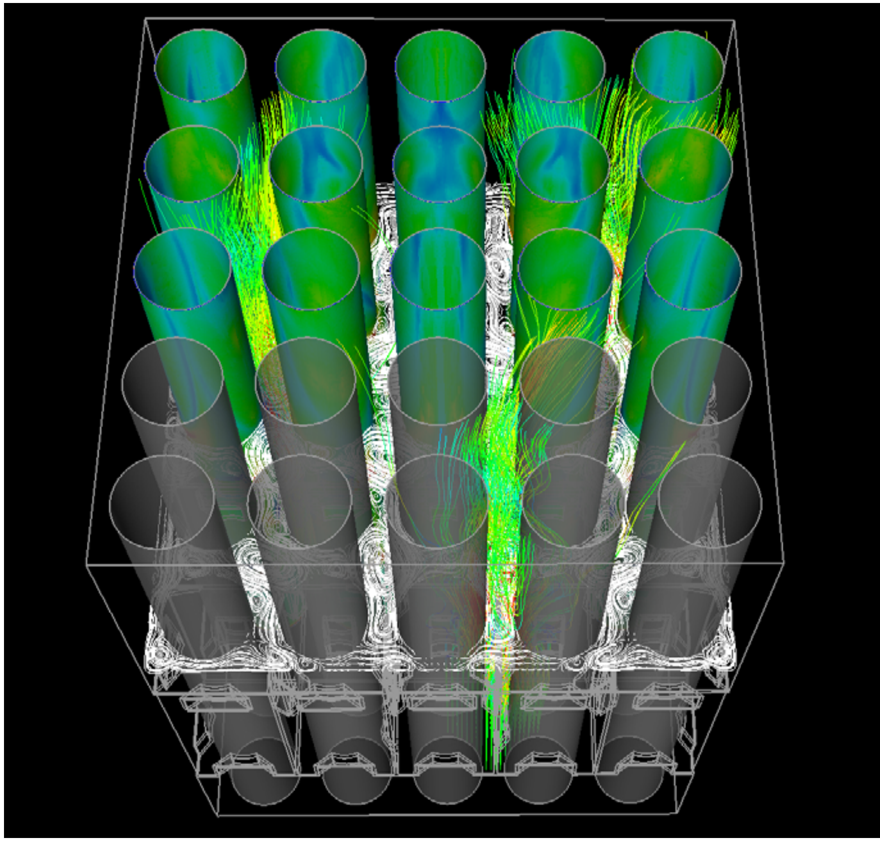


Numerical methodology for the study of a fluid flow through a mixing grid

Contributors:

J. Bonelle, Y. Fournier, F. Jusserand (R&D/MFEE), S.Ploix (R&D/SINETICS), L. Maas (INCKA), B. Quach (SOGETI)

Contents

- Industrial background :
  - Better understanding of fuel assemblies
- Numerical approach :
  - A numerical methodology overcoming experimental limits.
- First calculations :
  - Generation of hexahedral meshes and CFD calculations.
  - Improvement of numerical tools for HPC calculations on industrial grid configurations
- Visualization
  - Tool’s performance and functions
  - FSI needs

Industrial background:
Study of fuel assemblies

Better understanding of the mechanical and vibratory behaviour of the fuel assemblies inside the core vessel :

- Stretch of core vessels' operation campaign durations
- Multiple assembly suppliers: mixed cores
- Ultimate goal: prediction of rods' vibration induced fatigue: « fretting » phenomena

Function :

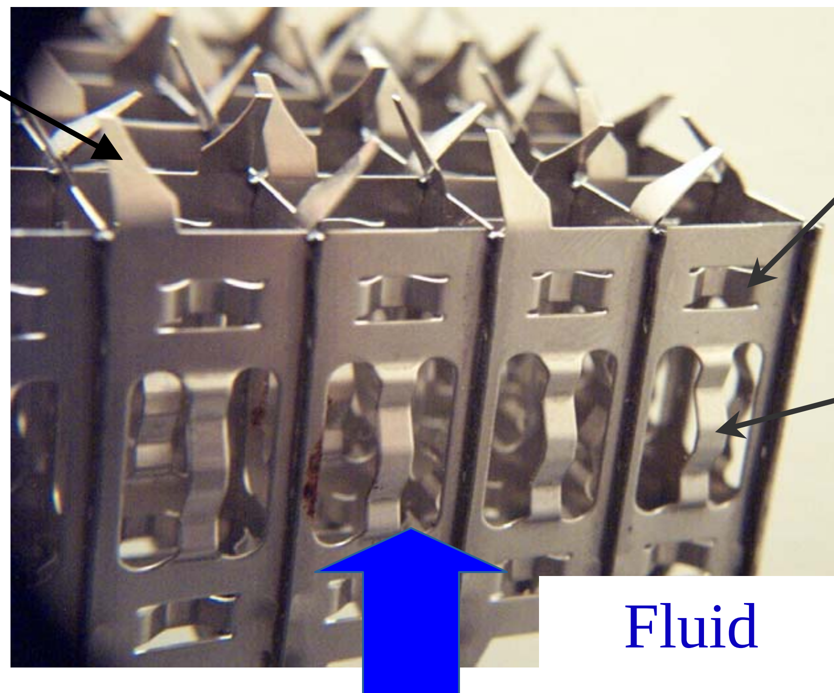
- Fuel rods are held in place by mixing grids
- Improvement of heat exchange and homogenization of coolant fluid's temperature

Vane

(ailette de re-circulation)

Dimple (bossette)

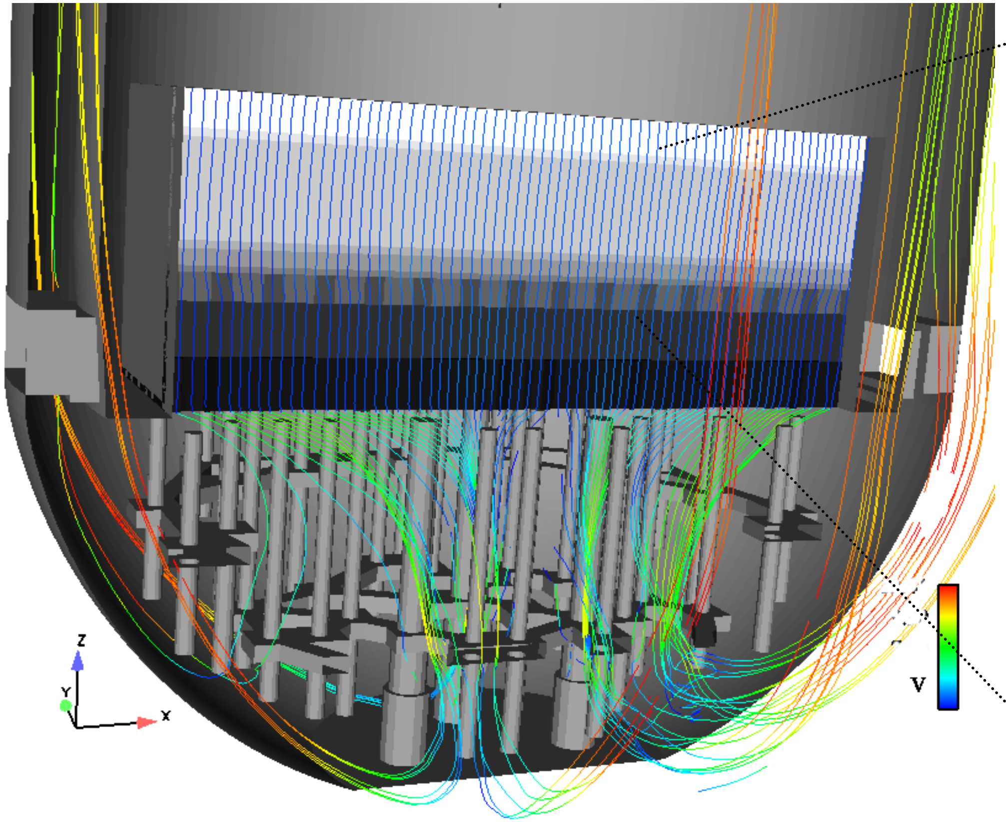
Spring (ressort)



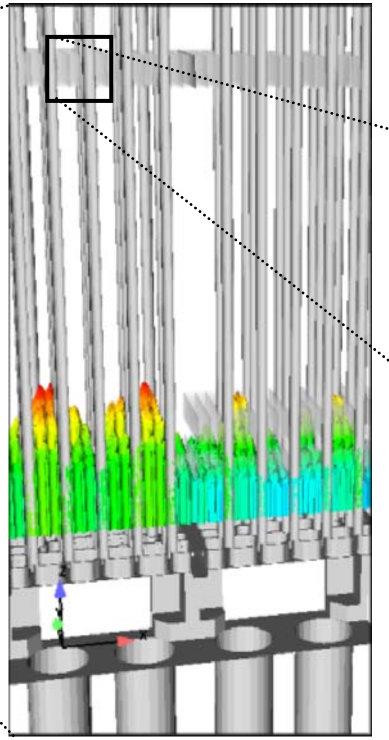
5x5 Mixing grid prototype based on AFA-XL design

A specific design for each type of mixing grid

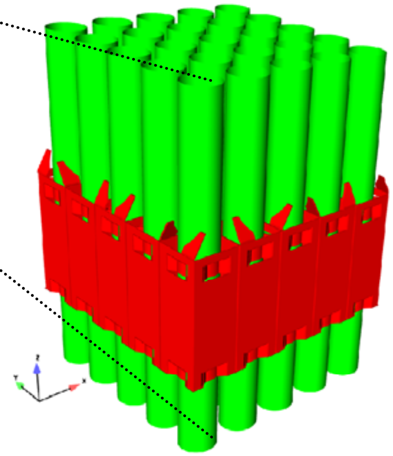
Numerical methodology



Lower part of 1300 MW core vessel



2 assemblies



Mixing grid

193 assemblies in a 1300 MW core vessel; 17*17 fuel rods per assembly held in place by 10 mixing grids

Numerical methodology : Chaining of CFD and Mechanical Calculations

CFD calculation
(*Code_Saturne®*)

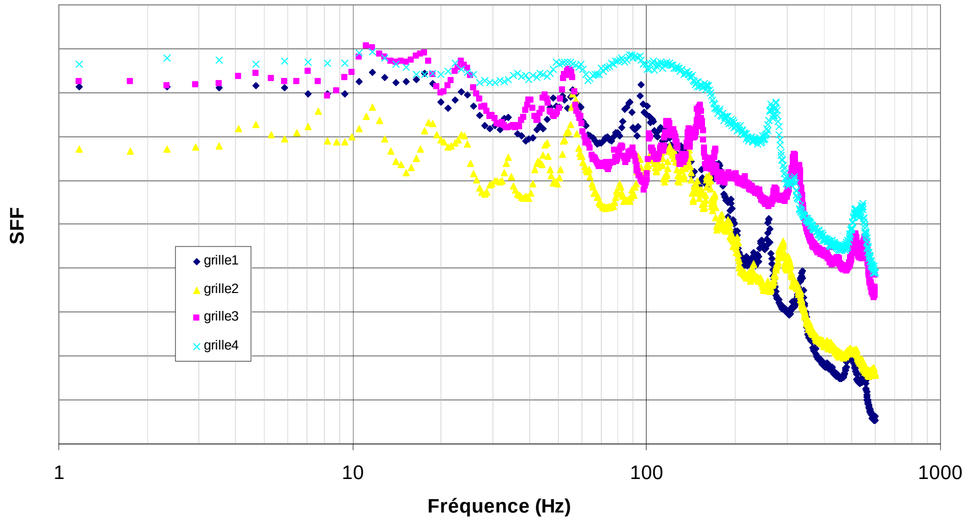
Mechanical modelisation

(*Code_Aster®*)

Vibratory behaviour

Forces acting on the fuel rods

Fluctuating excitations' spectra



Derivation of fluid spectra

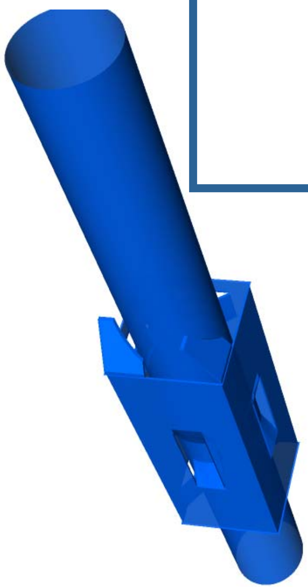
CFD methodology : A step by step approach

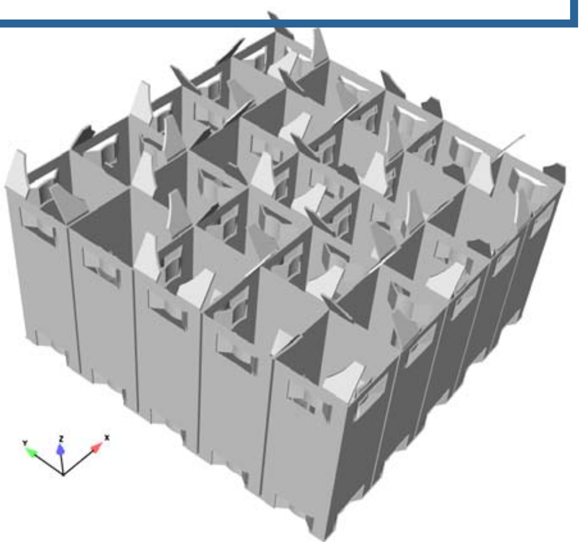
Elementary cases (tuning):

- Hexahedral meshes generation
- Sensitivity analysis (numerical options, turbulence models…)
- Derivation of fluid spectra

HPC prelimimary calculations:

- Improvement of numerical tools for large industrial configuration models



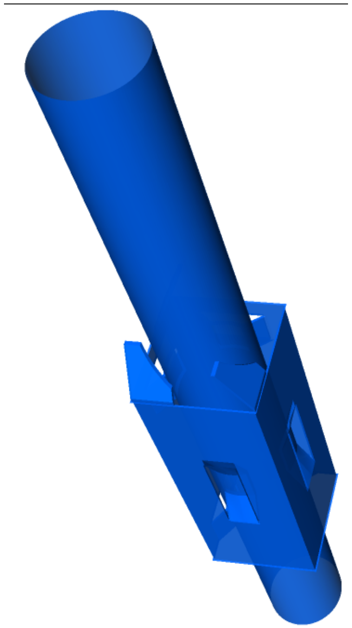


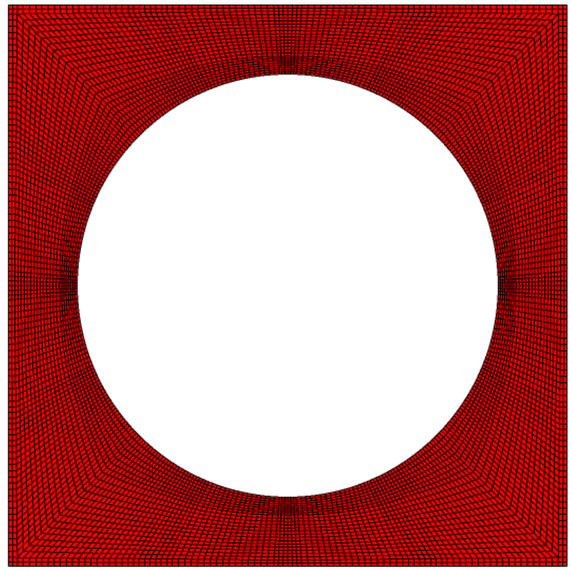
Real case complete study

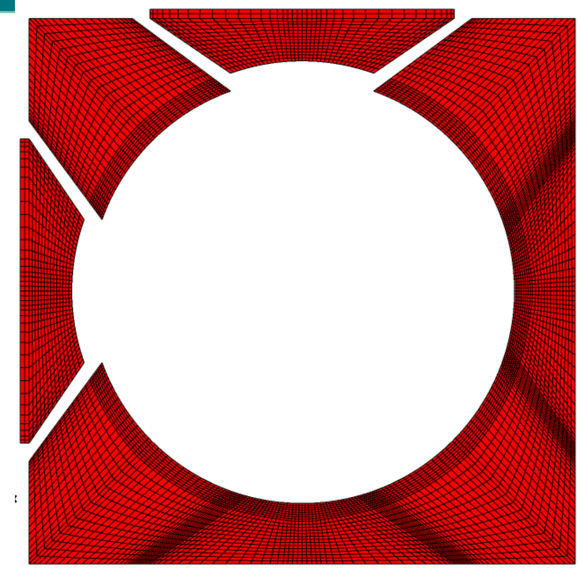
CFD methodology :
Hexahedral meshes generation

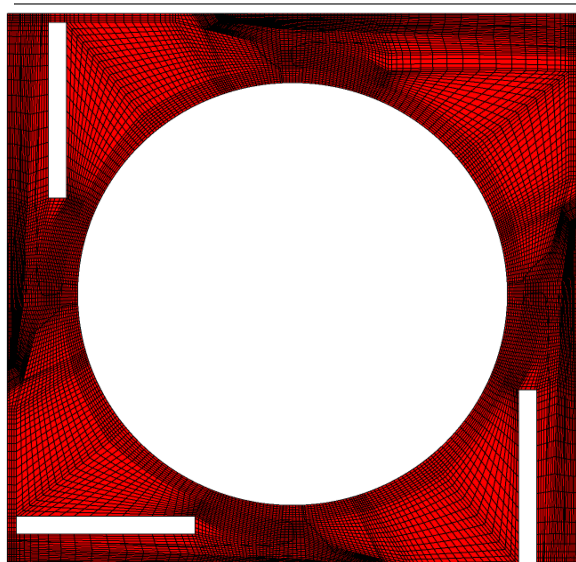
- Prototype grid : 5x5 AFA – XL
- Tests of different meshing tools:
    - SIMAIL
    - PAL-SALOME: GEOM and SMESH
    - GAMBIT
    - HARPOON
    - ICEM

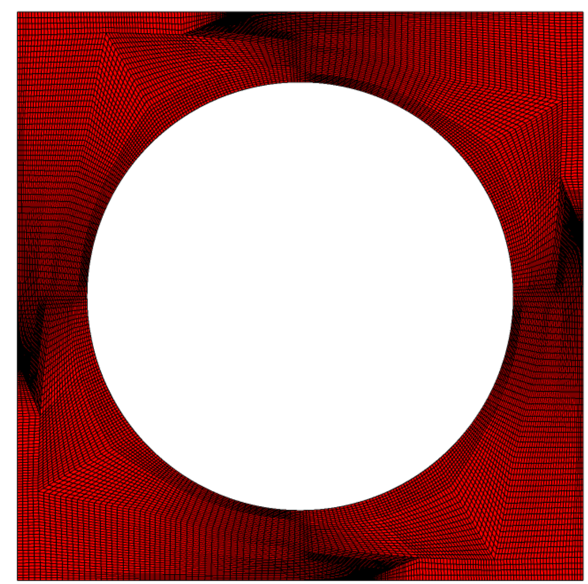
CFD Methodology : Hexahedral meshes generation



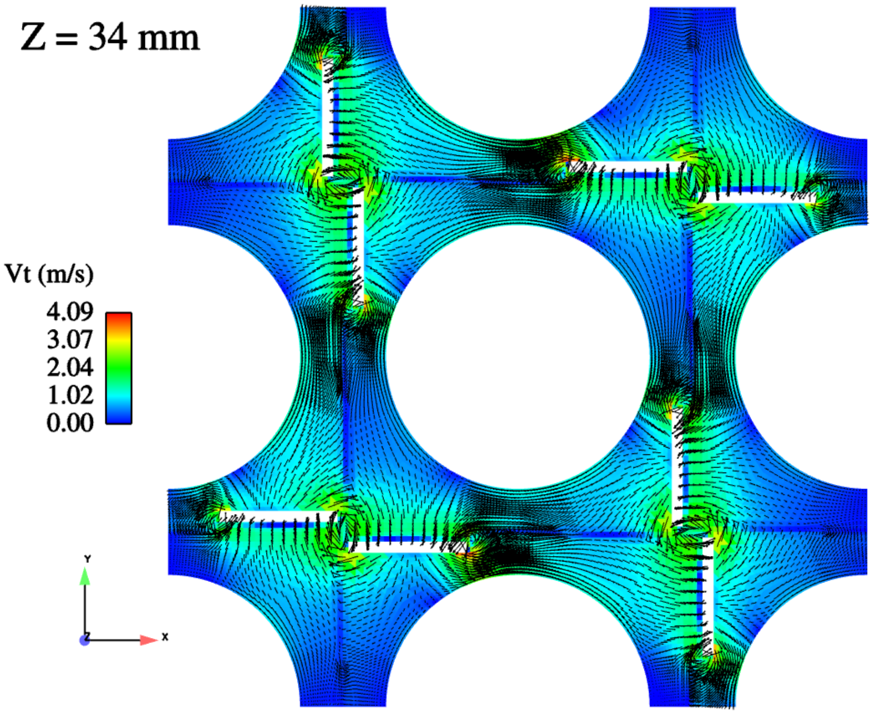


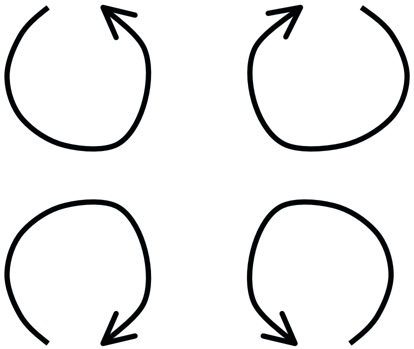


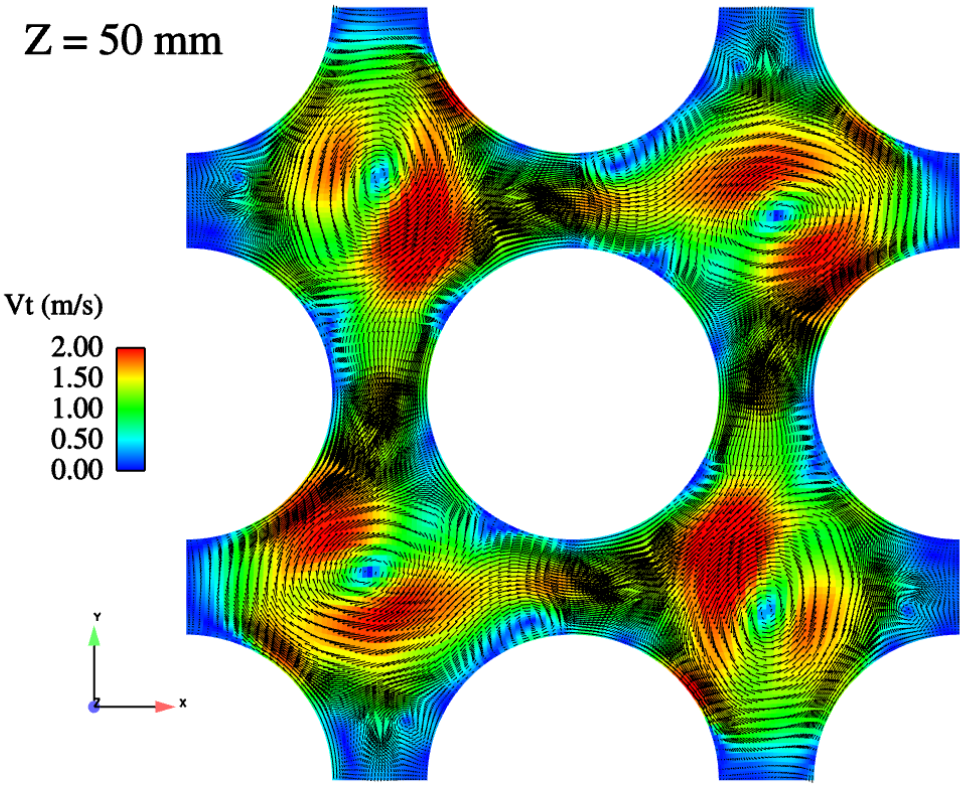




CFD Methodology :
First calculations on an elementary configuration



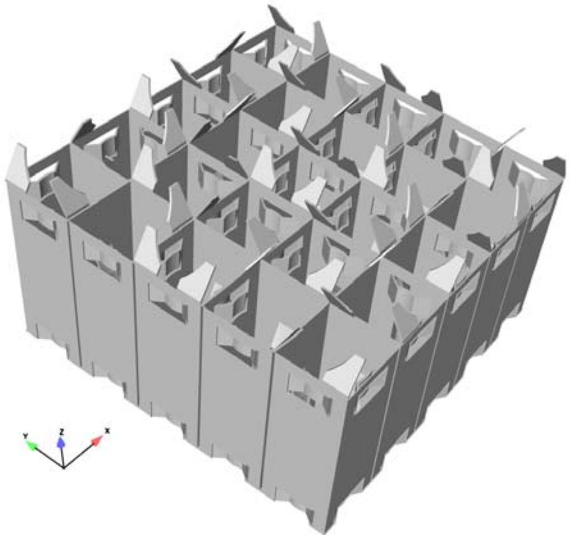


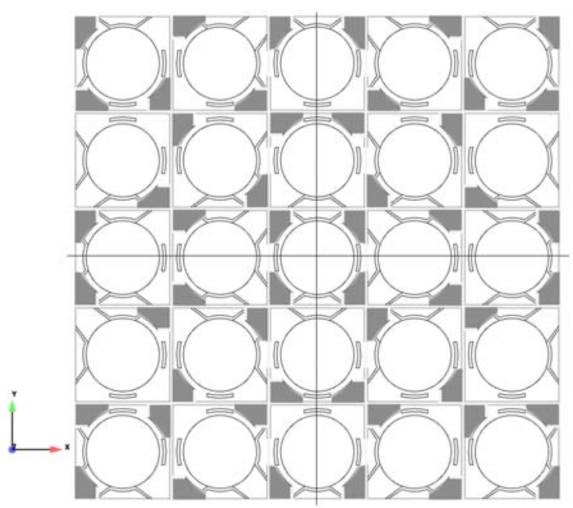


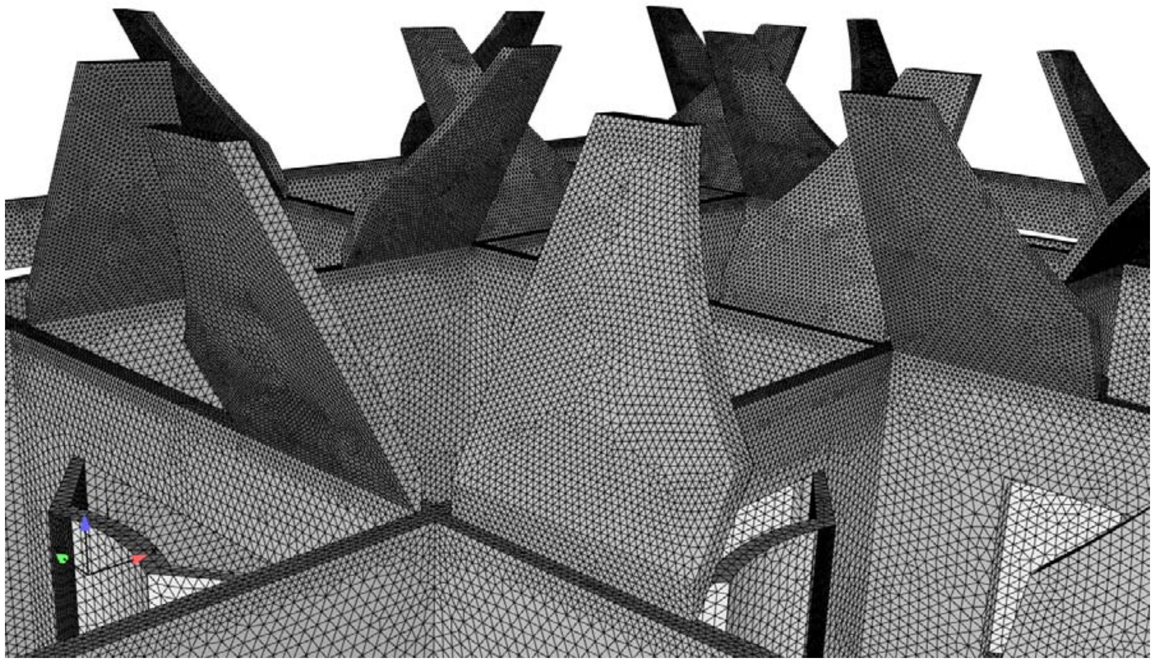
CFD Methodology : Improvement for HPC industrial configurations

- Prototype grid: 5x5 AFA – XL
- Tetrahedral mesh:
  - 100 M tetrahedra (~ 30 M Hexahedra)
- U-RANS approach: k – epsilon turbulence model
- 15 000 iterations
- Time step: 1. e-06 – 1. e-05
- Scalable wall function (IDEUCH = 2) great refinement
- Gradient reconstruction
  - Iterative reconstruction of the non-orthogonalities: IMRGRA = 0
  - Least squares method (partial neighborhood): IMRGRA = 3

CFD Methodology : Improvement for HPC industrial configurations



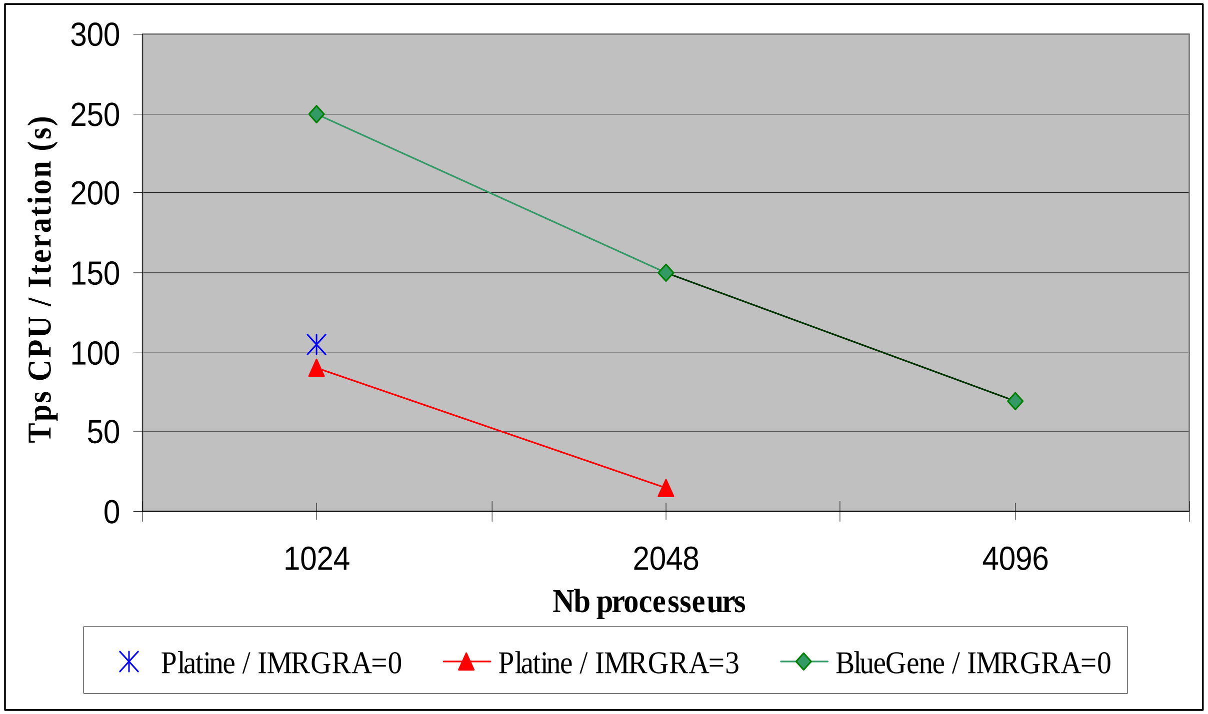




100 M Tetrahedra

CFD Methodology : Improvement for HPC industrial configurations

- Tests of *Code_Saturne®*'s preprocessor and kernel
- Performance results



Machine	BlueGene			Platine		
Number of processors	1024	2048	4096	1024	1024	2048
Number of cells per processor	99250	49650	24750	99250	99250	49650
IMRGRA	0	0	0	0	3	3
CPU time per iteration (s)	250	150	69	105	90	15

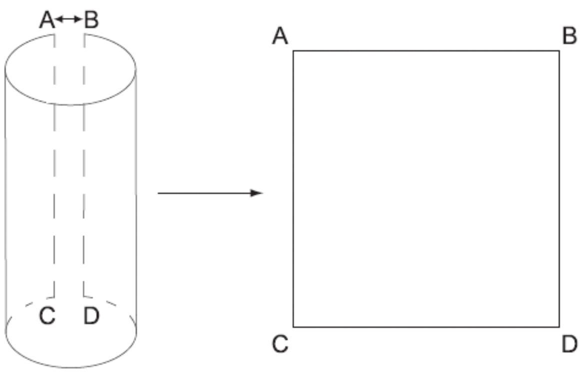
Conclusions

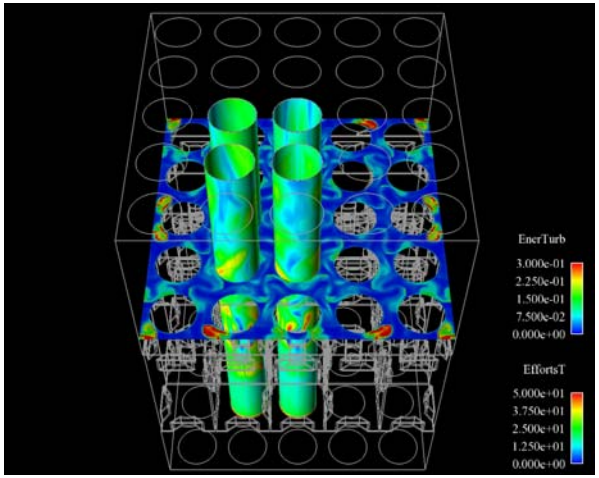
- Numerical tools have been improved for High Performance Calculations

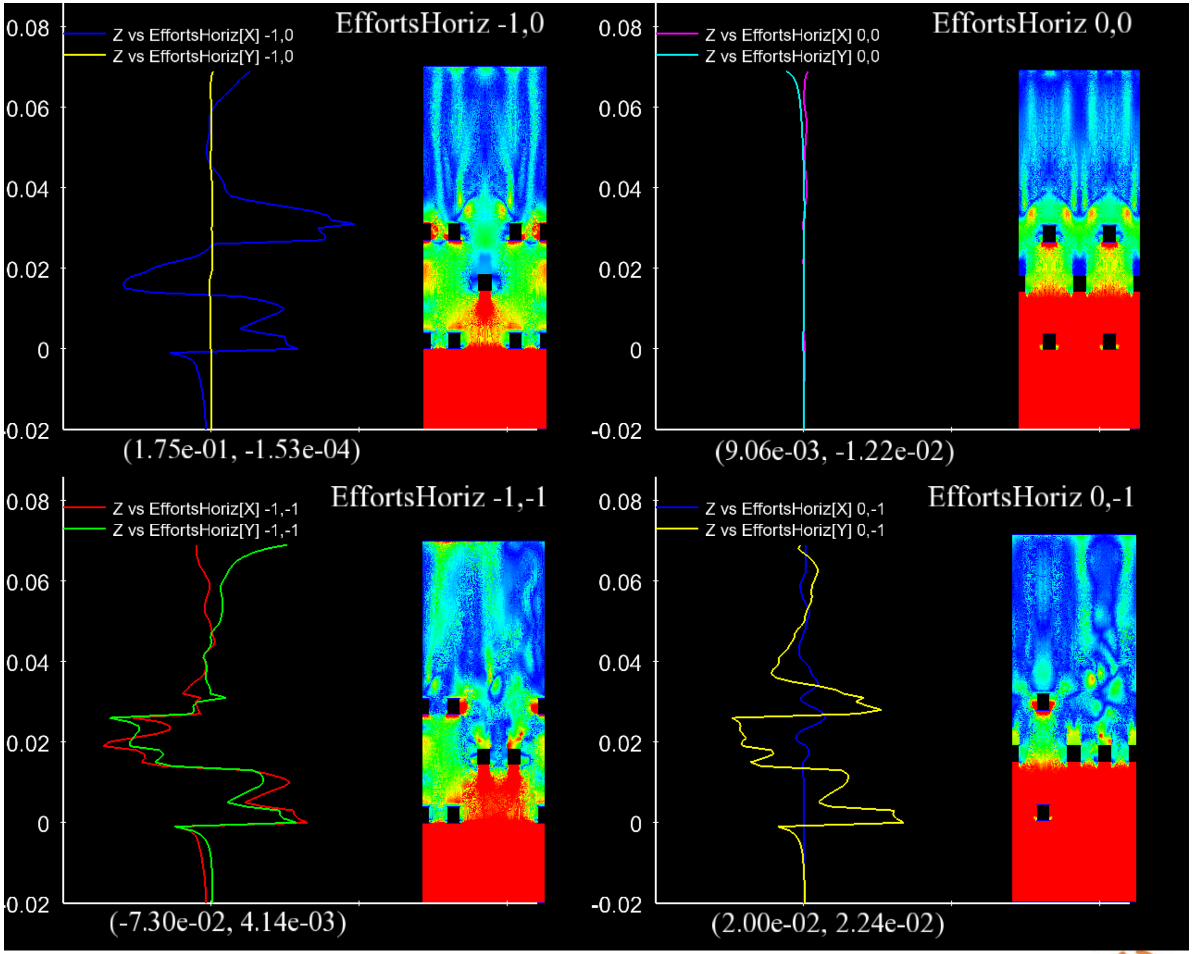
- Elementary calculations:

  - Generation of mixing grid’s hexahedral meshes
  - Start of thermo-hydraulic sensitivity analysis
  - Numerical derivation of fluid spectra: first investigations

CFD Methodology:
FSI needs





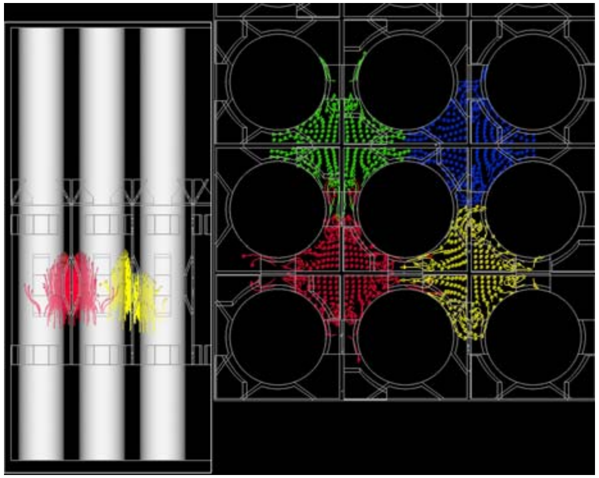


Visualization for Cachemire’07 case

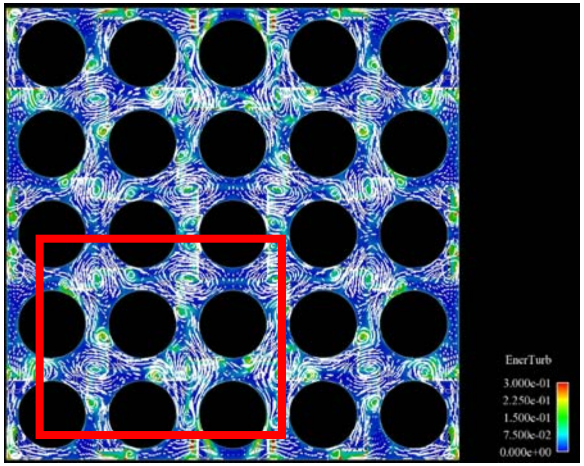
A few figures

- SMP machine with 32 Gbytes of RAM
- Mesh = 8 Gb RAM
- Each field = 2 Gb RAM
- 2 scalar + 3 vector fields → Σ = 30 Gb of RAM
- Data size on the domain skin at each step = 75 Mb

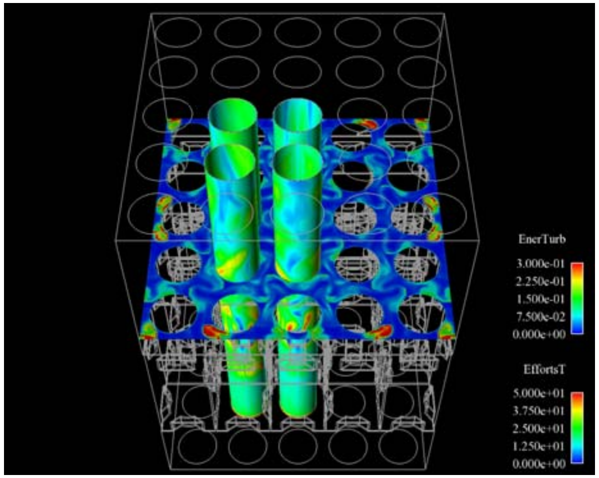
Visualization for Cachemire'07 case



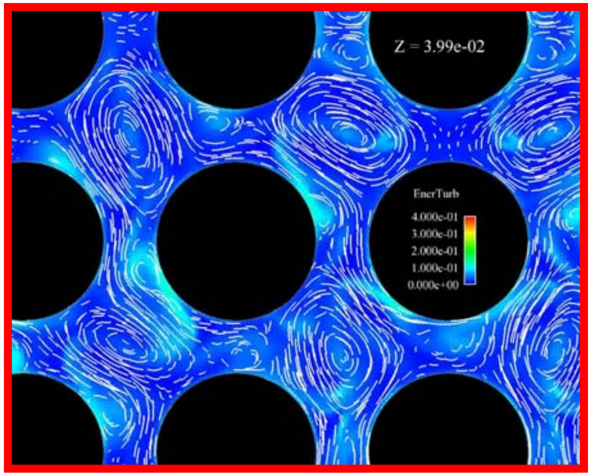
A. Mixing the fluid



C. Traversal structure of the flow

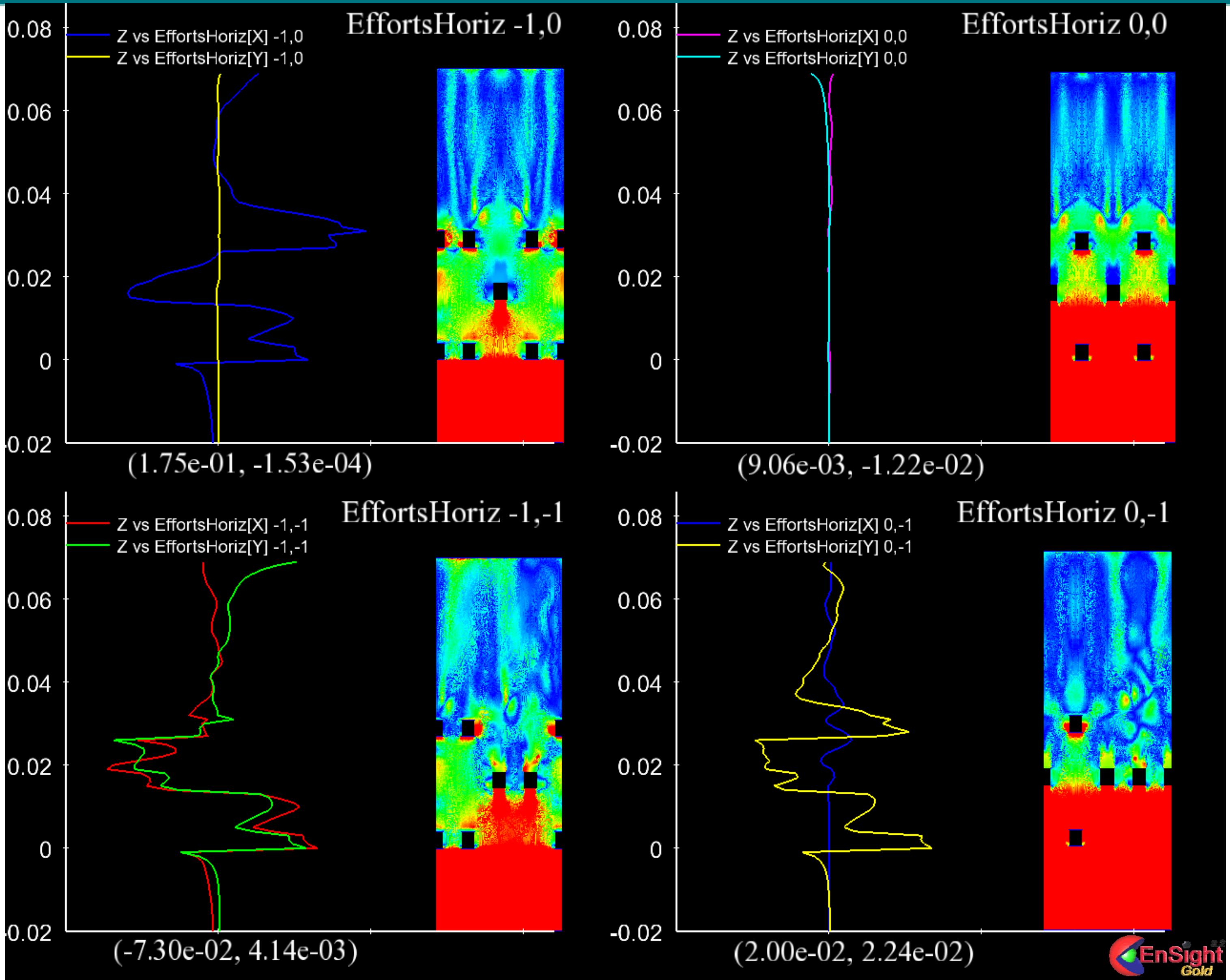


B. Introducing the cutting plane



D. Zoom on 3*3 rods

Horizontal stress variation on developed fuel rods



What is interactive?

Interactive visual exploration

- 3D navigation, Scalar maps

Semi-interactive (<1min)

- Iso-surface, cut-planes, developed rod, create some streamlines

During coffee break (1-5 min)

- Animation of a cutting plane or iso-surface
- Create streamlines on the whole volume
- Compute secondary fields

Made with scripts, batch processing

- Profiles and plots
- Complex animations

Roadmap

Today	Tomorrow	Later On
5*5 grid	17*17 grid	Full core vessel : • 17*17 grids • 10 grids per assembly • 196 assemblies
100 million tetrahedra	220 million hexahedra	300 billion hexahedra
Volume data (full analysis): 4 Gb on disk → **30 Gb RAM** Skin data (rod interaction only): 75 Mb on disk → **1 Gb RAM**	Volume data: 40 Gb/step=10Tb 40 Gb (1 step) → **300 Gb RAM** Skin data: 750 Mb / step = 15 Gb → **10 Gb RAM**	Volume data: 60 Tb/step=15Pb 60 Tb (1 step) → **500 Tb RAM** Skin data: 1 Tb / step = 200 Tb → **15 Tb RAM**
1 SMP machine 32 Gb RAM	**64 SMP nodes** 8 Gb / node = 512 Gb RAM	**8000 SMP nodes** 64 Gb / node = 512 Tb RAM

Extensions of the visualization service

For Tomorrow:

- Ensight Gold DR
    - Distributed on cluster
    - Polyhedron support
- Paraview with extensions
    - Polyhedrons support
    - RAM usage
    - Speed improvement
    - Improving the workflow

Extended renderings:

- Sprited particles
- Shadows
- Physiologically-inspired renderings
- parametric shaders to pilot sensitivity renderings

Acknowledgments

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C. Mouton, G. Thibault (R&D/SINETICS),