2016 *Code_Saturne* User Meeting

EDF – R&D
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RENUDA

Aero and thermal CFD studies of Reactor Buildings and Turbomachinery using SALOME and *Code_Saturne*

Contact

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Contents

1. Introduction

Introduction

- *Code_Saturne* is being used extensively by Renuda for a variety of applications :
  - Industrial R&D projects
  - Verification and validation
  - Code development
- Used as part of the open source chain SALOME – *Code_Saturne*
  - SALOME for CAD, volume meshing and post-processing
  - CFDStudy and *Code_Saturne* for model preparation and solving
- Ventilation, contaminant dispersion, combustion, mixing and filling units. Fixed and moving meshes, steady and transient physics, from PC to HPC
- This presentation focuses on an example of a reactor building study and a turbomachinery study

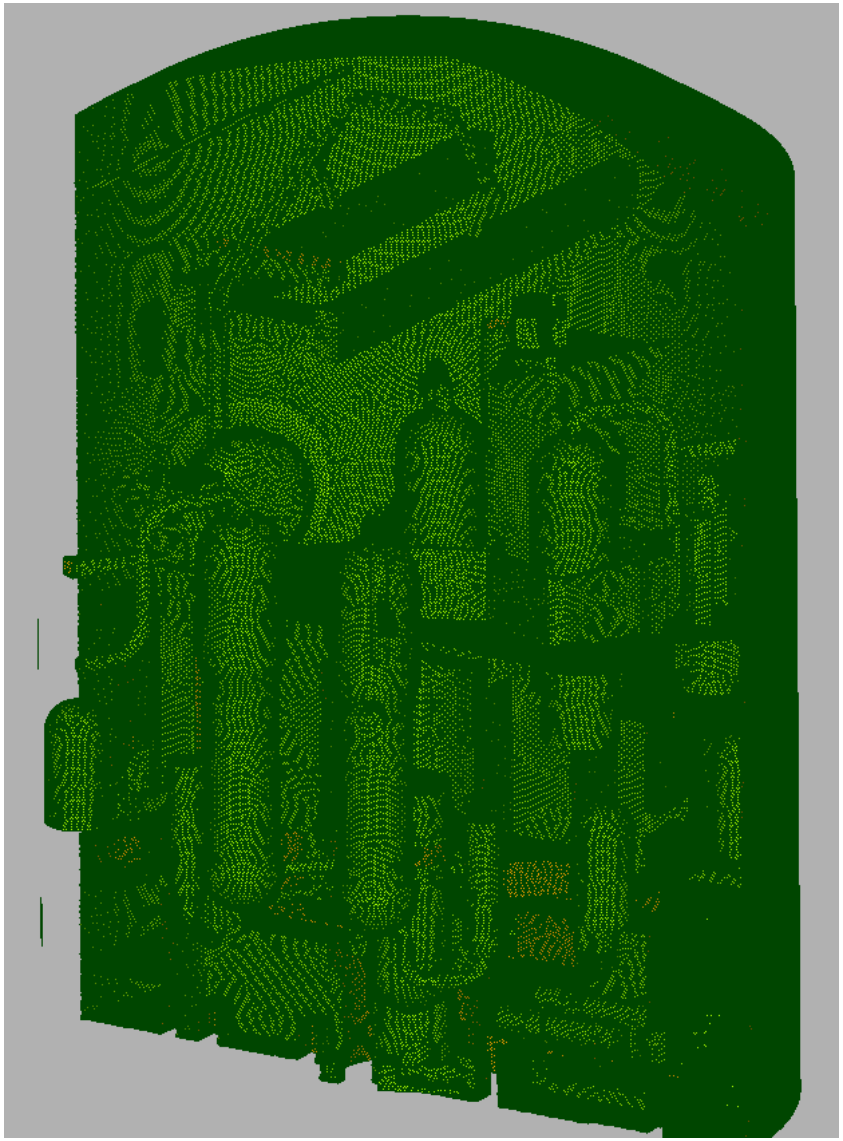
2. Reactor building aerothermodynamics

Background and Description

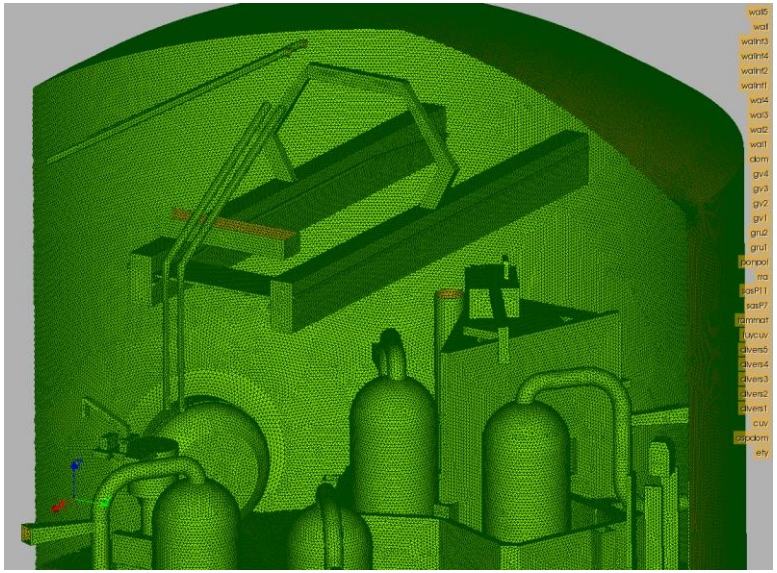
- During normal operation, air temperatures in the reactor building in the vicinity of the dome is elevated and can remain high even after shut down.
- Elevated temperatures pose problems for the operators of the polar deck, resulting in maintenance work being stopped for numerous periods for health and safety reasons - This can cause extended maintenance periods
- **The objectives of the work are to**
  - Evaluate if the observed temperature fields can be reproduced numerically to see if simulations can be a useful tool to help understand the influence of the different systems
  - For example, assess the impact of shutting down of one of the steam generators on the overall temperature field during the time frame from normal operation to shut down

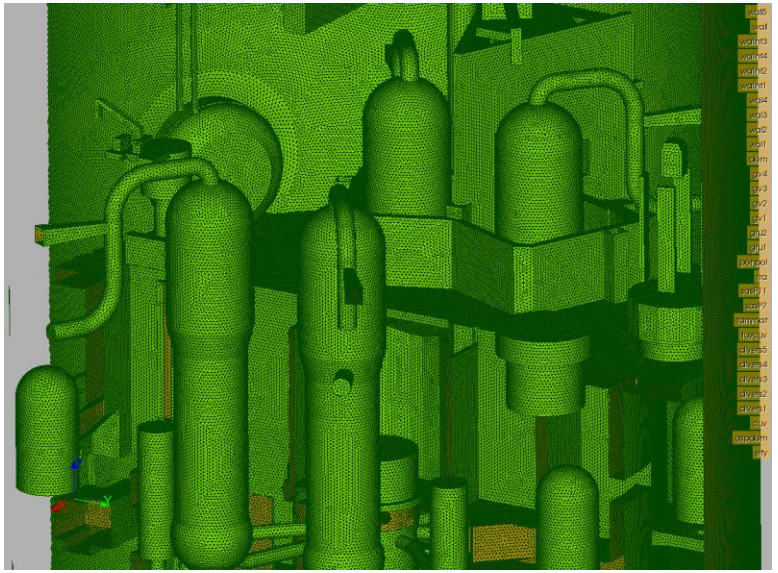
Volume Mesh

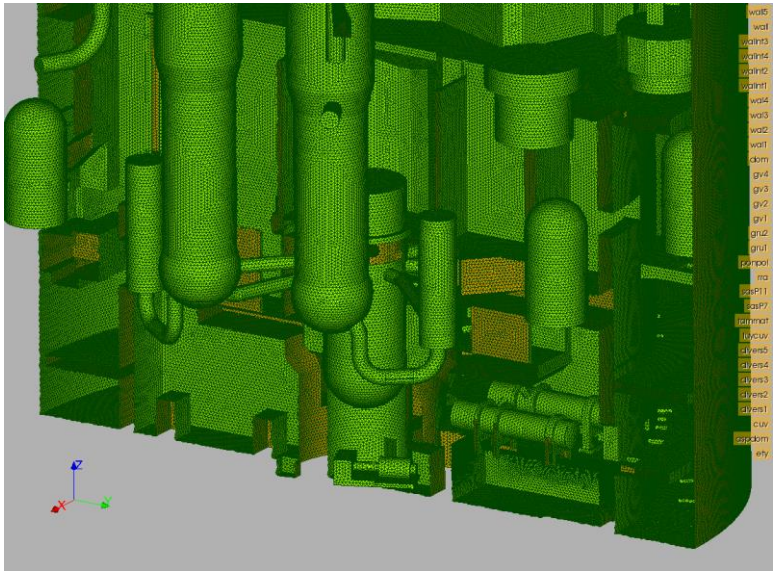
- The volume mesh of the reactor building was provided by EDF
- Tetrahedral cell mesh with 33 million cells



Volume Mesh







Operating Conditions

Operating Condition	Ventilation Circuits	Air Inlet Temp (°C)	Heat Injected (MW)	Steam Generator dT (°C/h)
1) Standard	3 EVR circuits	T_0	W_0	-
2) Standard	3 EVR circuits	T_0+5	W_0	-
3) Standard	4 EVR circuits	T_0	W_0	-
4) Preparation for shut down	3 EVR circuits	T_0	Variable	5.3

1) The reactor building is in its normal mode of operation
2) As per 1, but the cooling air temperature increased by 5°C to assess the impact of this increase in the dome air temperature
3) As per 1, but with 4 EVR circuits in operation in order to assess the impact on the dome air temperature
4) Analysis of the dome air temperature evolution as the reactor is being shut down and steam generator 1 is taken off (for the model, $T_{surface}$ reduced by 5.3°C/hour)

CFD Model

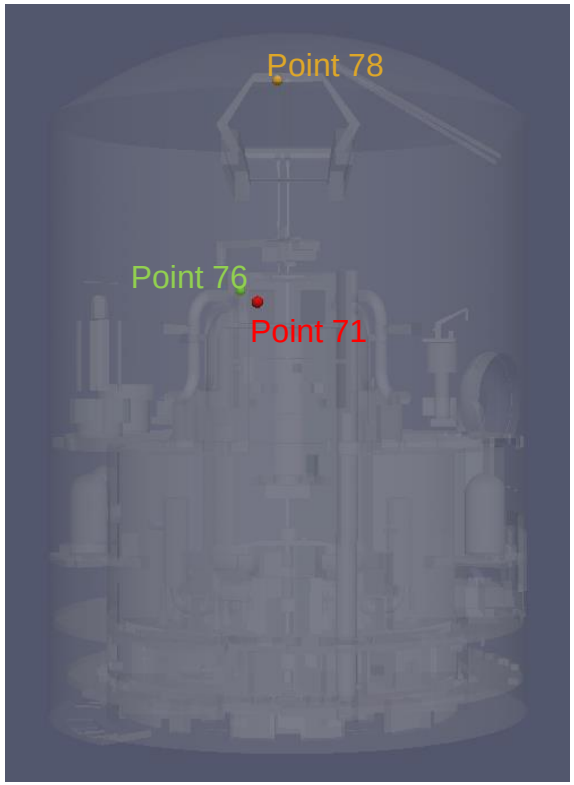
- **Operating conditions**
  - 1, 2 and 3 – Steady state compressible flow with heat transfer
  - 3 was restarted from 1
  - 4 – Unsteady compressible flow with heat transfer (restarted from1)
- **Solution algorithms**
  - Conditions 1 to 3 : SIMPLE for 70000 iterations
  - Condition 4 : SIMPLEC – Δt = 2s for 36 hours of real time
    - Frozen velocity and pressure fields from condition 1
- **Physical properties**
  - ρ = f(T), μ = 1.81x10^{-5} Pa.s, C_p=1004.7 J/kgK , k = 0.057 W/mK
- k-ε turbulence with universal law of the wall model

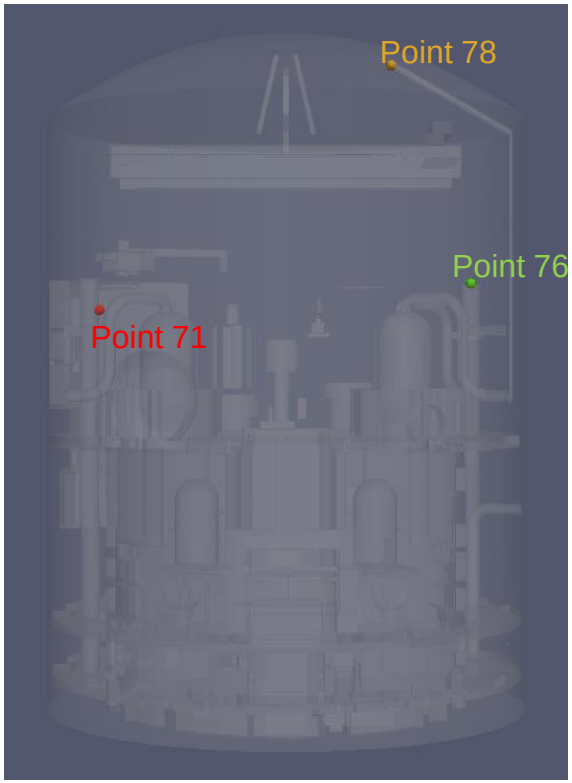
Boundary Conditions

- Inlet boundaries with positive or negative flow rates
- Free outlets
- Walls
  - Heat flux for steam generators and reactor core wall
  - For condition 4, variable temperature on one of the steam generators
  - Adiabatic for all other walls
- Heat source term for lower parts of the reactor building

Monitoring Probes

- During the calculations, the temperature is monitored at several locations throughout the domain
- The position of the monitoring probes for air temperature near the dome is shown below

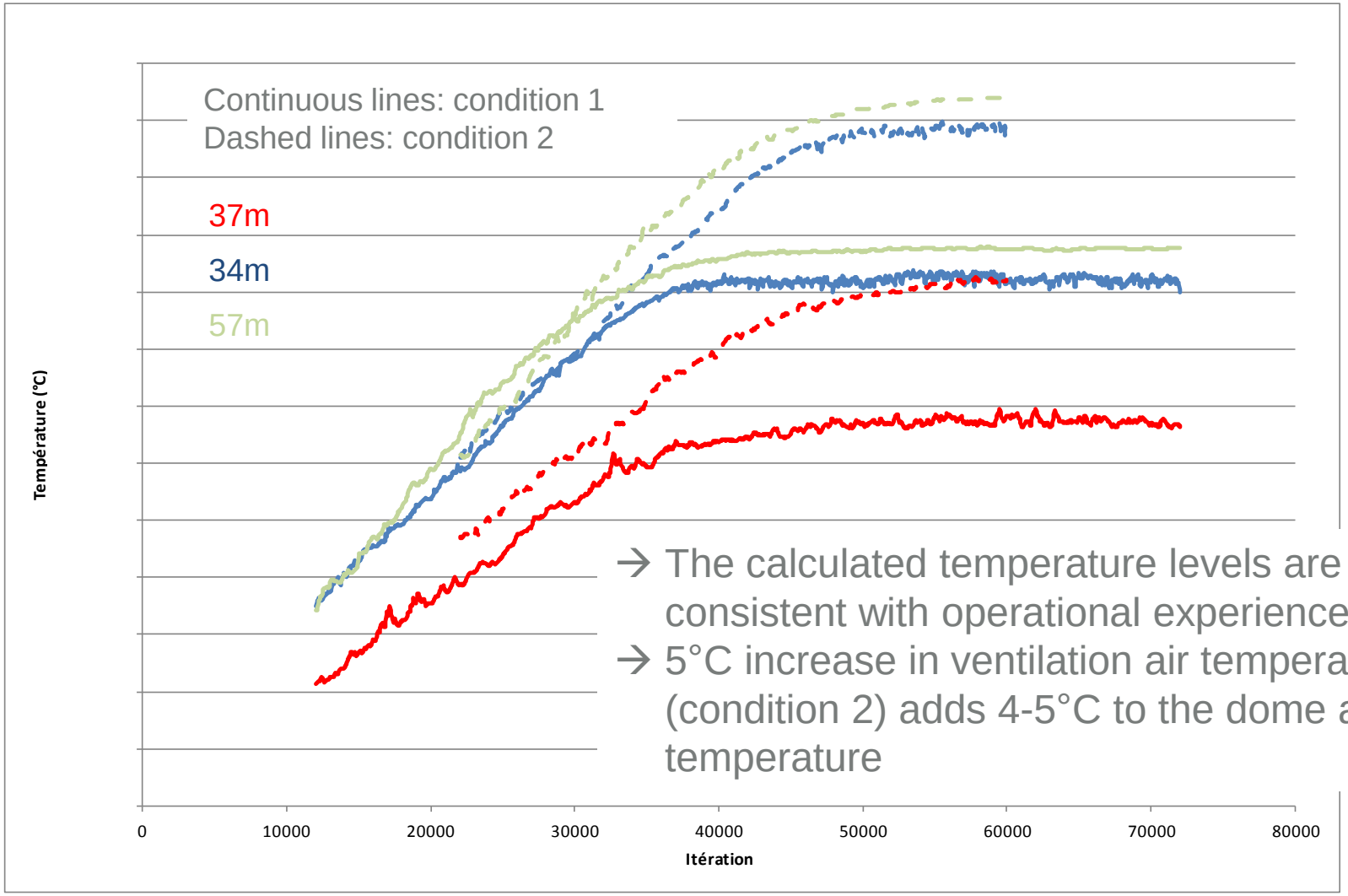




Probe	X (m)	Y (m)	Z (m)
71	-17.5	2.5	34.4
76	17.54	4.8	37.0
78	9.78	1.0	57.125

Results – Conditions 1 and 2

- Air temperatures near the dome

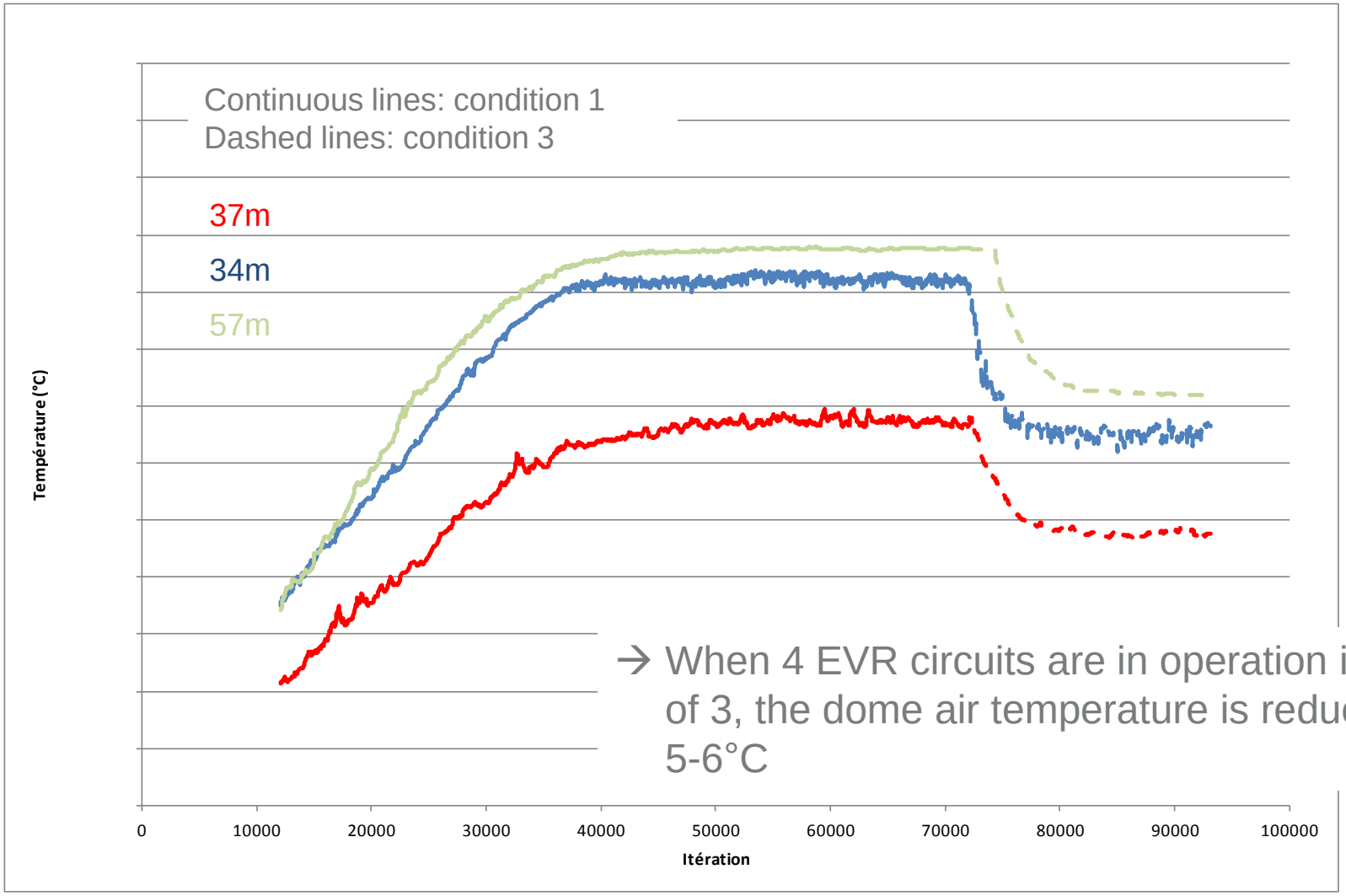


→ The calculated temperature levels are consistent with operational experience

→ 5°C increase in ventilation air temperature (condition 2) adds 4-5°C to the dome air temperature

Results – Conditions 1 and 3

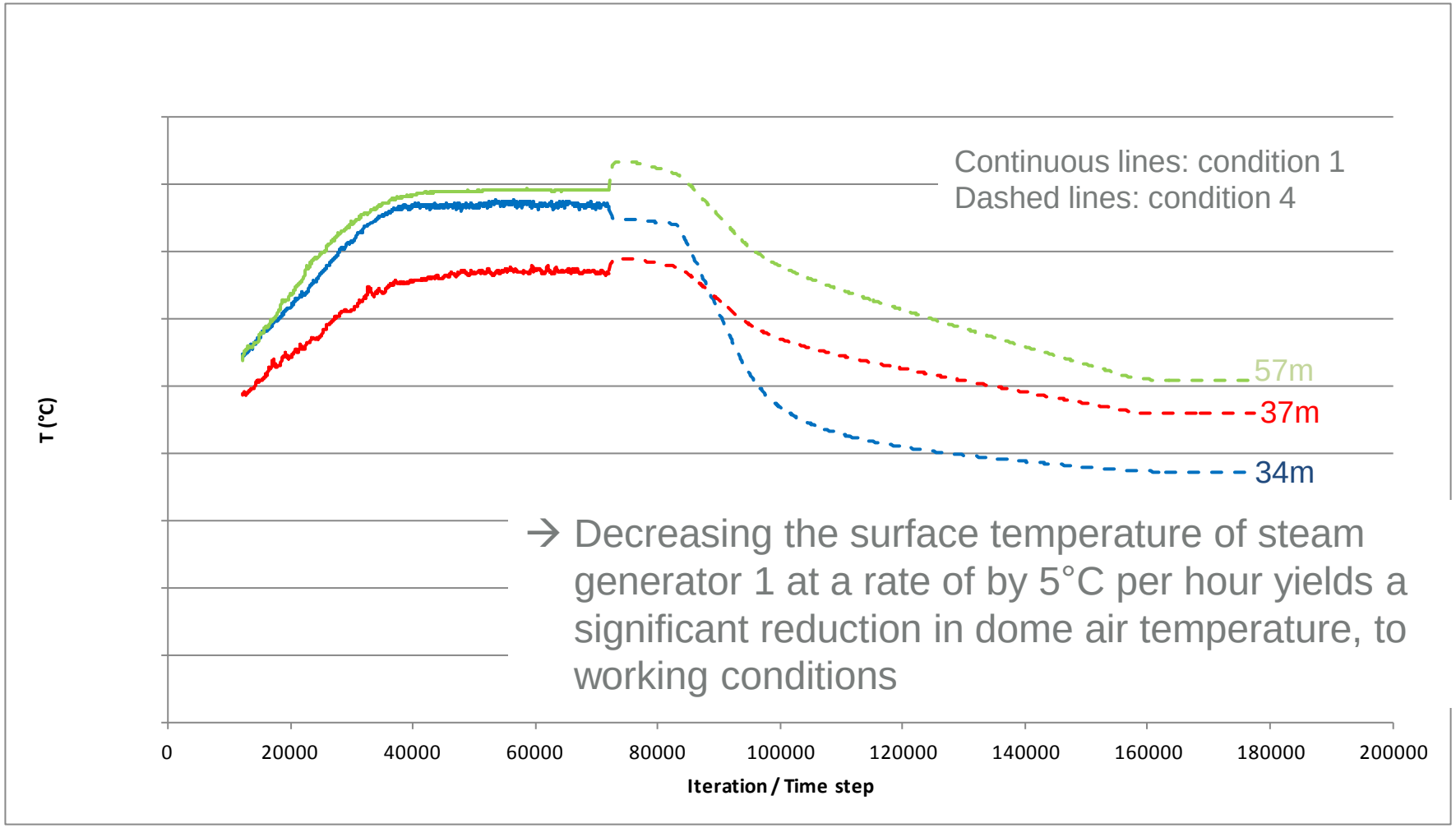
- Air temperatures near the dome



→ When 4 EVR circuits are in operation instead of 3, the dome air temperature is reduced by 5-6°C

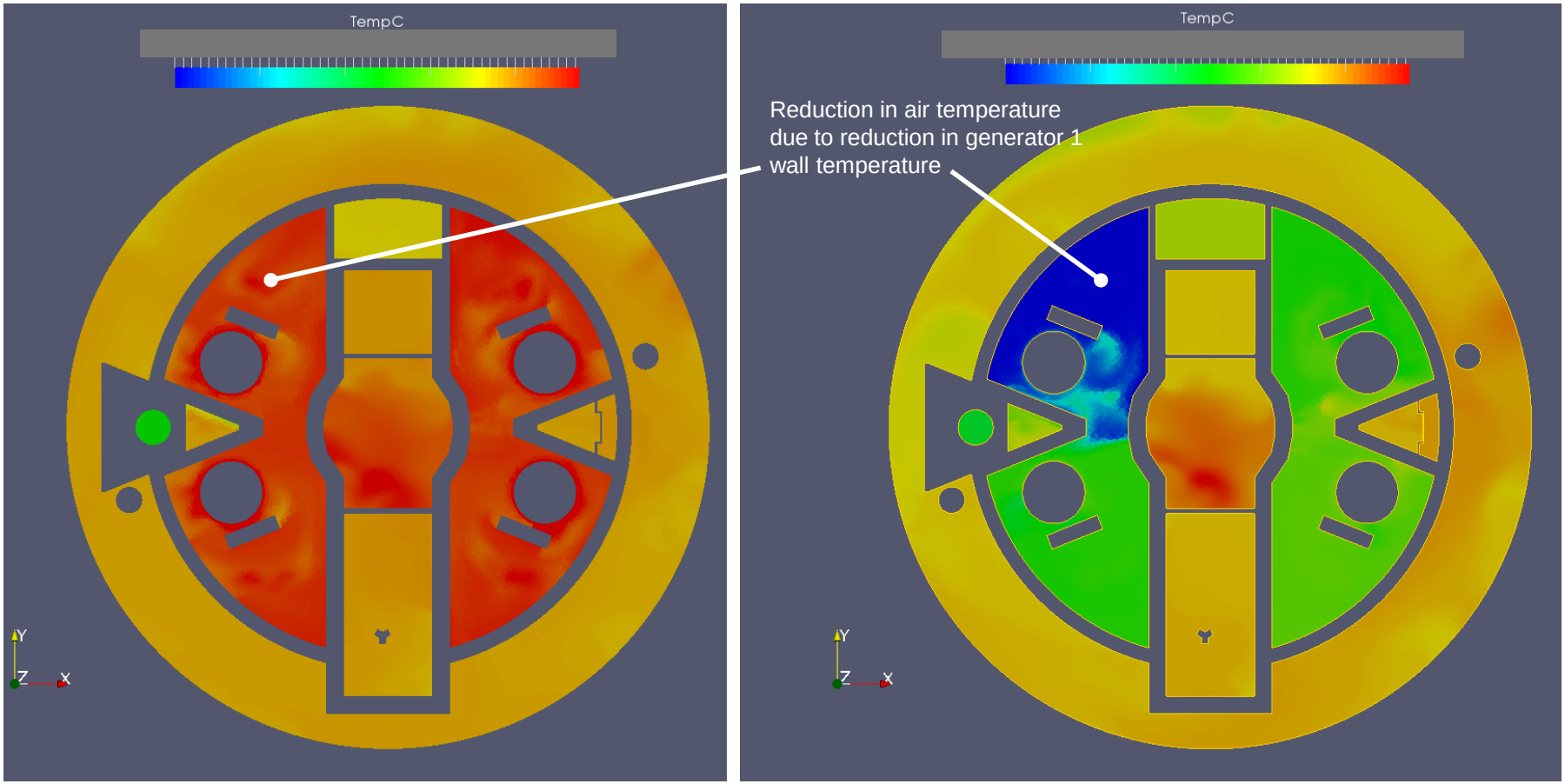
Results – Conditions 1 and 4

- Air temperatures near the dome



Results – Conditions 1 and 4

- Air temperatures in the reactor building

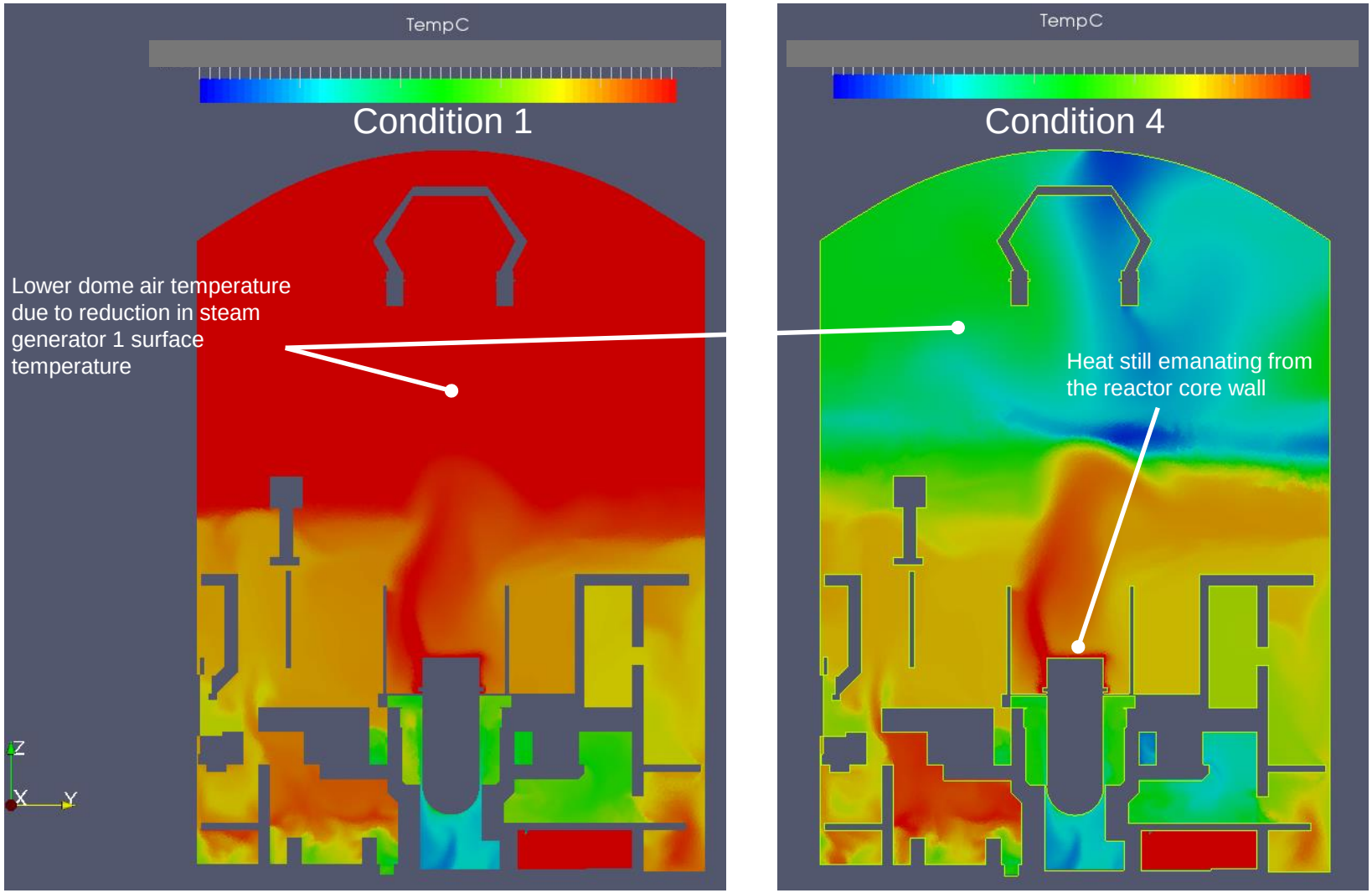


Condition 1

Condition 4

Results – Conditions 1 and 4

- Air temperatures in the reactor building



Results – Conditions 1 and 4

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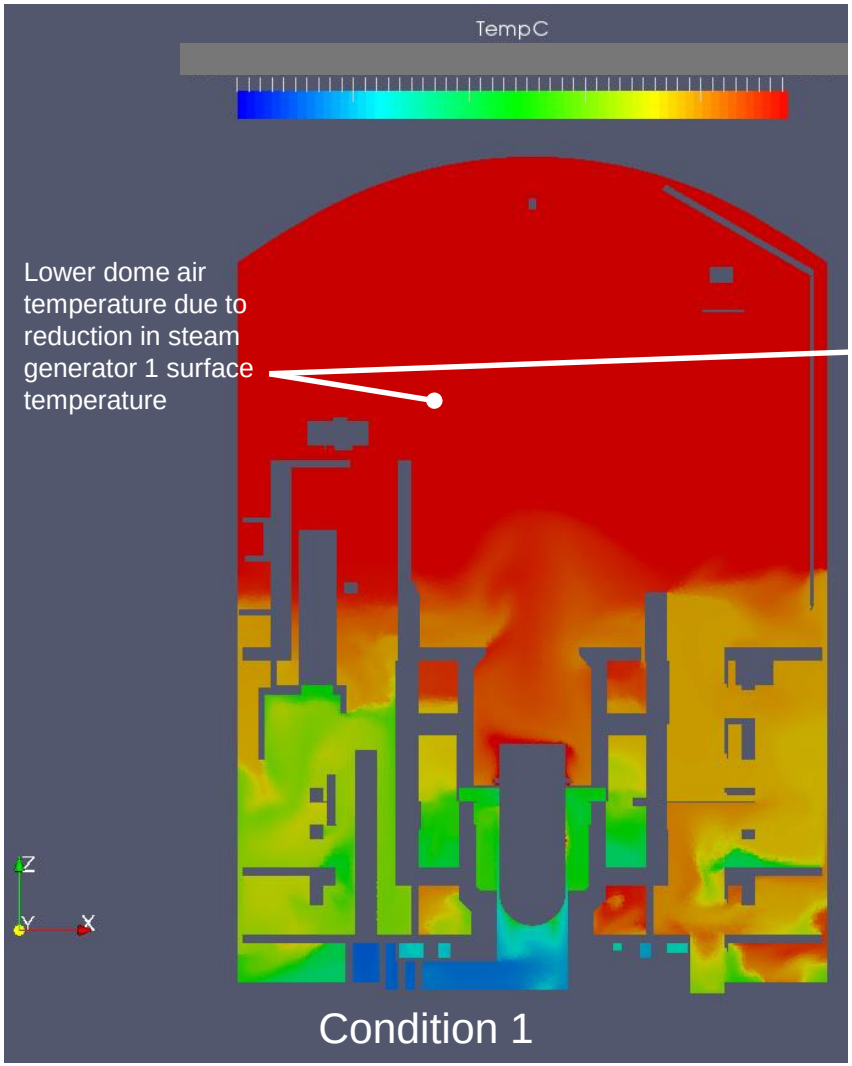
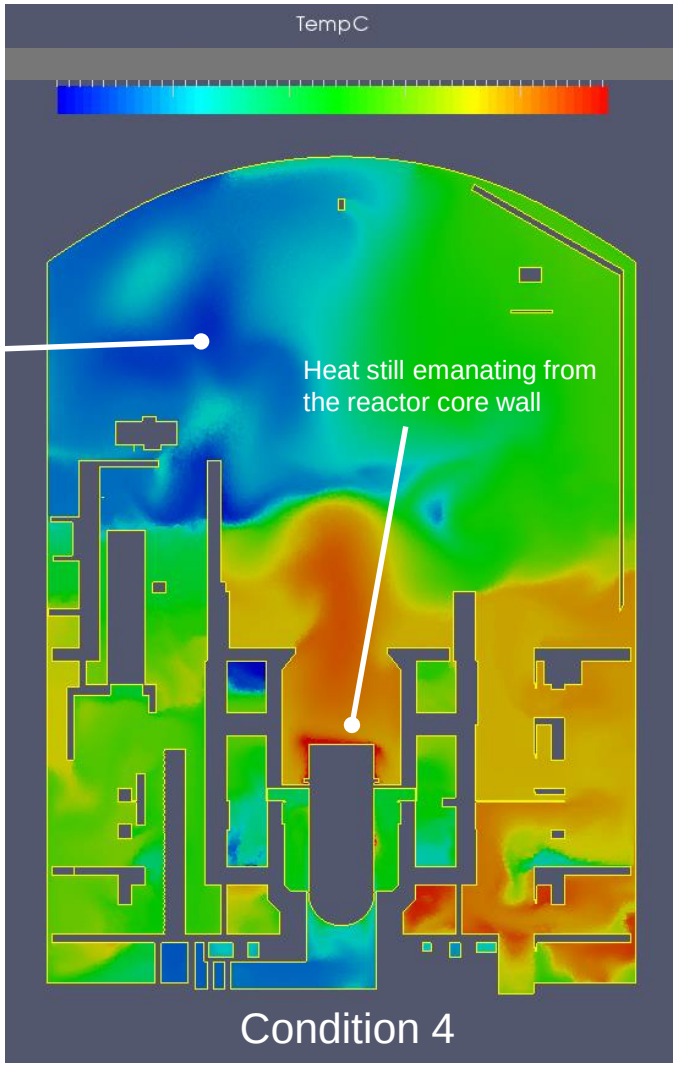
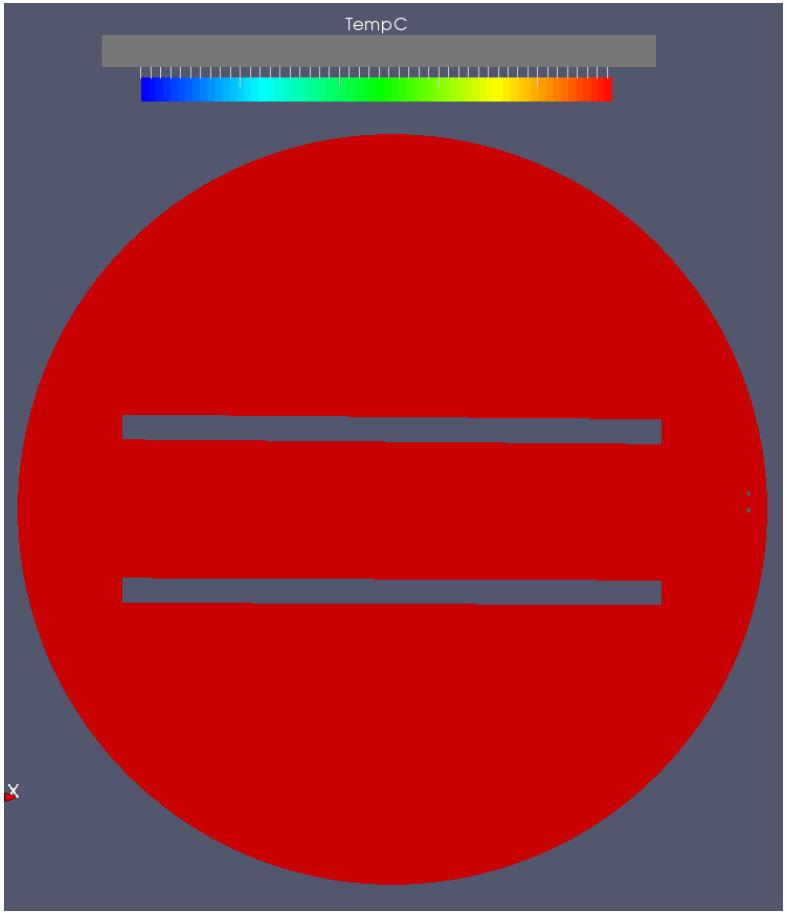


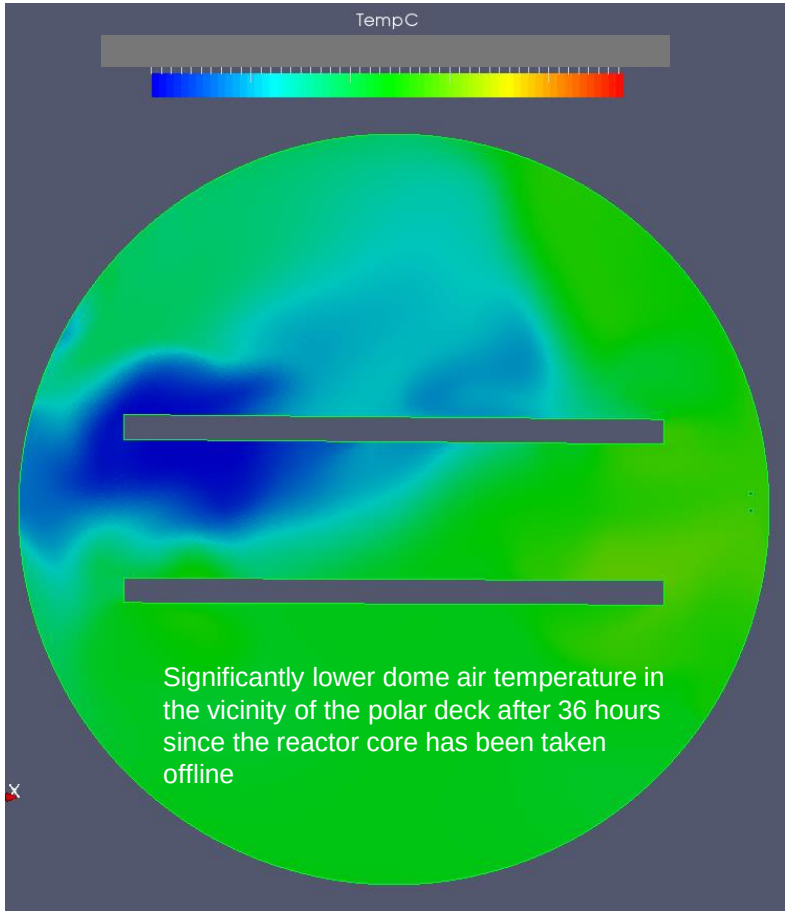


Results – Conditions 1 and 4

- Air temperatures in the reactor building



Condition 1



Condition 4

Summary

- *Code_Saturne* has been successfully used to model aerothermal flow in the reactor building
- Some of the simulations can be run steady state and provide meaningful results
  - A significant reduction in CPU time when compared to an unsteady simulation
- The results indicate that
  - Heat transfer from the steam generators and the reactor core the contribute significantly to the high dome air temperature
  - Blowing cooling air at higher temperature increases the dome air temperature in proportion
  - Activating all 4 EVR circuits yields a notable dome air temperature reduction
  - Simulating the cooling off of steam generator shows a strong decrease in the dome air temperature

Summary

- CFD simulations can help design and validate approaches to decreasing the dome air temperatures to desired levels

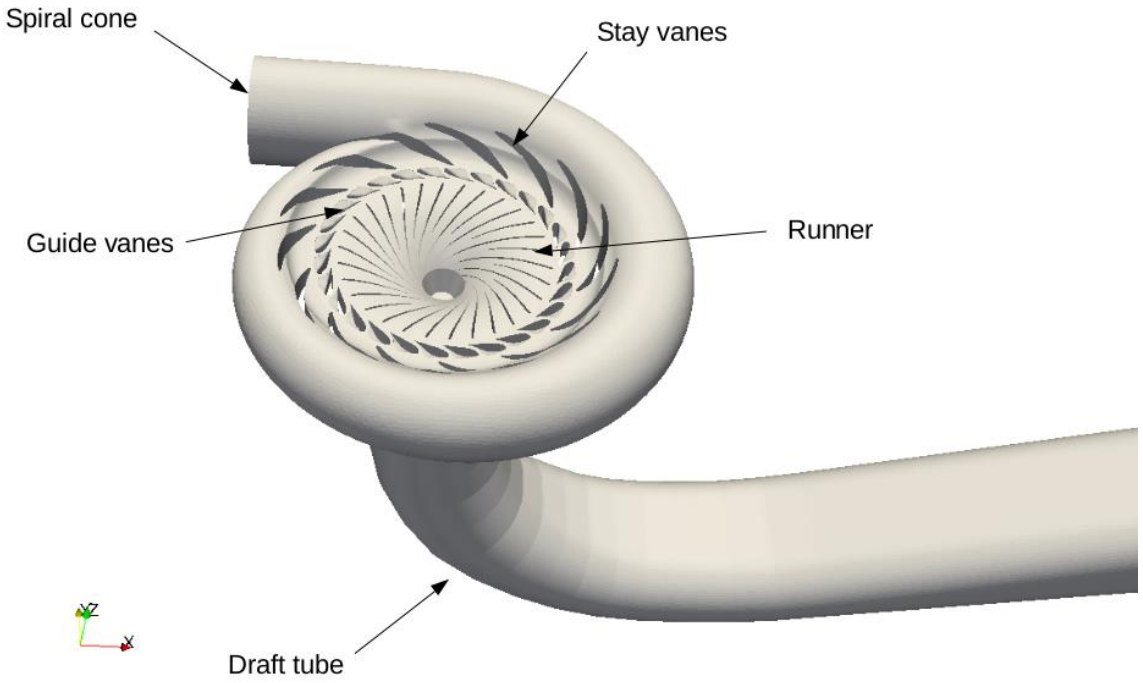
3. Francis Turbine

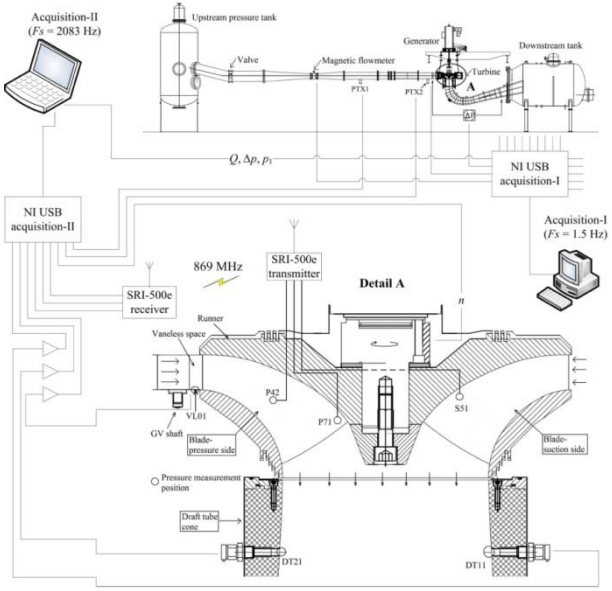
Background and Description

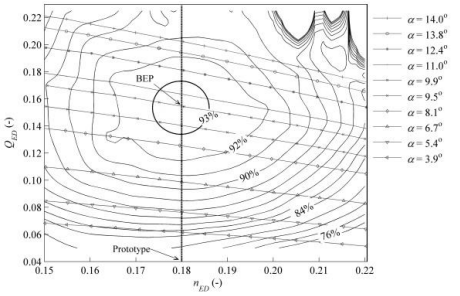
- Hydro electricity: Francis turbine
  - Performance
  - Variable operating points
  - Steady and unsteady operations
  - Vortex prediction
- **The objectives of the work are to**
  - Perform full 3D simulations of a Francis Turbine
  - Chosen model: Francis 99 Norwegian Hydropower Centre

Turbine Tokke

- Norwegian Hydropower Centre (NVKS)
- Reduced scale model of a real turbine in operation at the Tokke plant in Norway

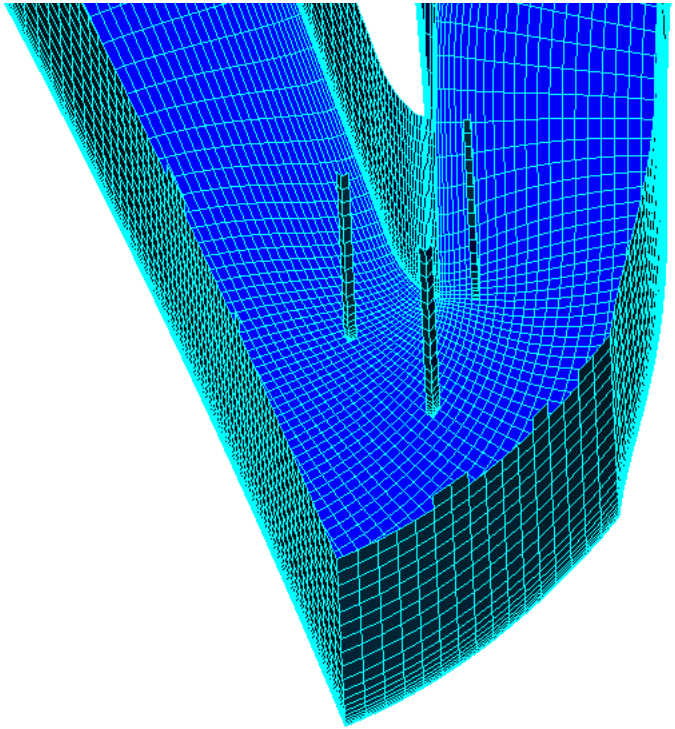


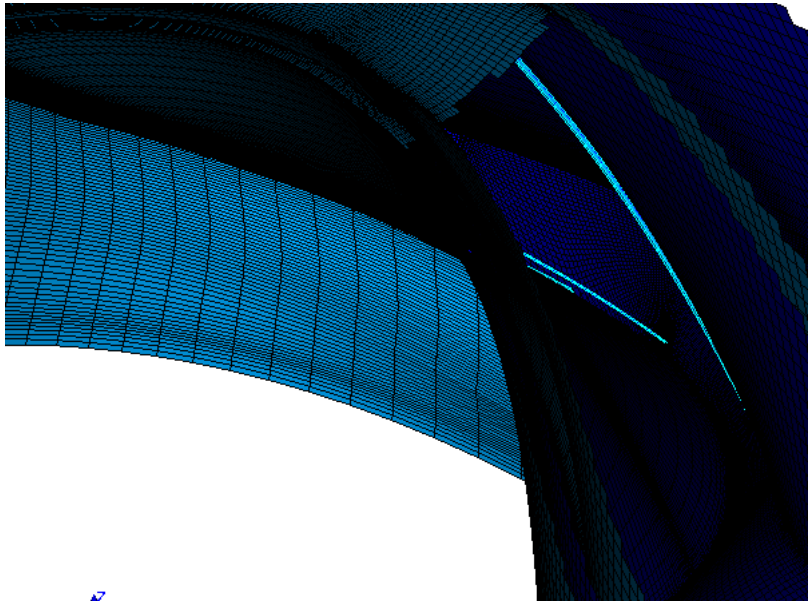




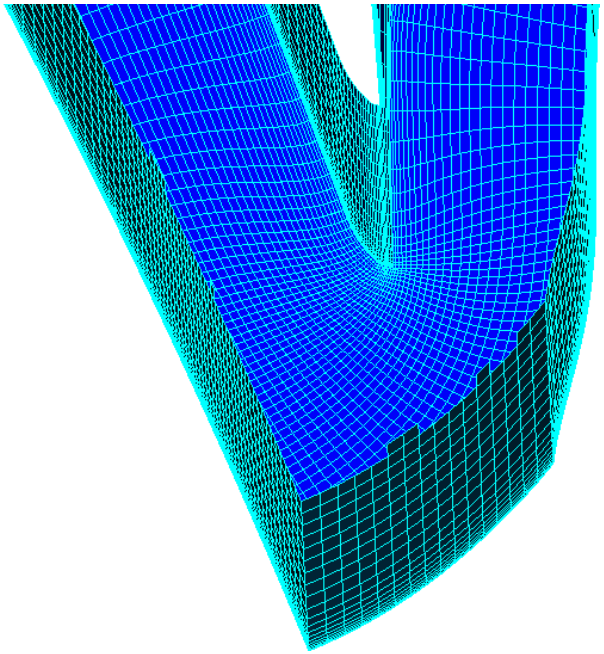
BEP CFD Model

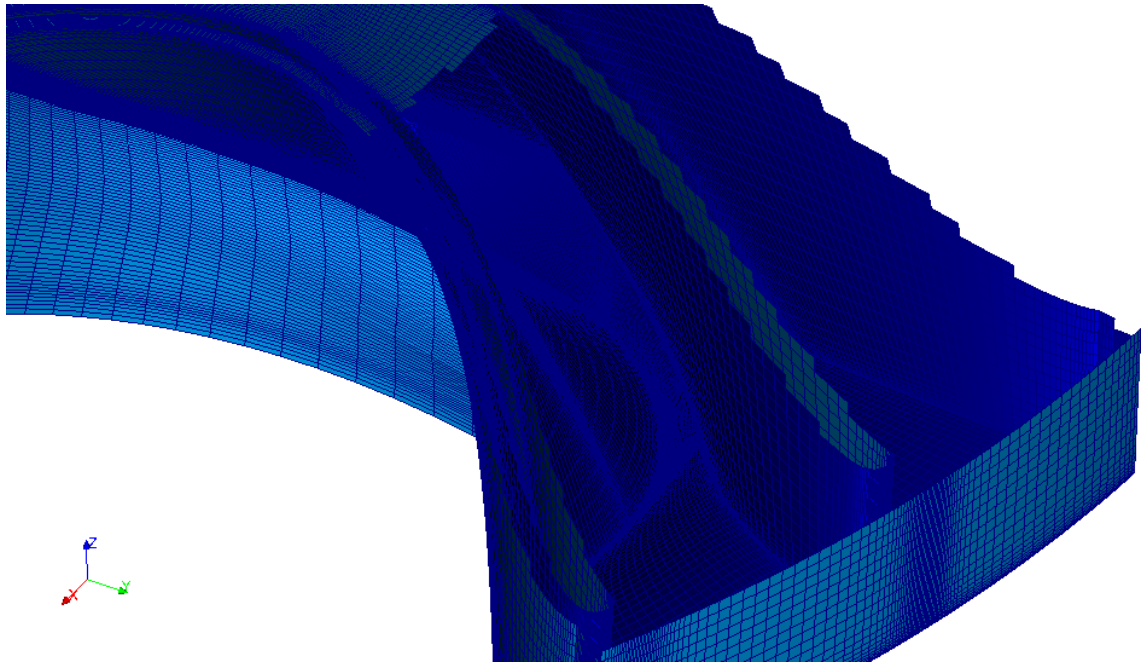
- Elemental meshes obtained from the NVKS
- Rebuilt in 3D → SALOME
- Cleaned → SALOME
- **Significant meshing work on the interfaces** → SALOME





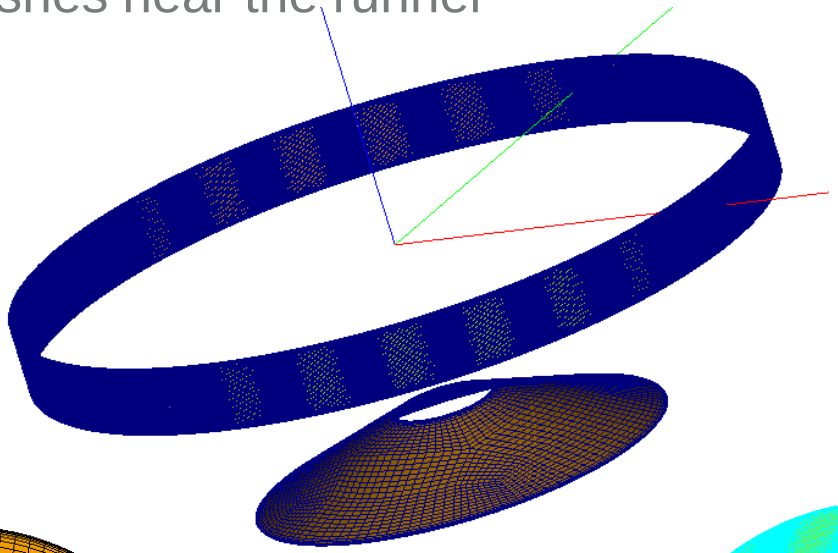
Mesh Construction

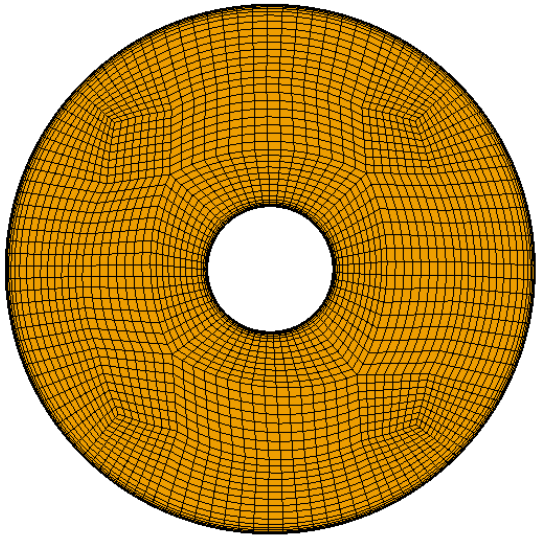


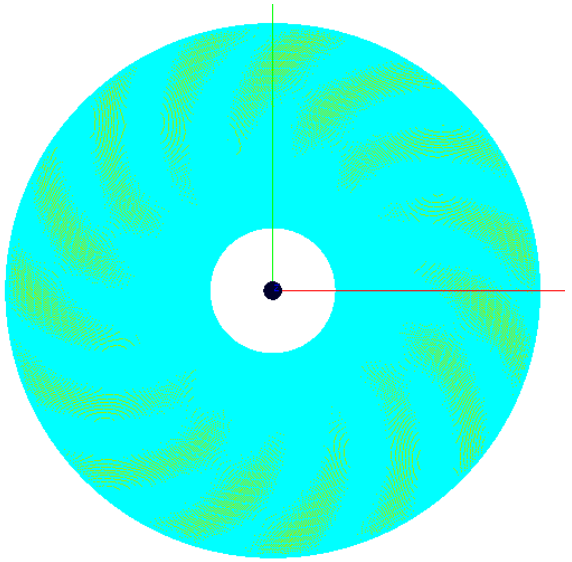


Interfaces

- Very different meshes near the runner

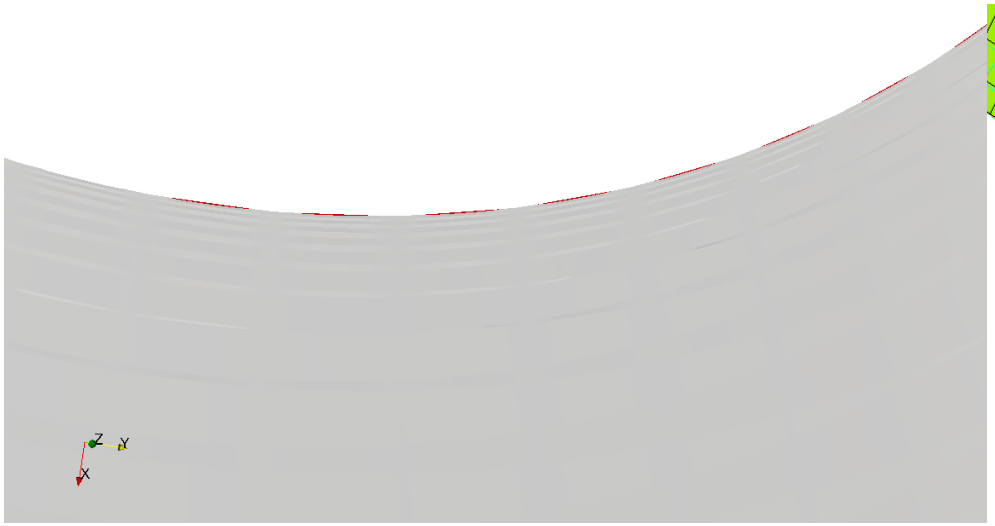


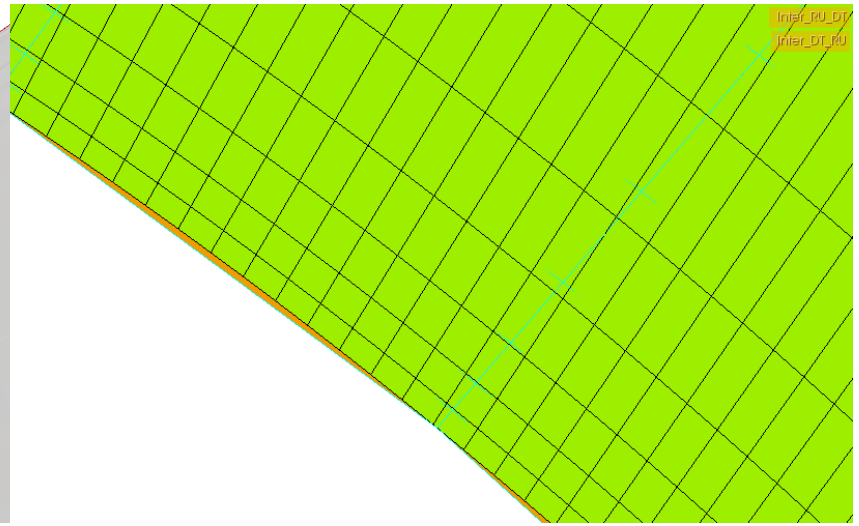




Interfaces

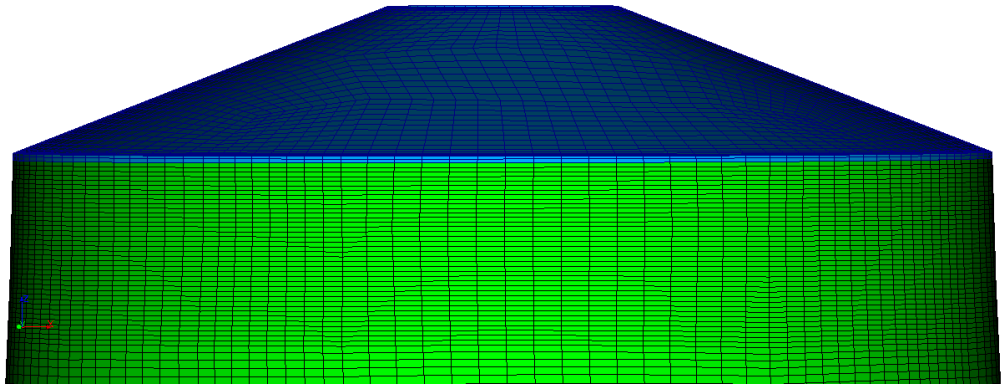
- Errors detected at the runner outlet's interface
- Widely disparate cell sizes on each side
- Particularly critical on the smaller, inner diameter

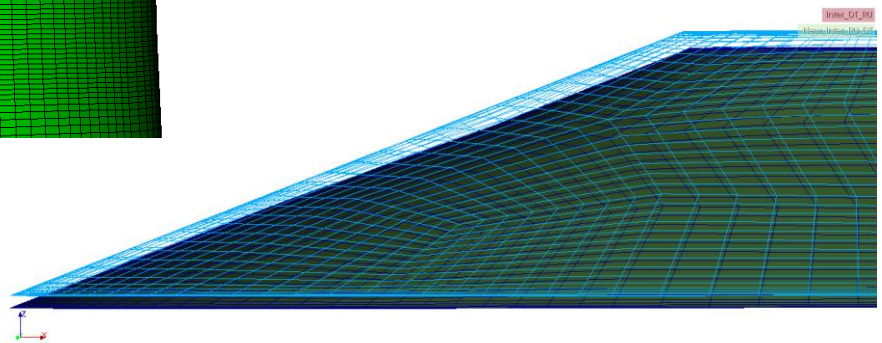




Method 1

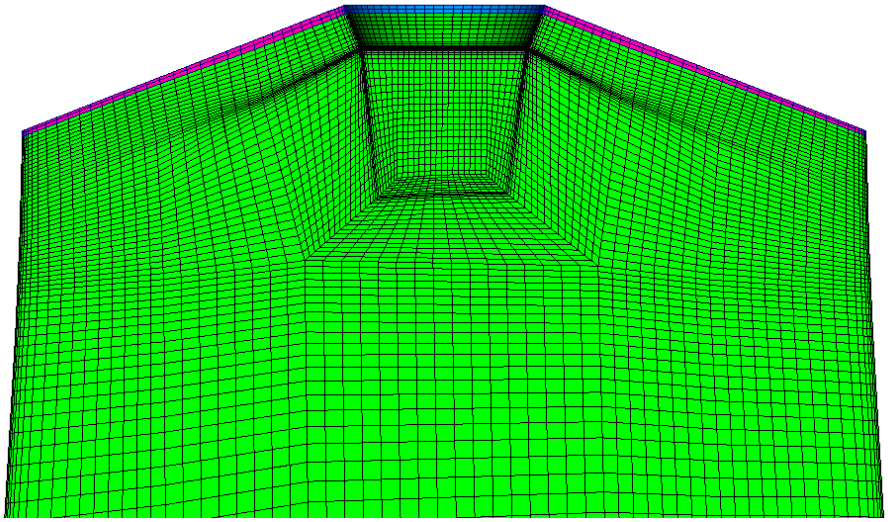
- To enforce a conformal interface:
  - Dissociate a layer of cells from the draft tube and give it to the runner
  - Move the interface inside the draft tube
- Entirely coded in SALOME script

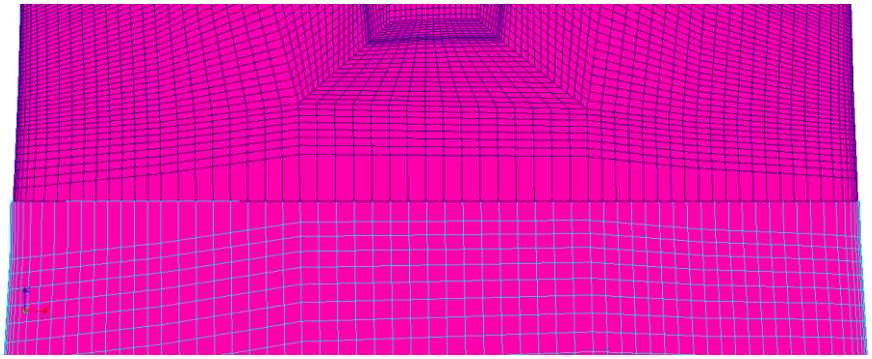




Method 2

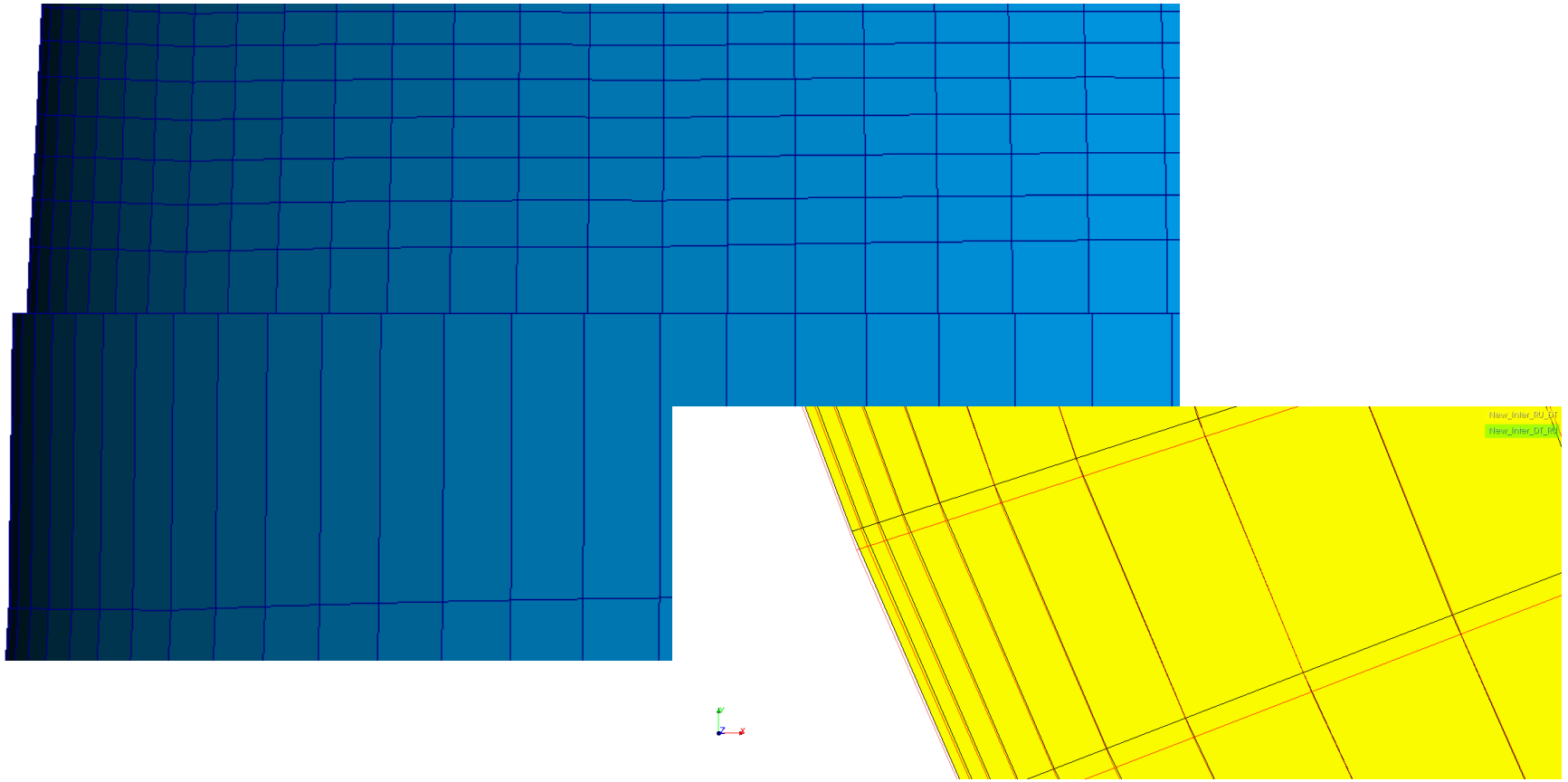
- Create an entirely new interface
- Multi-step process, entirely scripted in SALOME
- Excavate a layer to make room for a horizontal, planar, circular disk





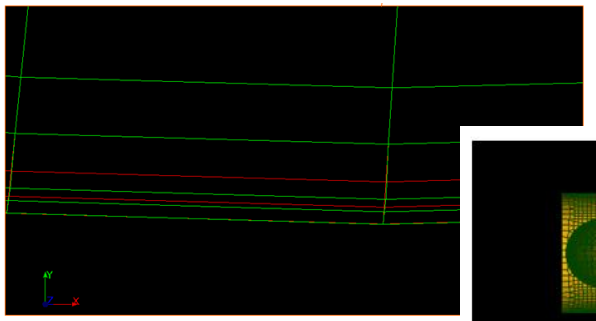
Method 2

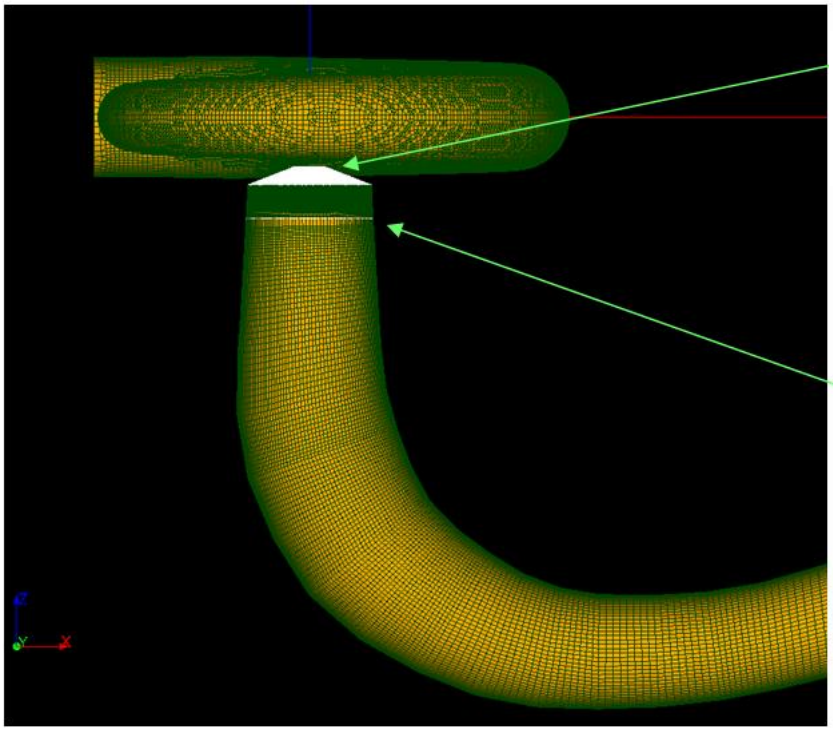
- Move nodes to rescale on each side
- Move nodes to have a circular interface



Method 2

- Move nodes on the two outer layers to obtain large enough, regular cells



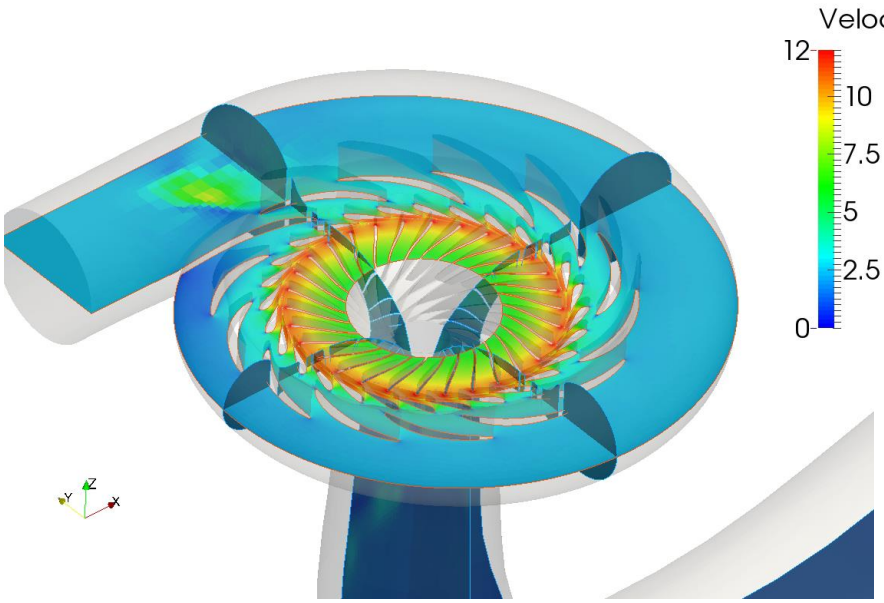


Initial interface which becomes fixed with the runner

New conformal interface

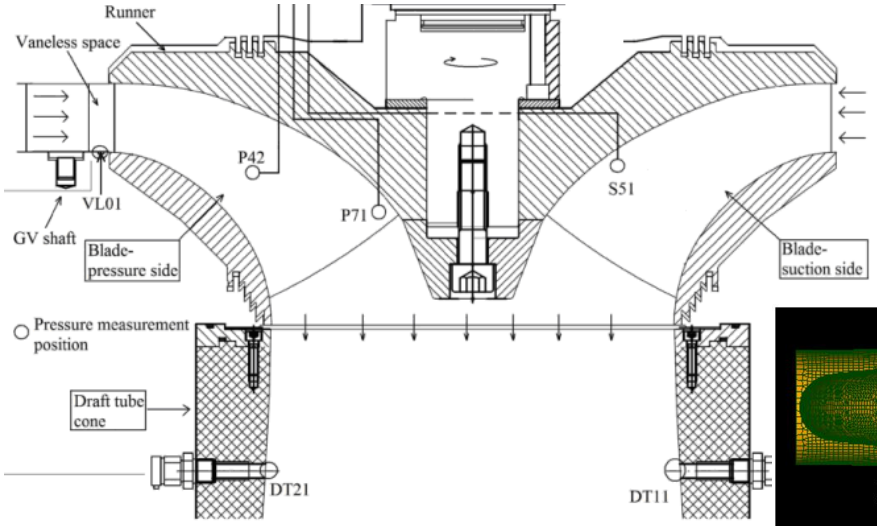
Preliminary Results

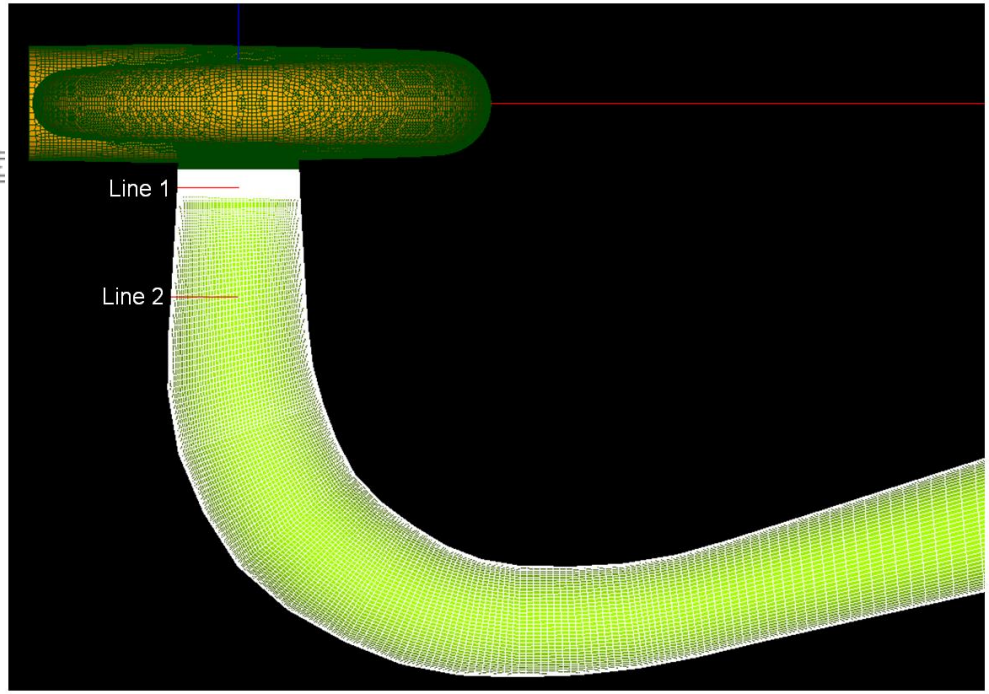
- Velocity magnitude



Preliminary Results

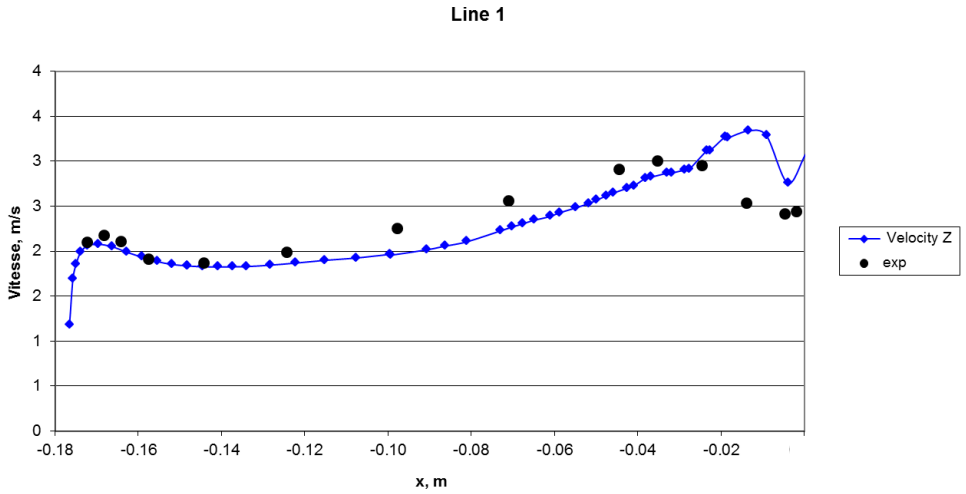
- Comparison with experimental data

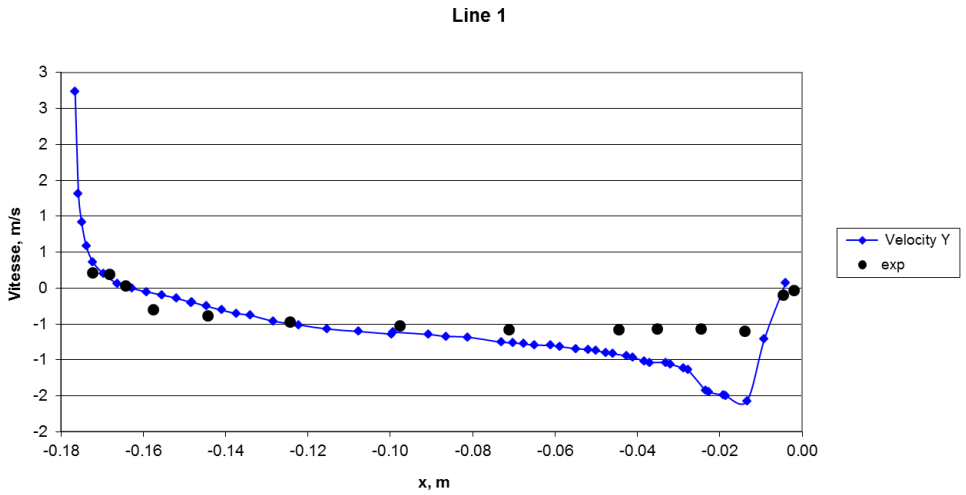




Preliminary Results

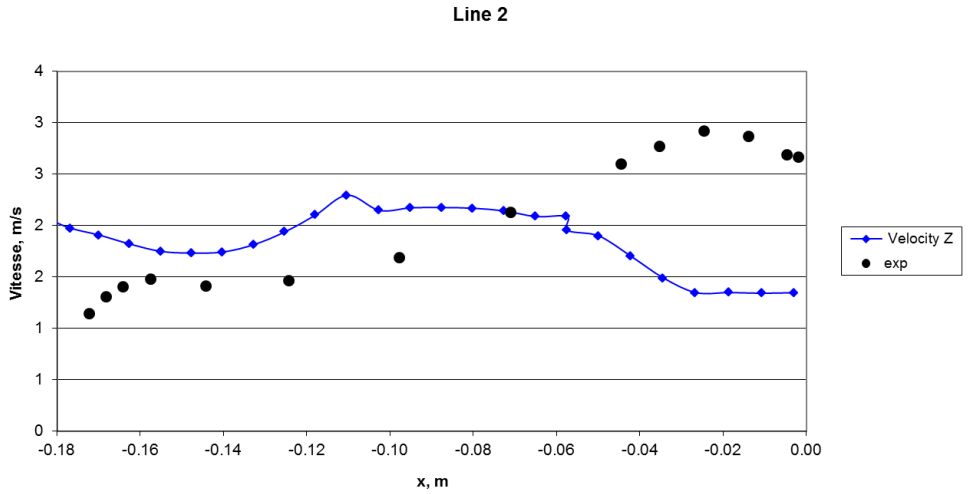
- Axial and radial velocities along line 1 (closest to the runner)

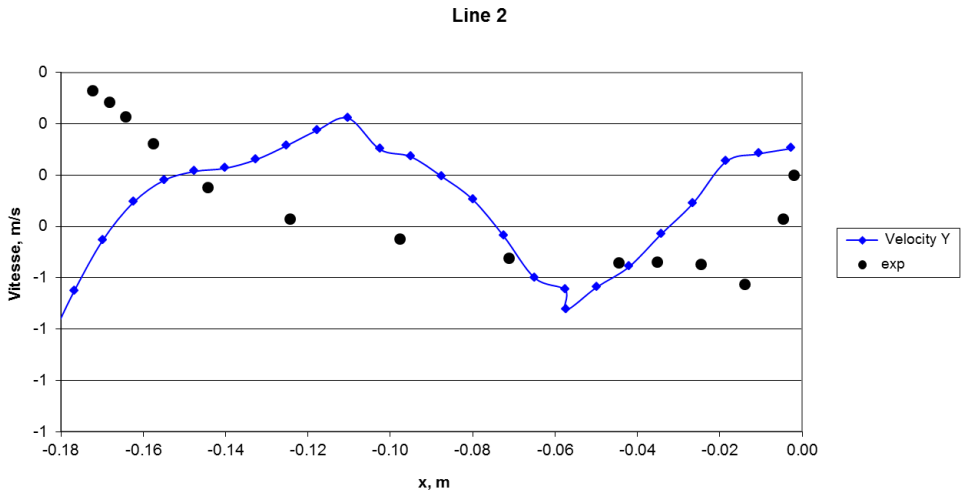




Preliminary Results

- Axial and radial velocities along line 2 (furthest to the runner)





Summary

- SALOME and *Code_Saturne* have been successfully used for a first model of a real Francis turbine
- Very encouraging results
- This and previous work with the turbomachinery module show that stable calculations can be achieved. But, it is very important to first set very good interfaces
- Renuda and EDF are bidding to present results at the Second Workshop in December 2016
  - Steady state operating points
  - Unsteady operating points
  - Turbulence modelling