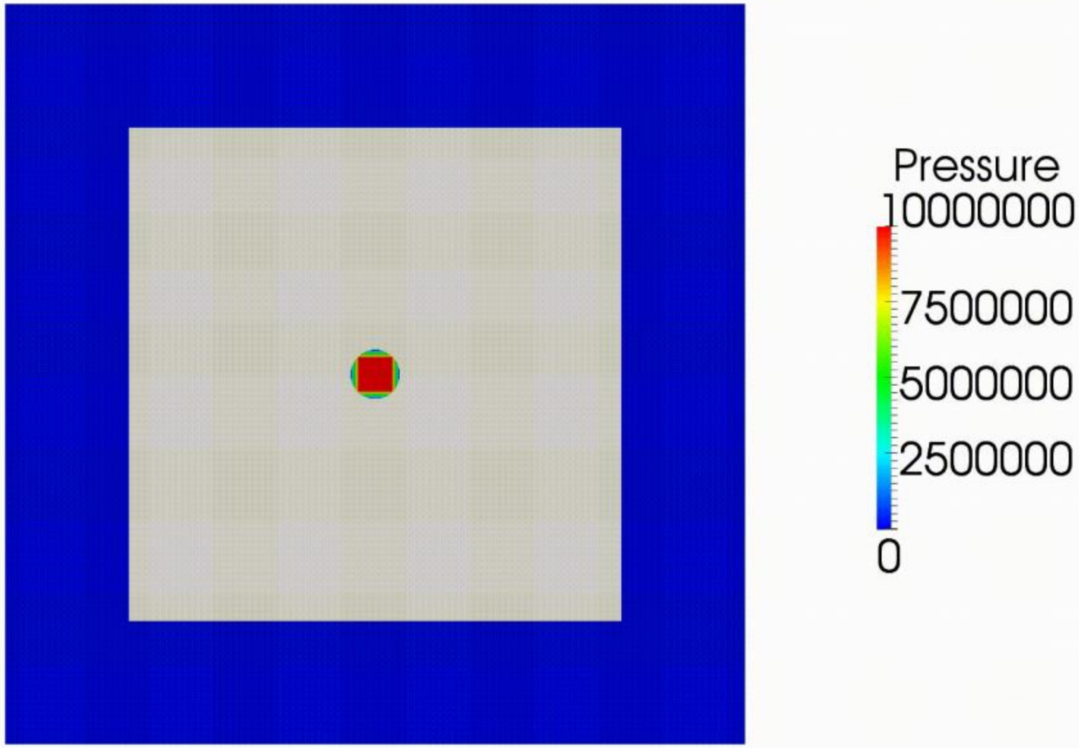


$p_0 = 516Pa$

Fluid mesh size: 0.08m*0.08m

Beam mesh size: 0.04m*0.04m

Blasting



$Gas:$

$$p_0 = 1e+8Pa$$

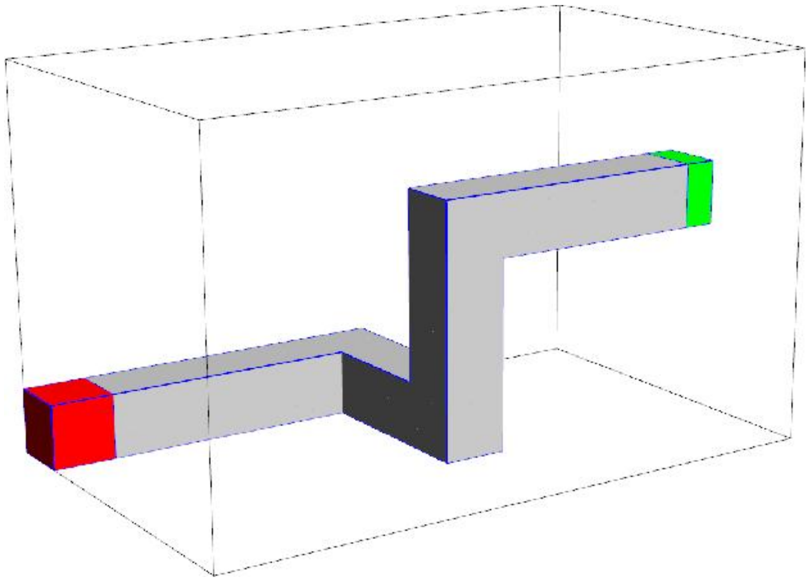
$$T = 1000K$$

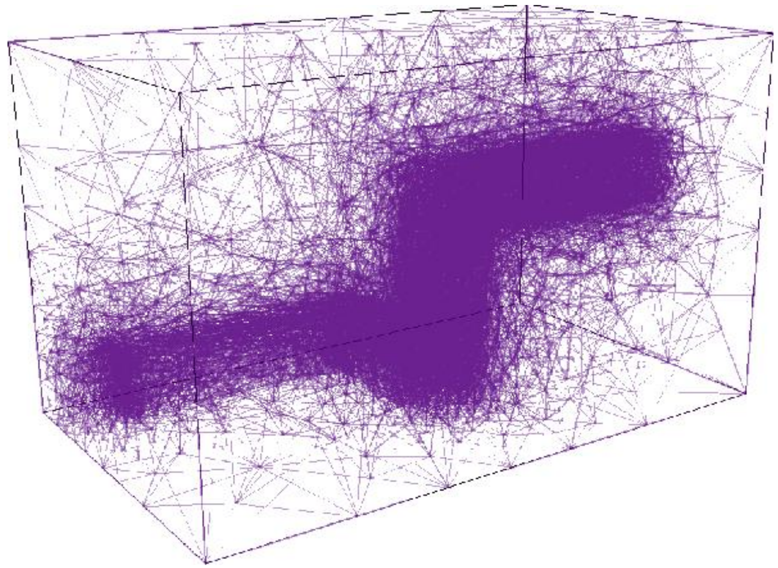
Block: 2m*2m concrete   Centre hole: R=10cm

Fluid mesh size: 0.033m*0.033m

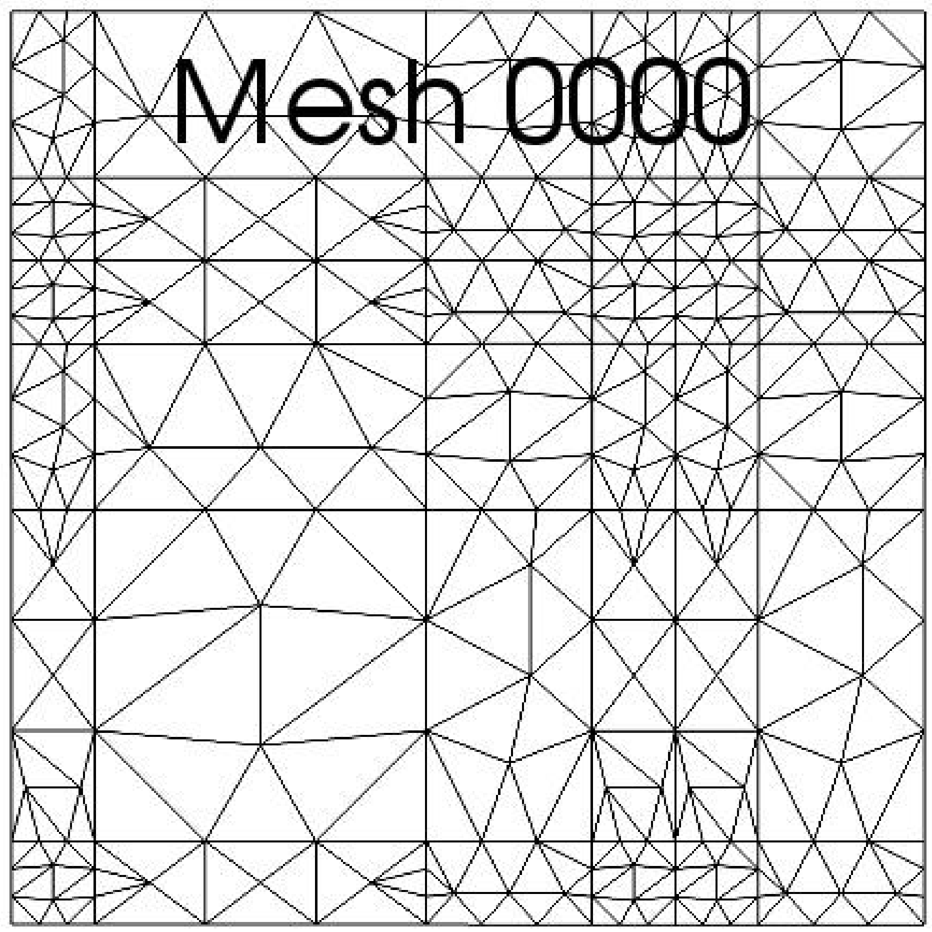
Block mesh size: 0.03m*0.03m

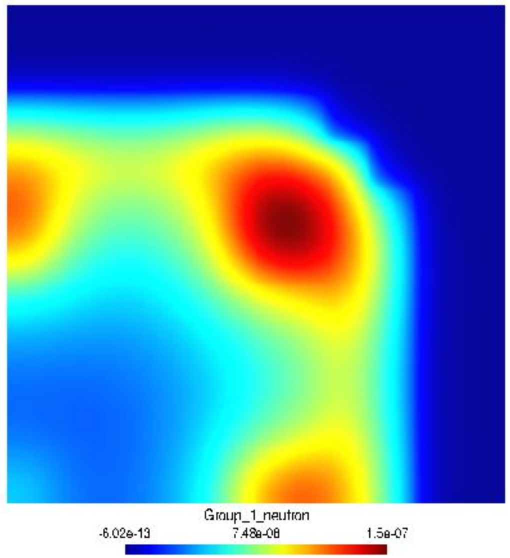
Radiation transport

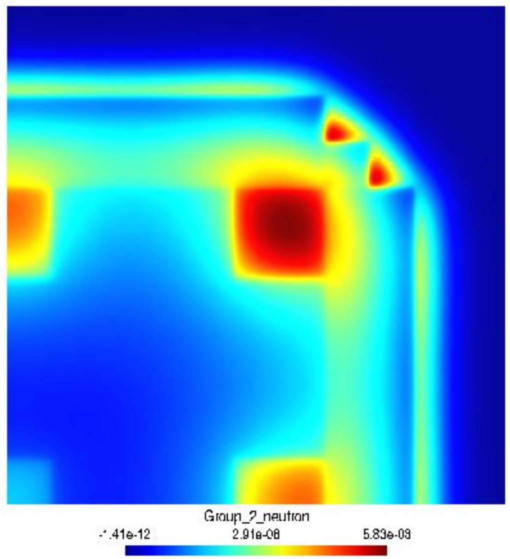




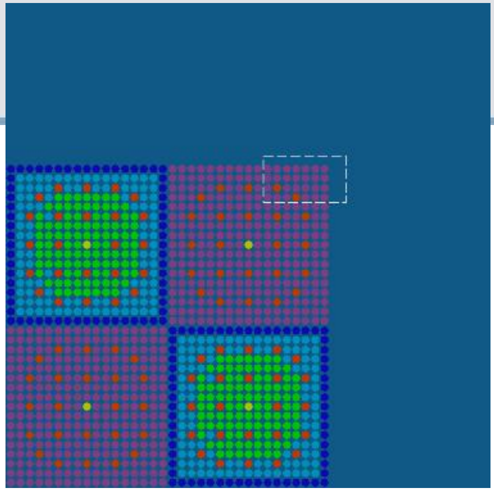
Radiation transport -Reactor physics

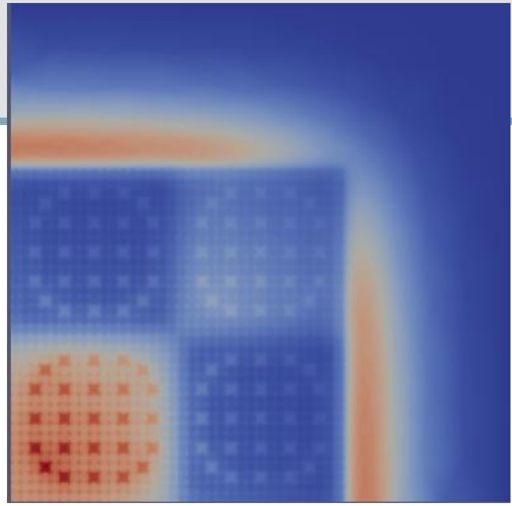


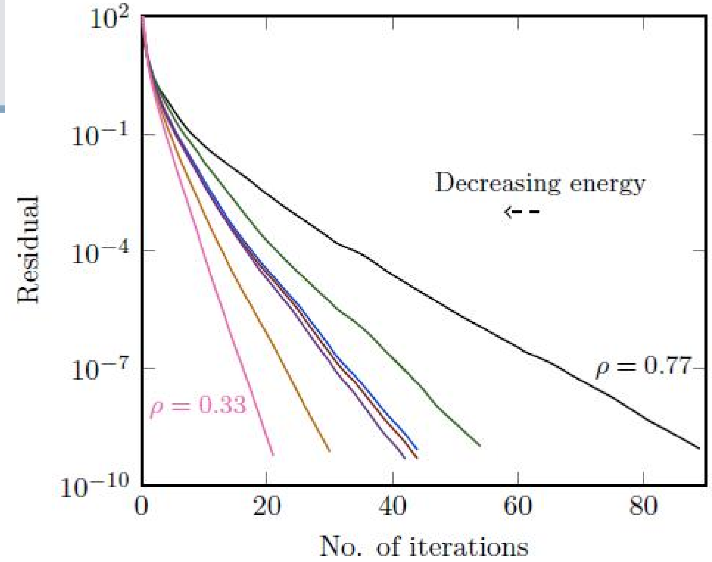


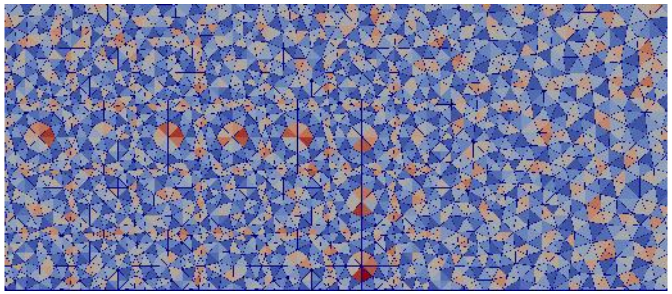


Multi-grid preconditioned solvers: C5G7 Benchmark



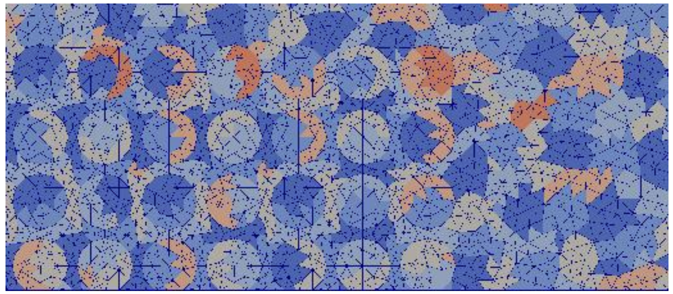


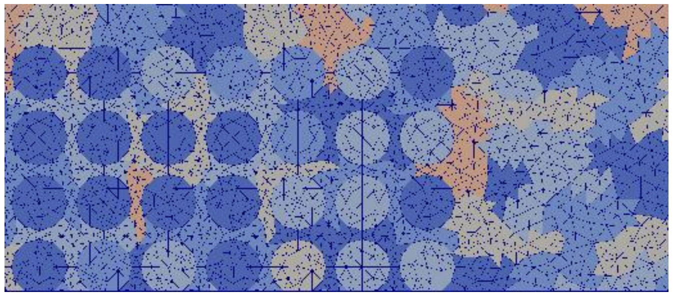




134K elements

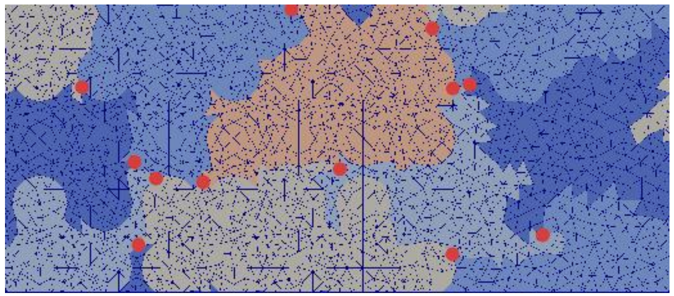
10K elements





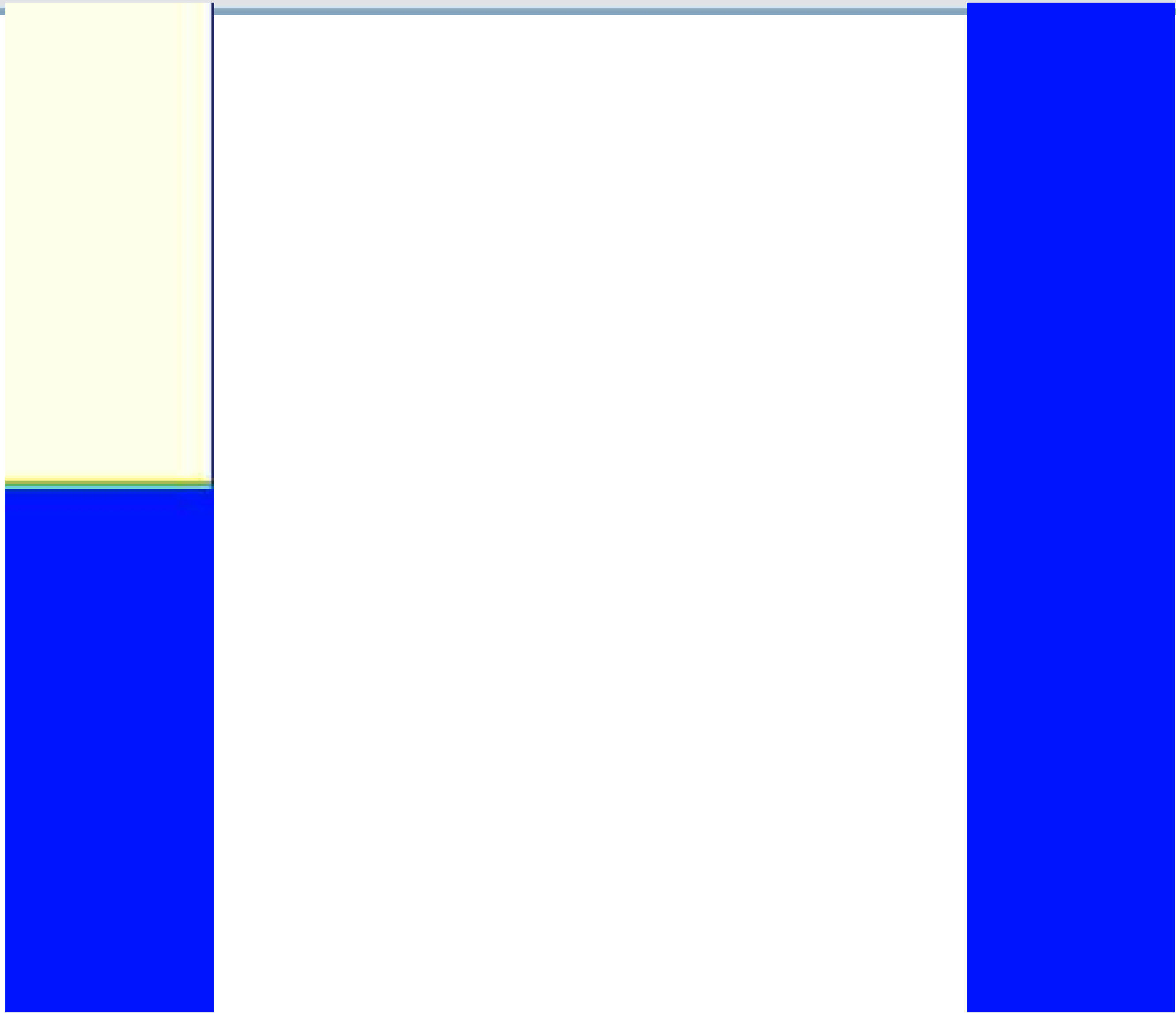
3K elements

0.5K elements



Coupled Multi-phase and RT Model: FETCH

Validation: Tracy (voln frac. (left); temp. (right))

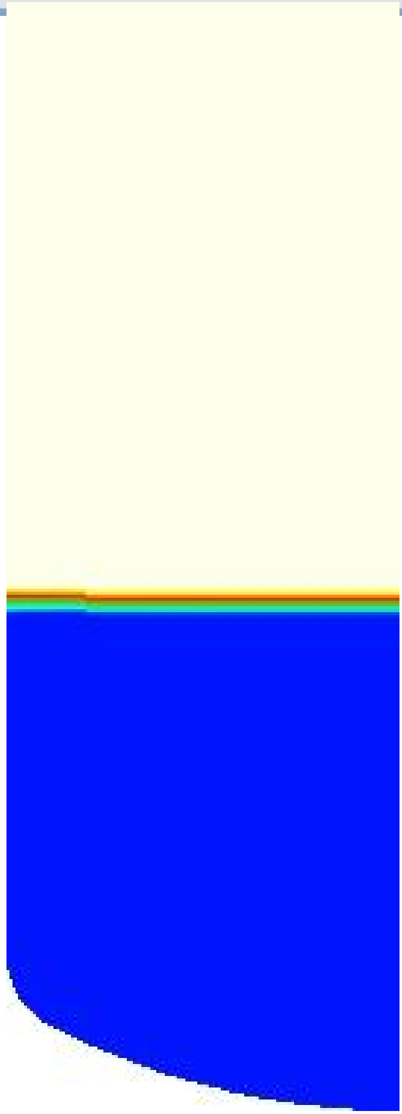


Coupled Multi-phase and RT Model: FETCH

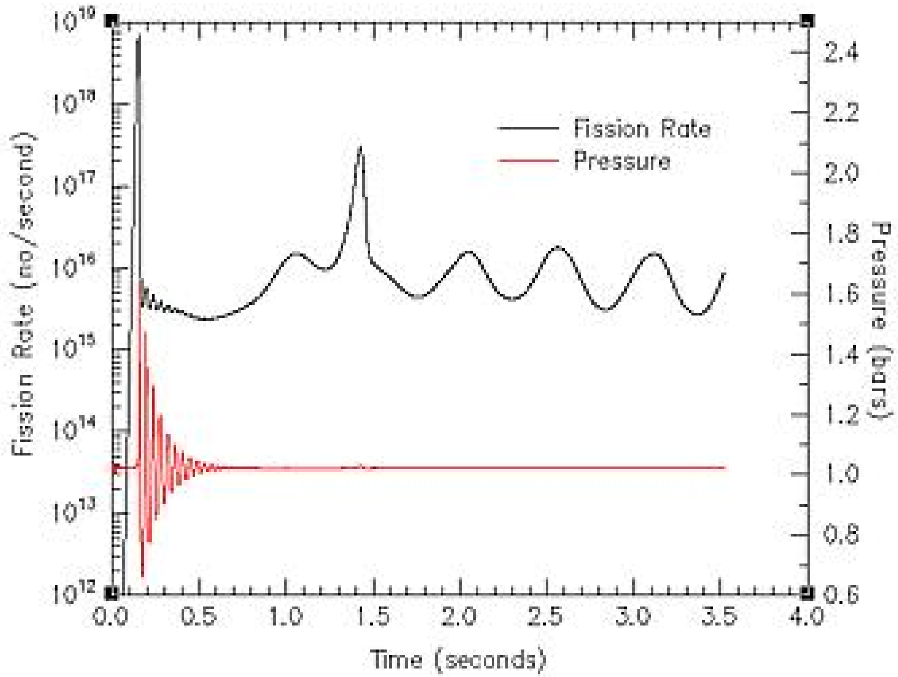
Benchmark: Bubbly Flows - JCO Japan Criticality Accident (AMCG-JAEA)

Axi-symmetric model

Gas volume fraction

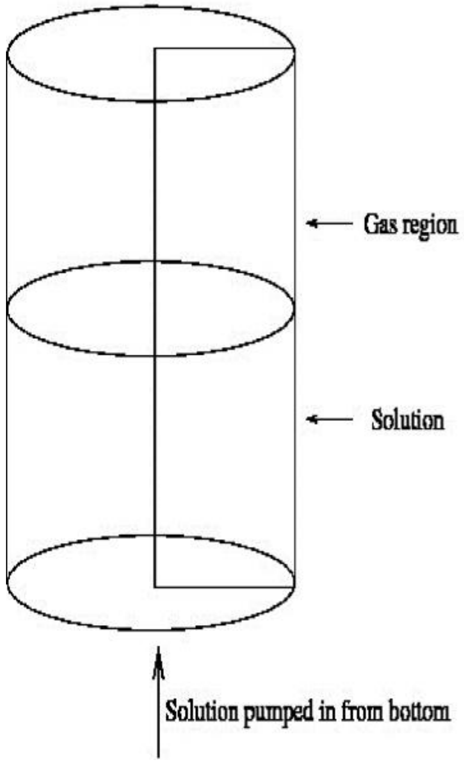


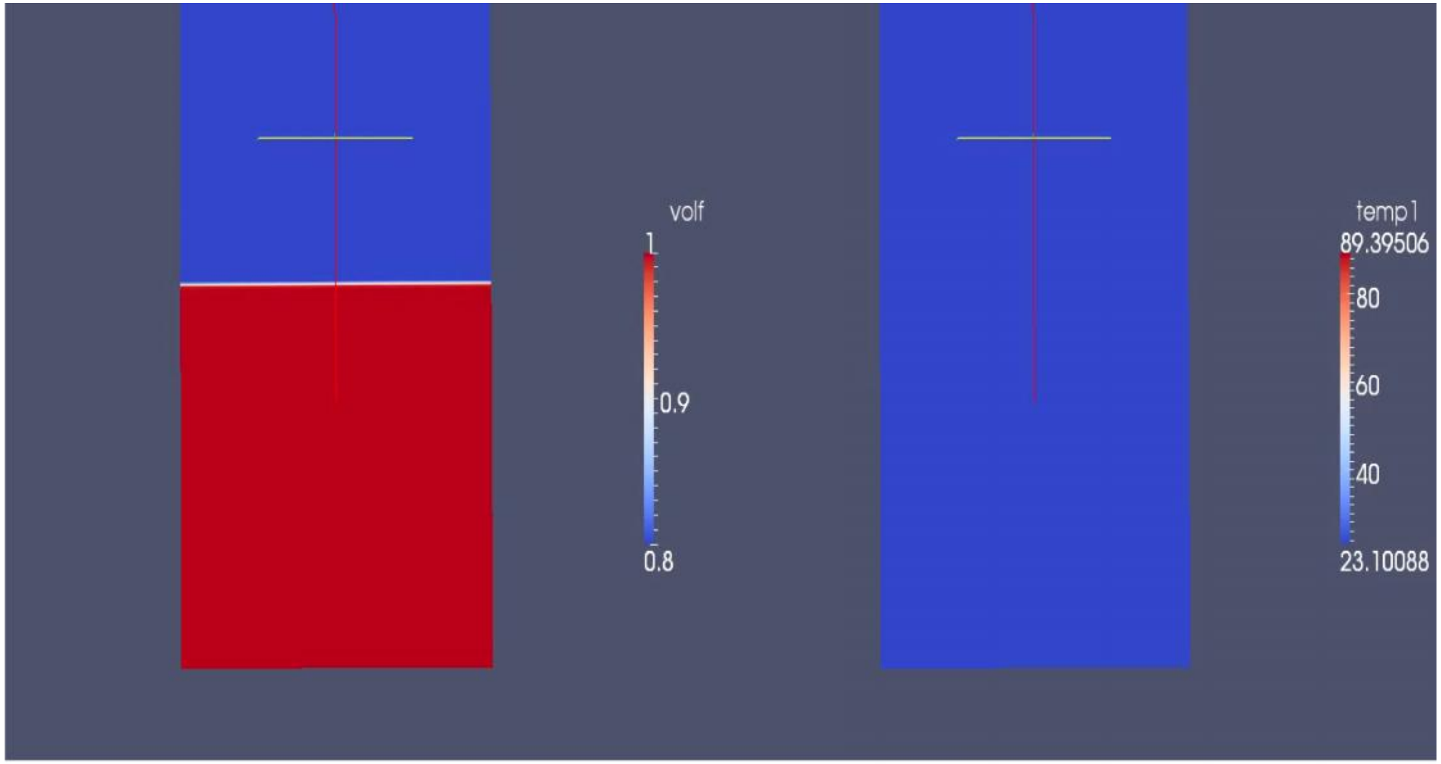
- Modelled ‘adding the last bucket’ as continuous filling
- Independent response to UK media interest



Y12 criticality accident

Dynamics over the first 30 seconds

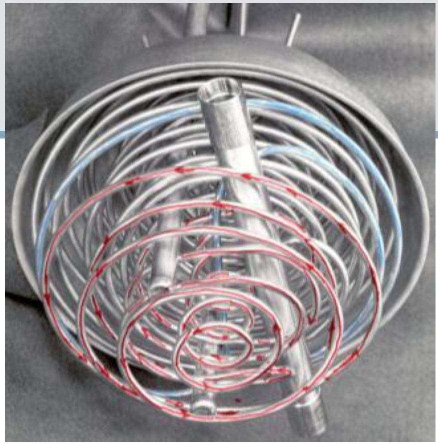




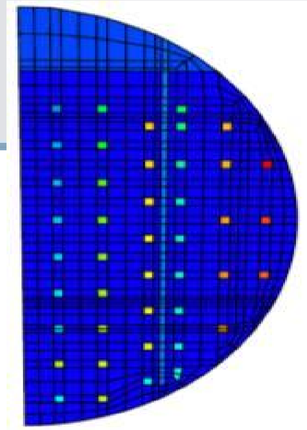
Volume Fraction of the gas(blue) and liquid (red) phase

Solution Temperature

SUPO simulation

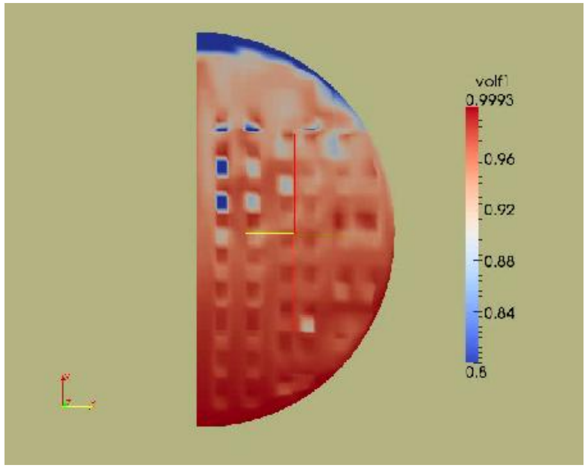


SUPO with half shell removed

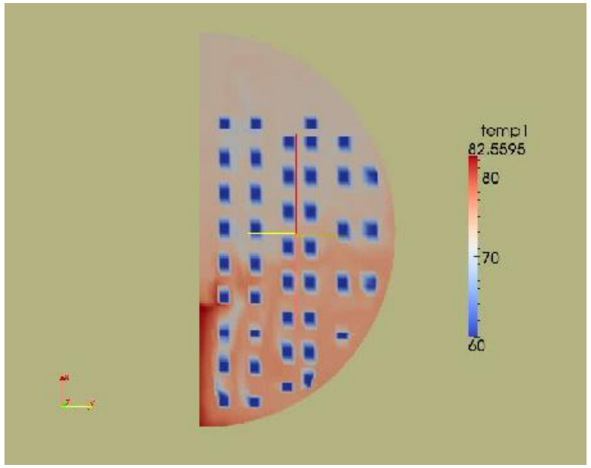


SUPO modelled in axisymmetric geometry

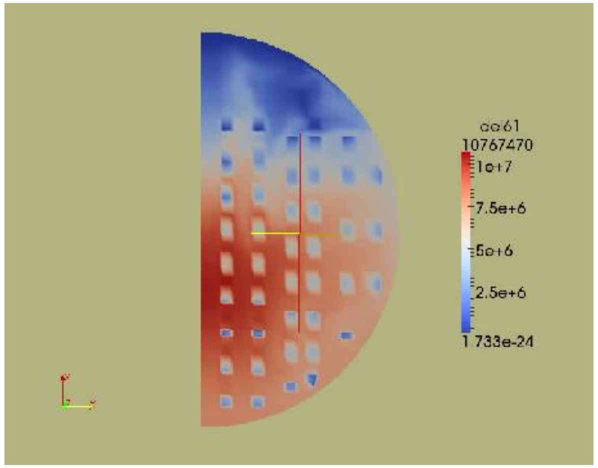
- Spherical; ~1 ft in diameter
- Contains an enriched uranium solution
- Cooled using three 20 ft long cooling coils submerged into the solution
- Contains other internal components that will affect fluid flow patterns.



Volume Fraction of the gas(blue) and liquid (red) phase

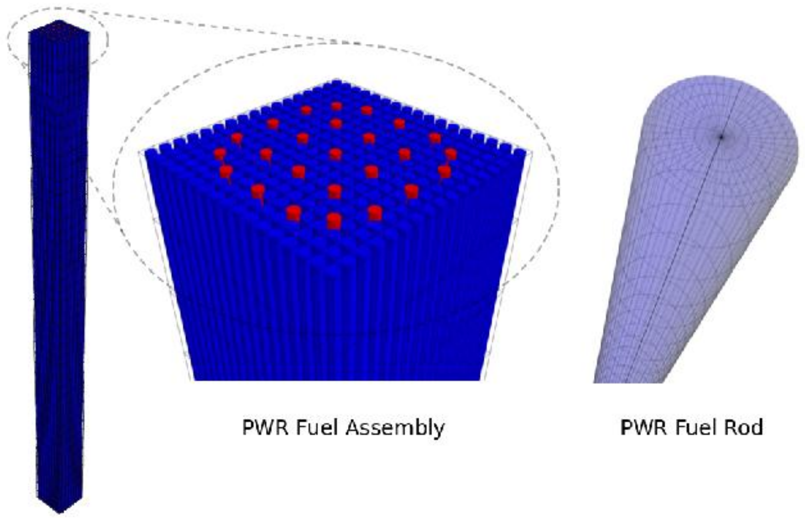


Solution Temperature

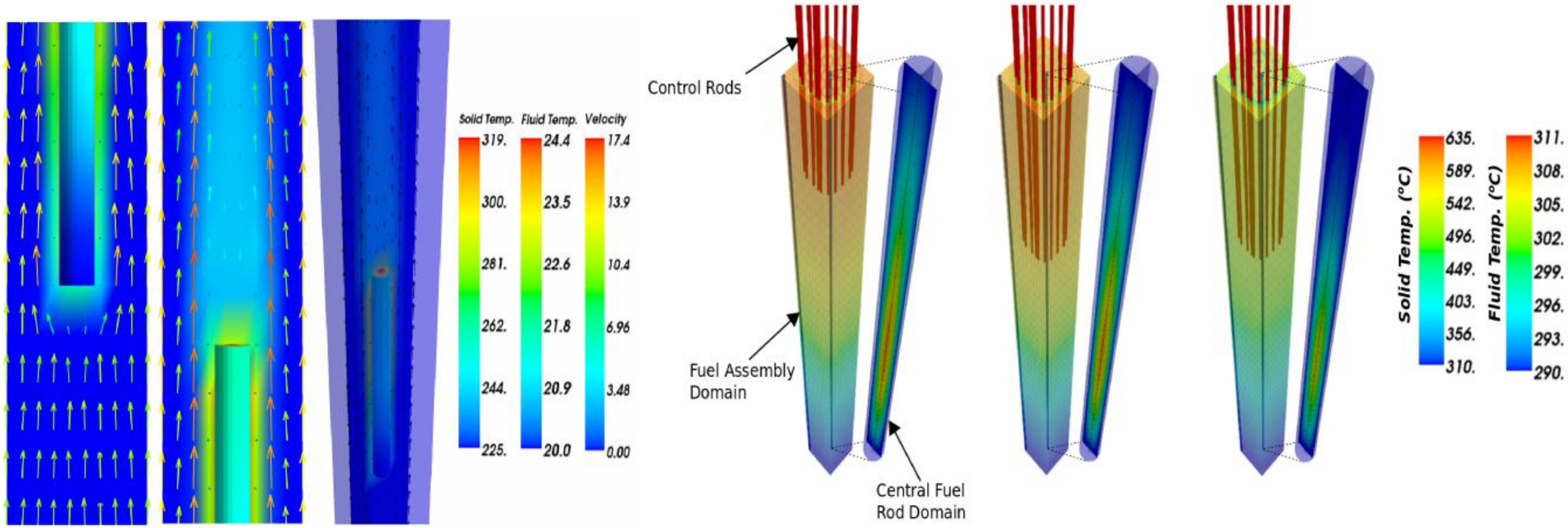


Power Distribution

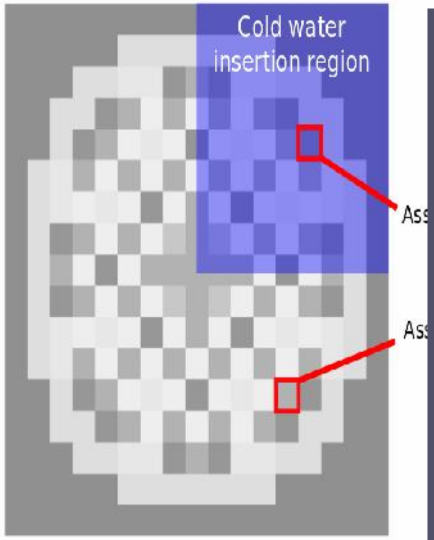
Modelling of PWR assemblies

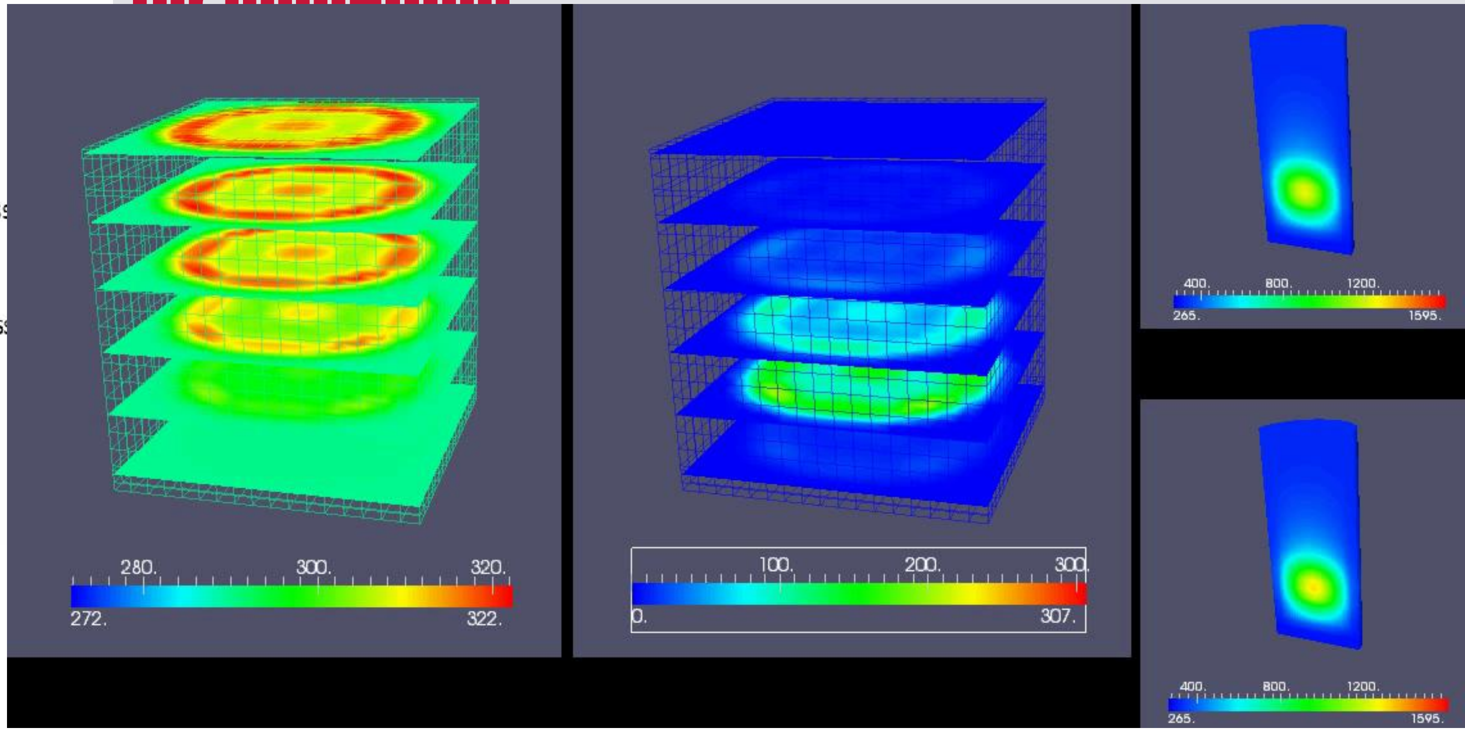


- 17x17 fuel pin assembly with moving control rods and coolant flow.
- Heat generation and diffusion within solid pins modelled.
- Displacement of fluid around the pins and transfer of heat to the coolant is simulated.
- We are able to calculate assembly power.



Full core reactor modelling





Coolant enters the core 20 Deg. C. Cooler in one 1/4 of the core due to an excessive stream demand

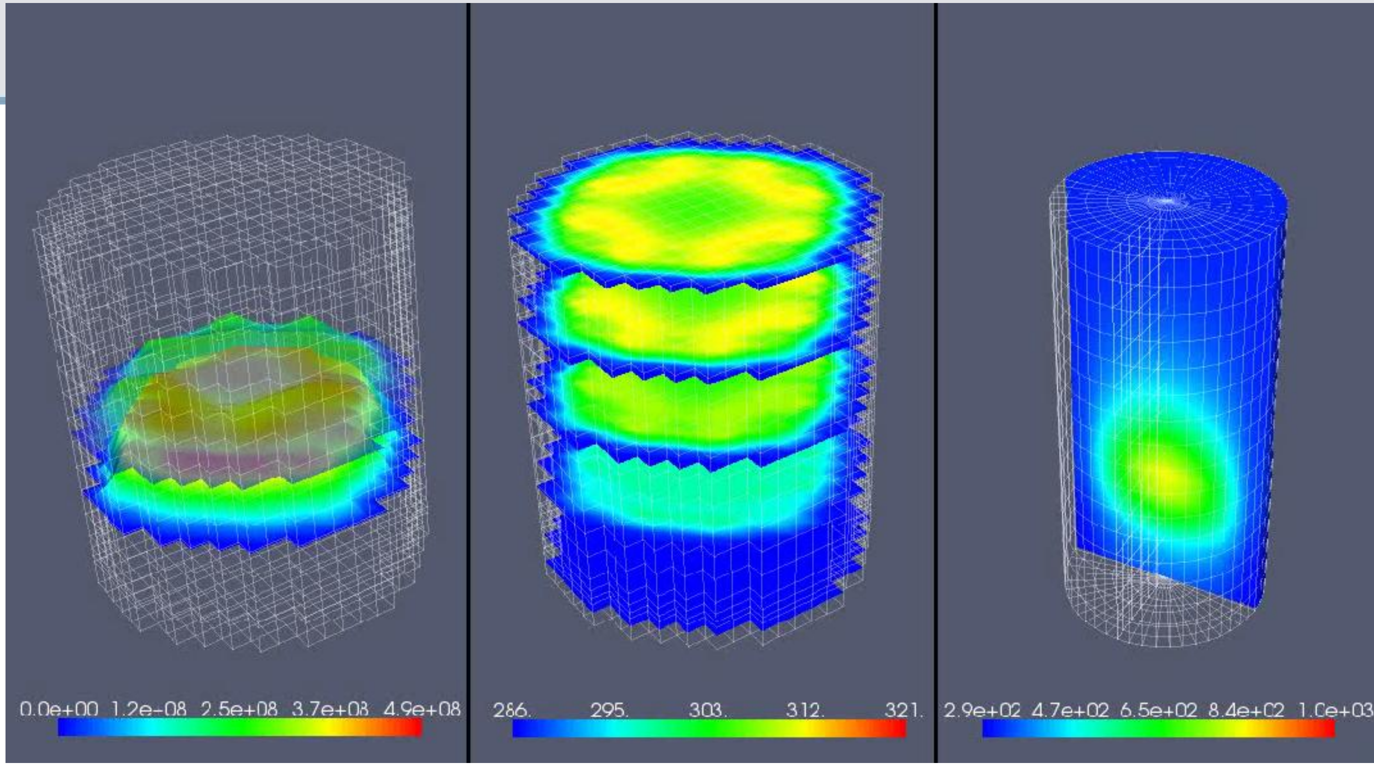
Fluid temperature

Reactor Power

Pin temperatur

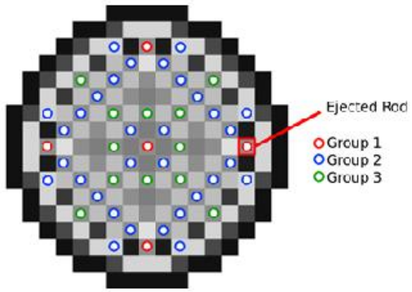
These technologies have been extended further to model full PWR cores.
Here an asymmetric core perturbation is simulated where ¼ of the core experiences a colder cooling water at it inlet.

Full core reactor modelling



power Coolant temperature Pin temperature

Here another PWR core is simulated initially from an intended operational state. In this simulation the effects o sudden control rod ejection is studied.



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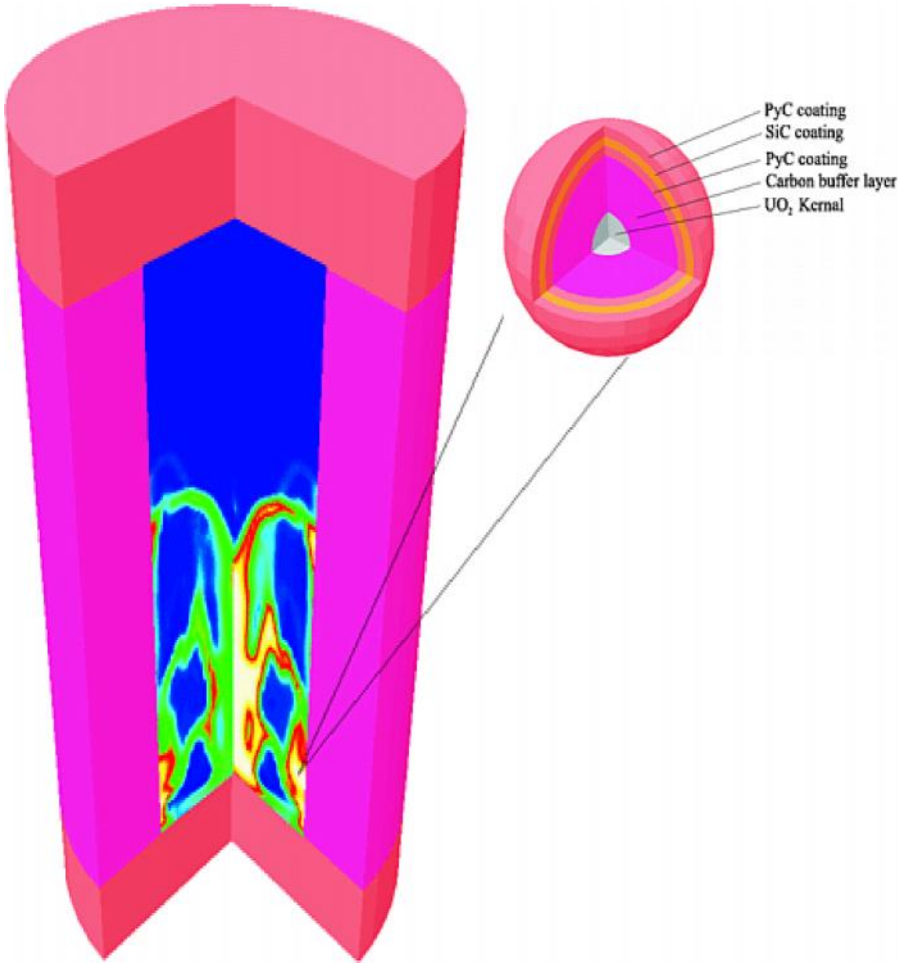
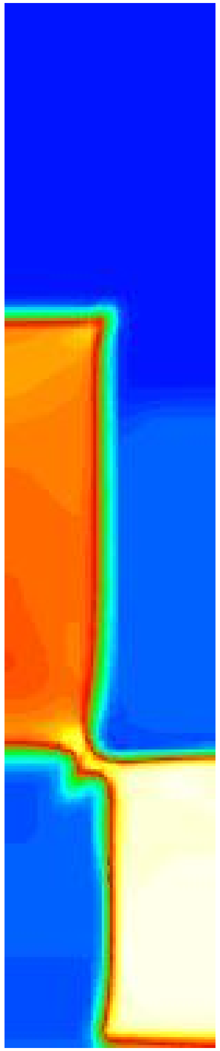
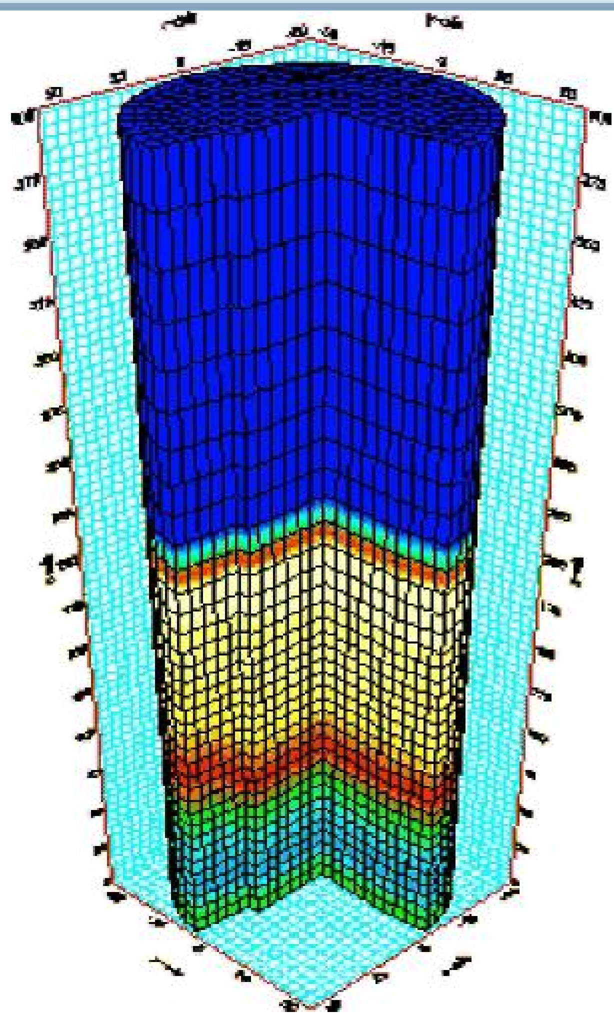
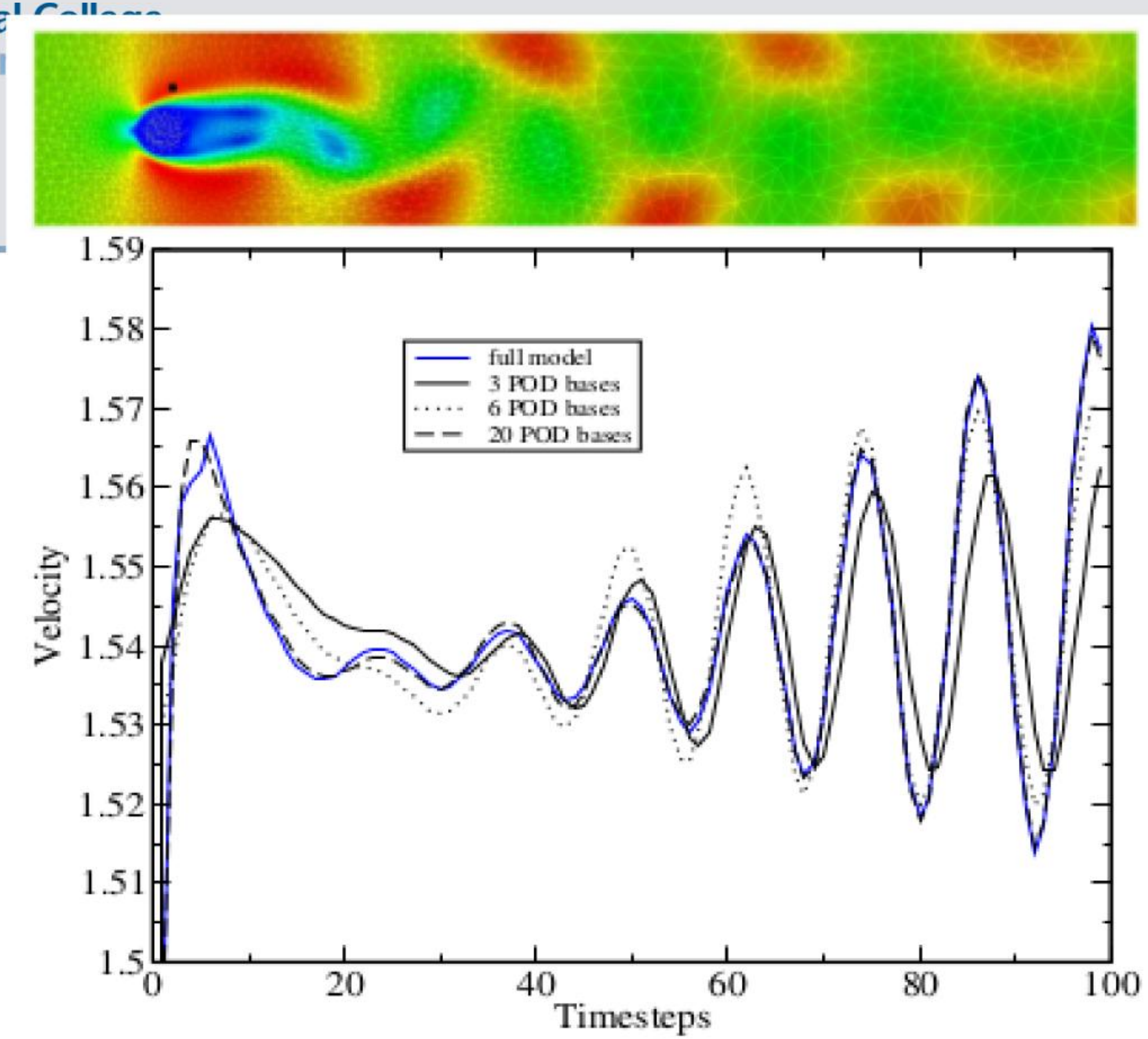
Coupled Multiphase Flow and Neutron-Radiation Transport Model: Conceptual Nuclear Fluidised Bed Reactor





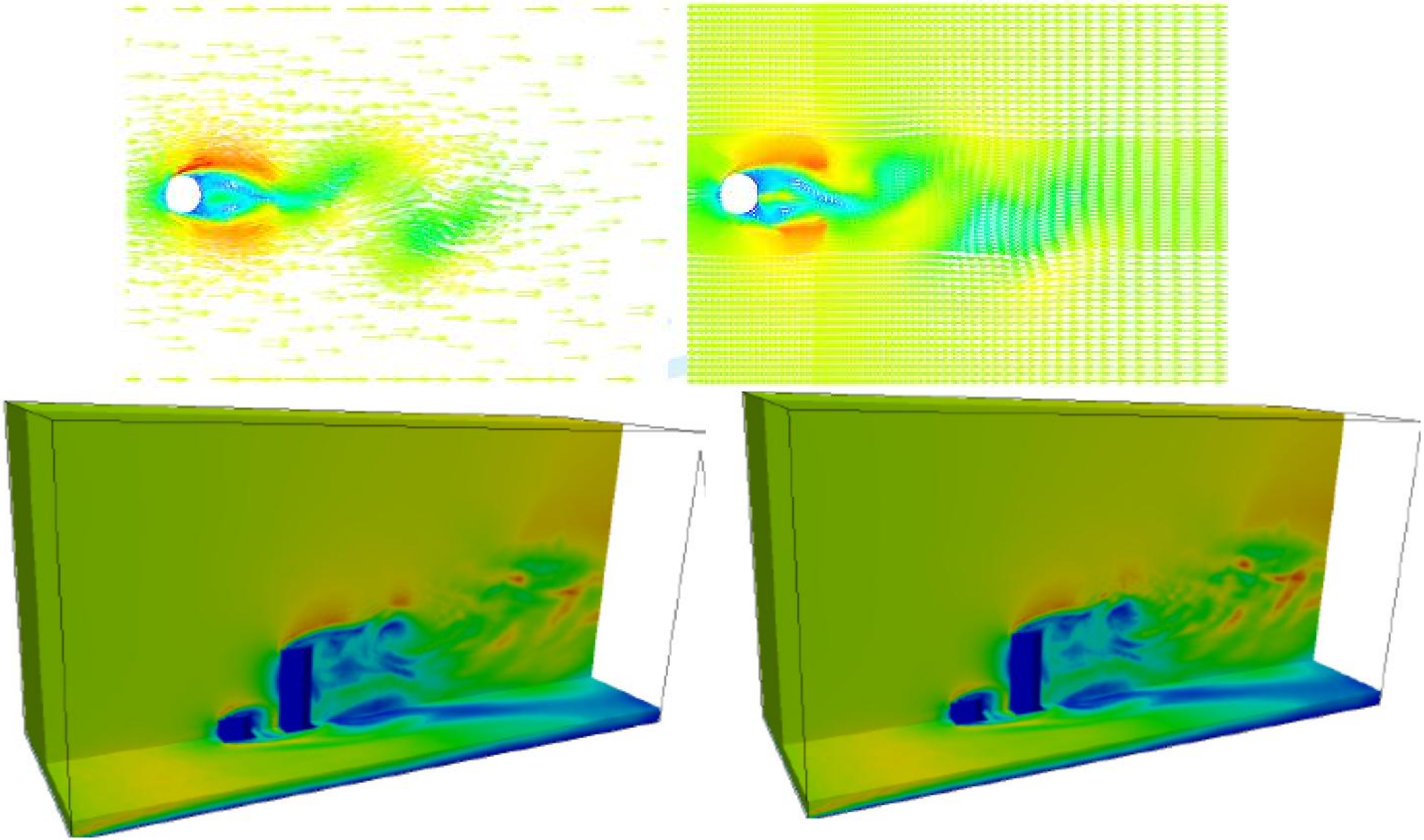




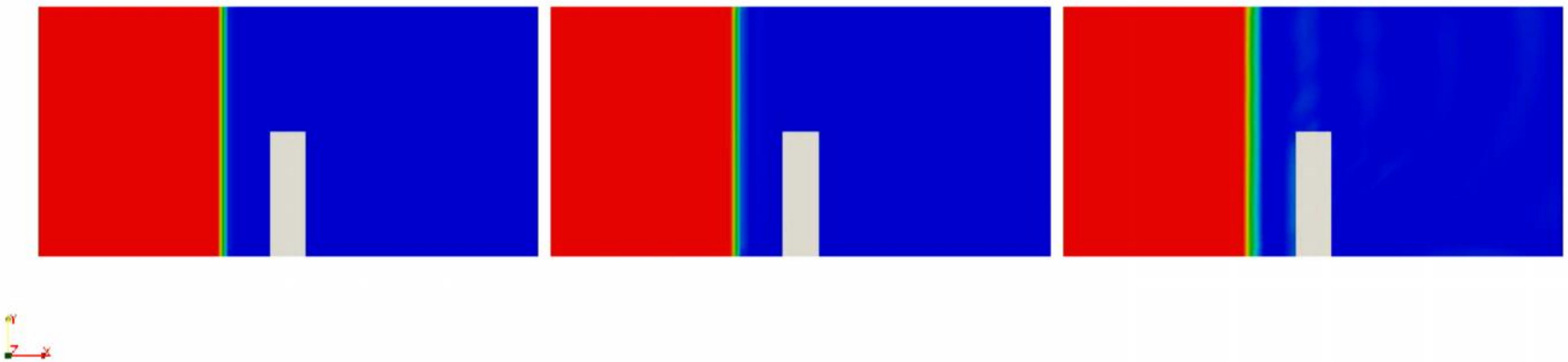
Velocity solution from high fidelity model and FSI NIROM using 3, 6 and 20 POD bases at point (x=0.27543, y=0.29336)

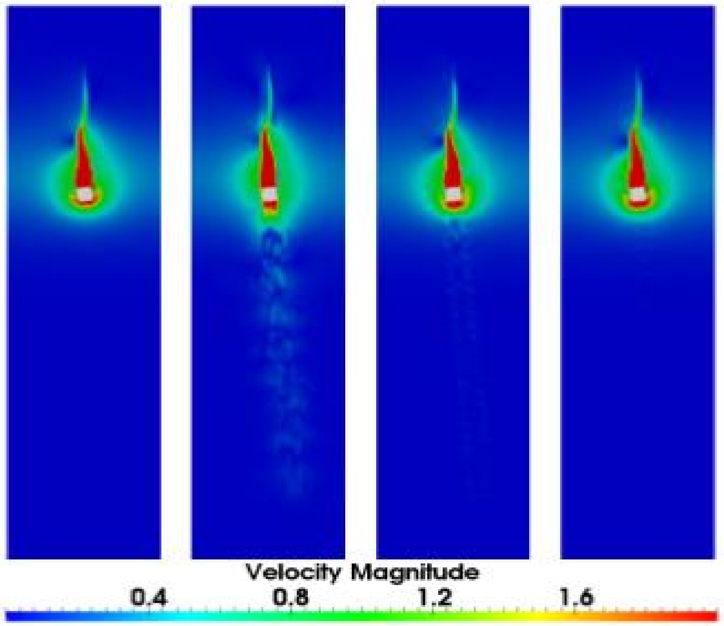
Reduced order model - Nonintrusive

Full model and ROM : flow past cylinder, flow past 2 buildings

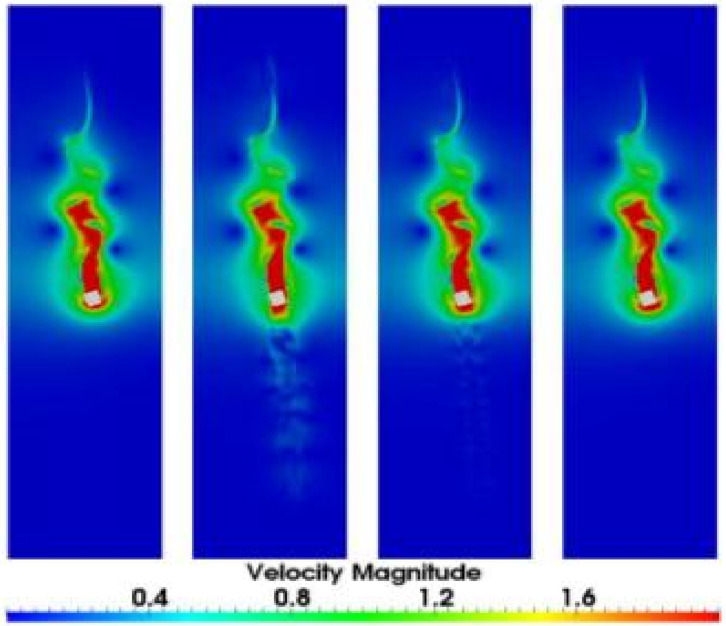


Left: Full model, Middle: 30 POD bases, Right:12 POD bases

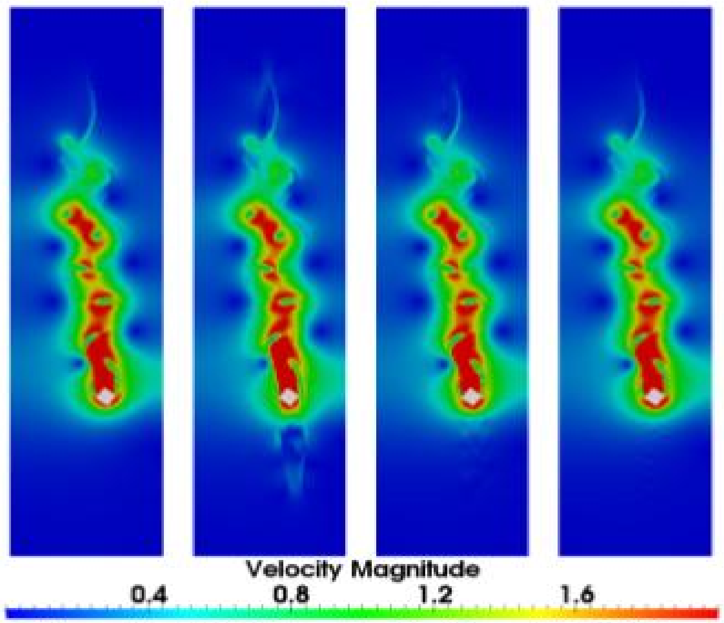




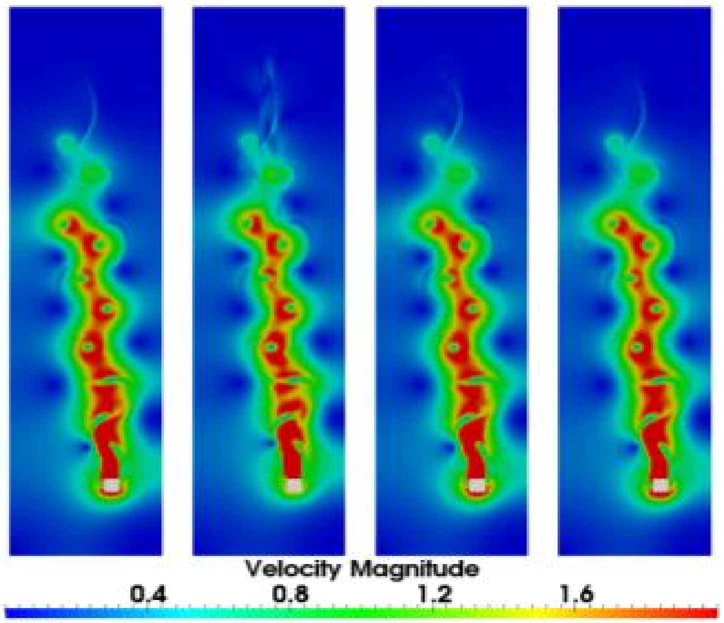
(a) Full model, NIROM with 12, 36 and 72 POD, $t = 1.0$



(b) Full model, NIROM with 12, 36 and 72 POD, $t = 1.5$



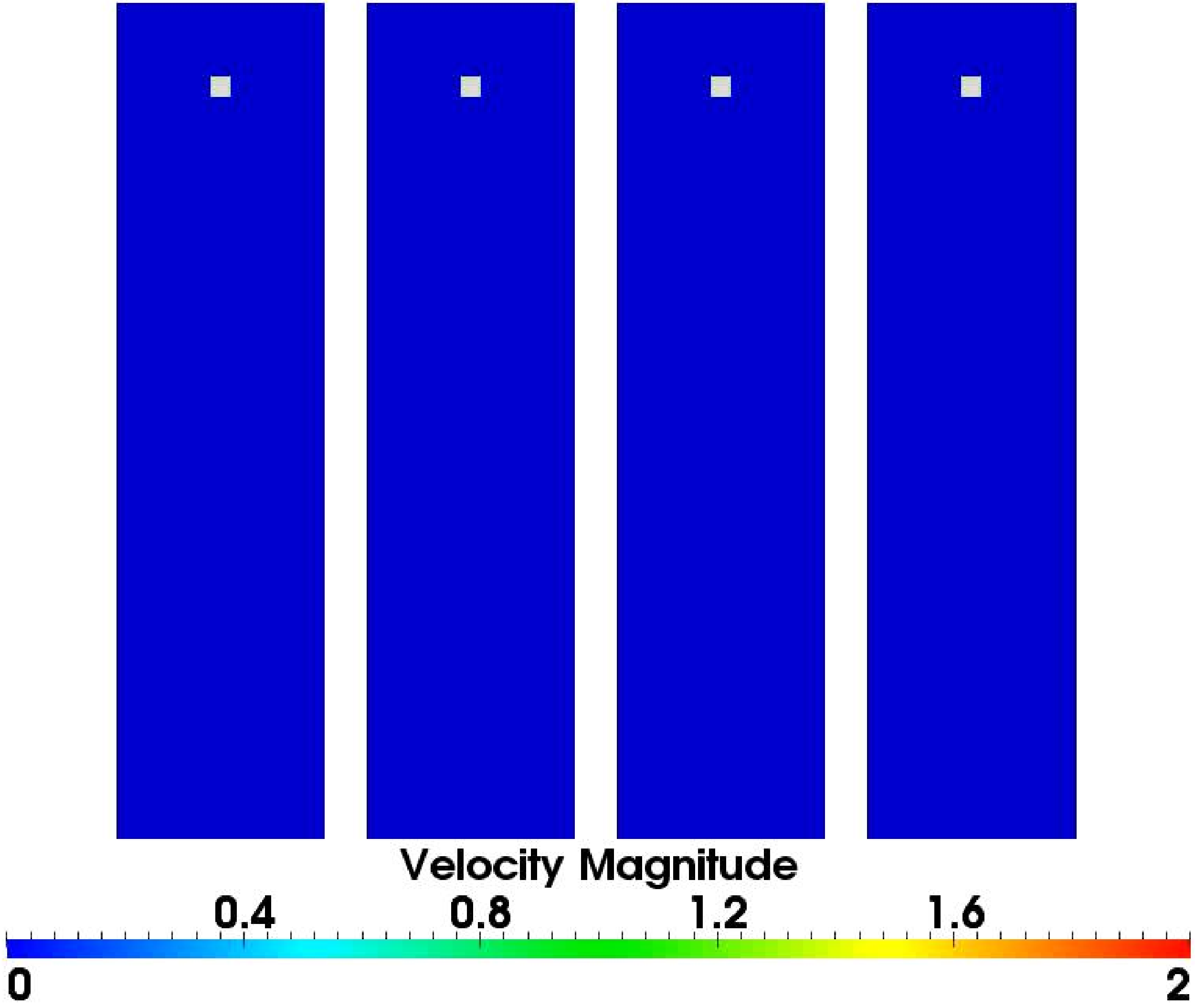
(c) Full model, NIROM with 12, 36 and 72 POD, $t = 2.0$



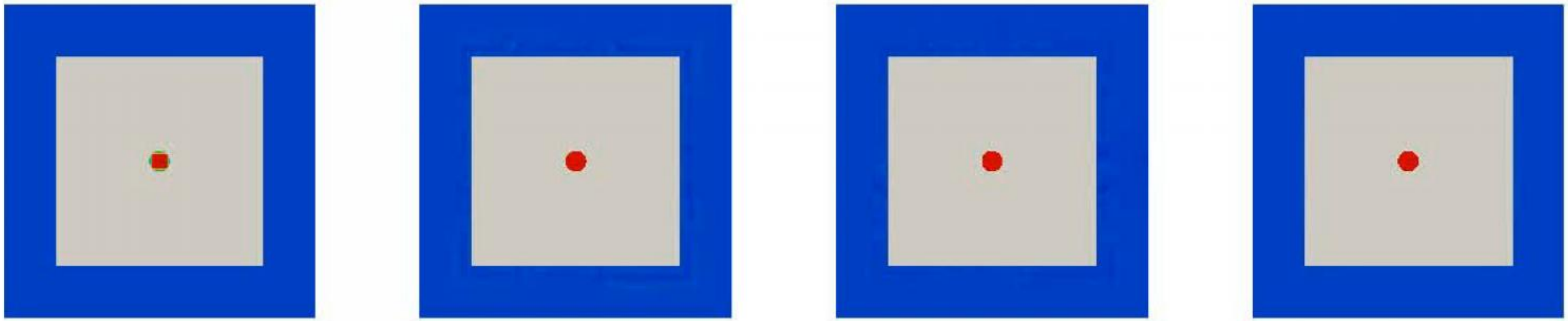
(d) Full model, NIROM with 12, 36 and 72 POD, $t = 2.5$

Funded by Janet Watson PhD scholarship at ESE, Imperial college.

Full, NIROM with 12, 36 and 72 POD bases



Full model, NIROM with 6, 12 and 50 POD bases.



Time analysis

The simulations were performed on 12 cores machine of an Intel(R) Xeon(R) X5680 processor with 3.3GHz and 48GB RAM.
The test cases were run in serial, which means only one core was used when simulating

Table 1: Comparison of the online CPU time (dimensionless) required for running the full model and POD-RBF ROMs during one time step.

Cases	Model	assembling and solving	projection	interpolation	total
bending beam	Full model	4.95120	0	0	4.95120
	NIROM	0	0.0003	0.0001	0.00040
blasting	Full model	224.47059	0	0	224.47059
	NIROM	0	0.0003	0.0001	0.00040

Speedup: 561,175, five orders of magnitude.

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Conclusions

- Multi-physics solids/fluids/radiation coupling aided by multi-scale/adaptive resolution

- Goal based error measures for mesh adaptivity

- Future directions: reduced modelling, uncertainty, linking models with observations and experiments