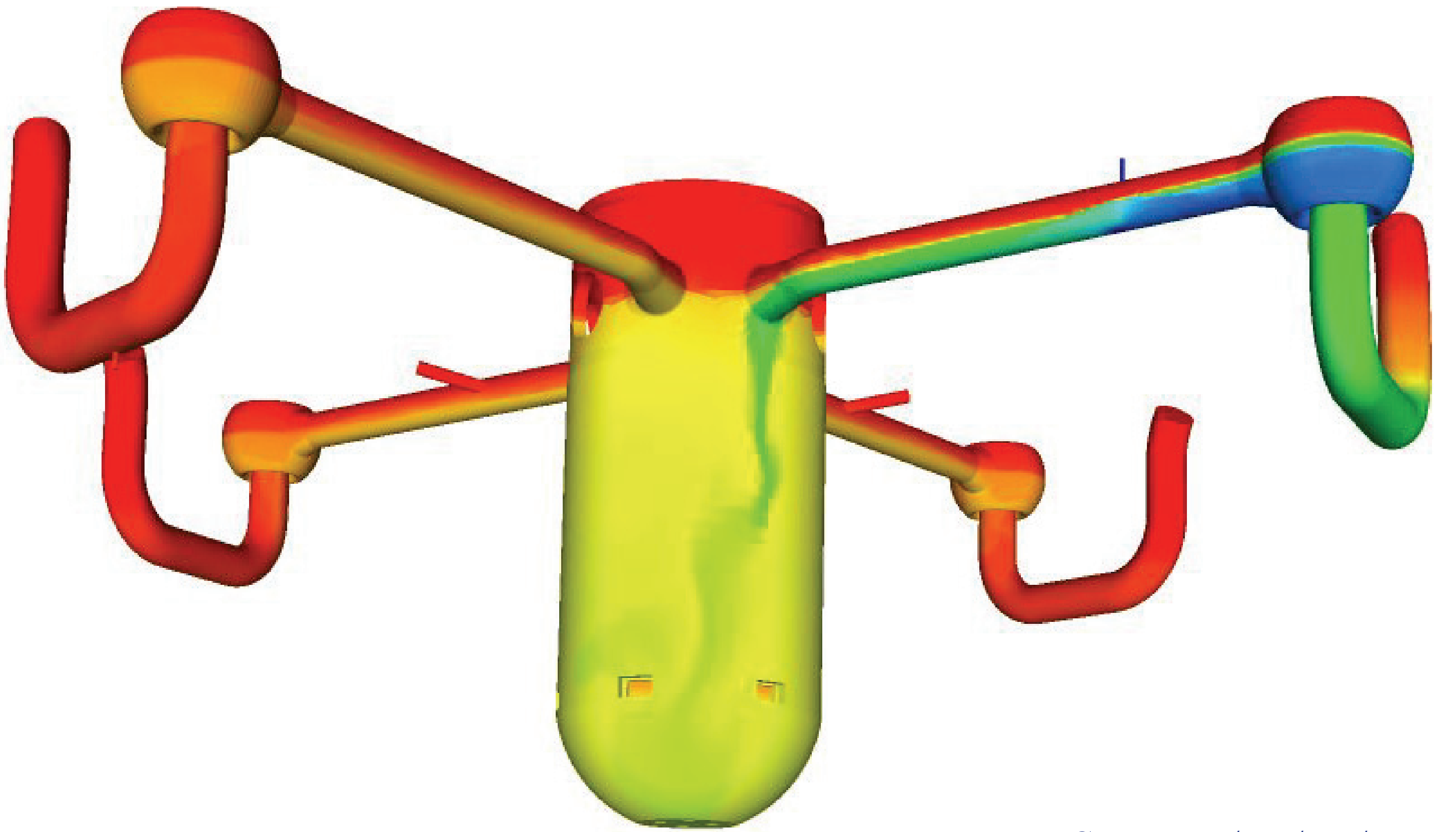
External heterogeneous dilution: formation of a boron depleted slug



SEPTEN/PR/TL/THL

Meryll Colombet

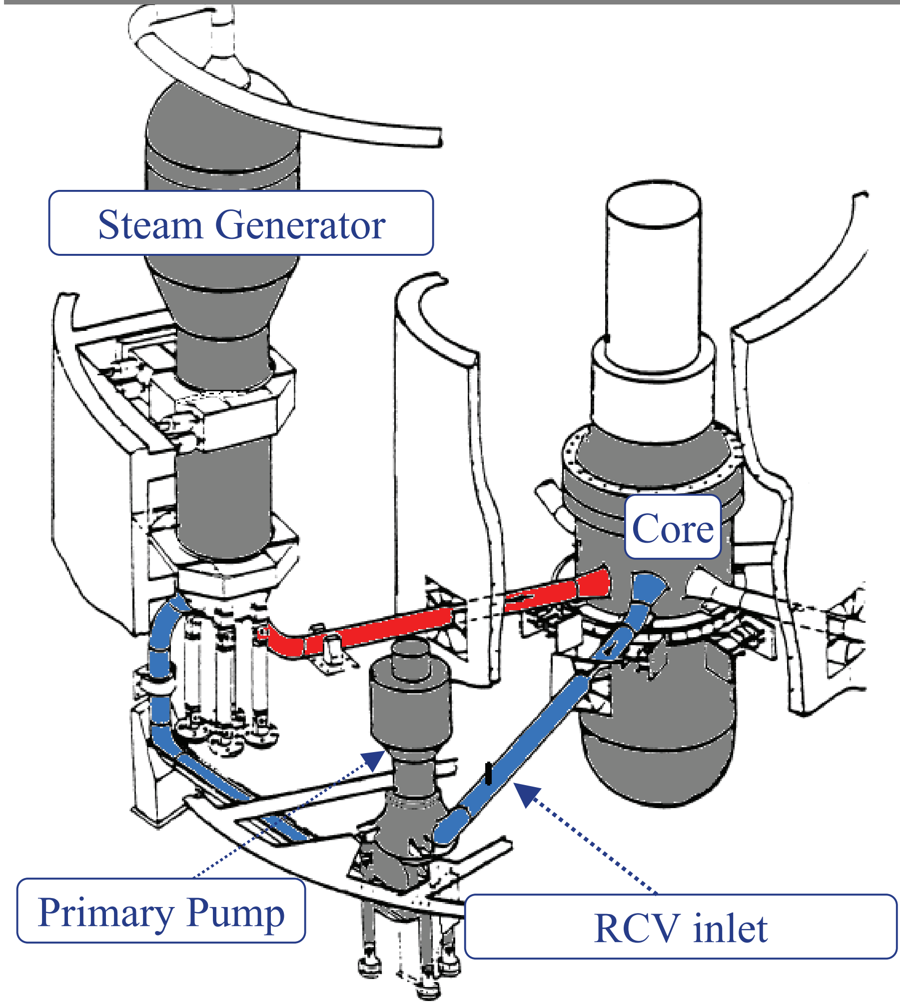
- SEPTEN/PR/TL/ THL
  - CFD calculations with *Code_Saturne* since 2006
    - Heterogeneous dilution and thermal shock on the vessel
    - AREVA studies monitoring

- External heterogeneous dilution accident
  - Formation of a boron depleted slug in the loop seal (U leg)

Overview

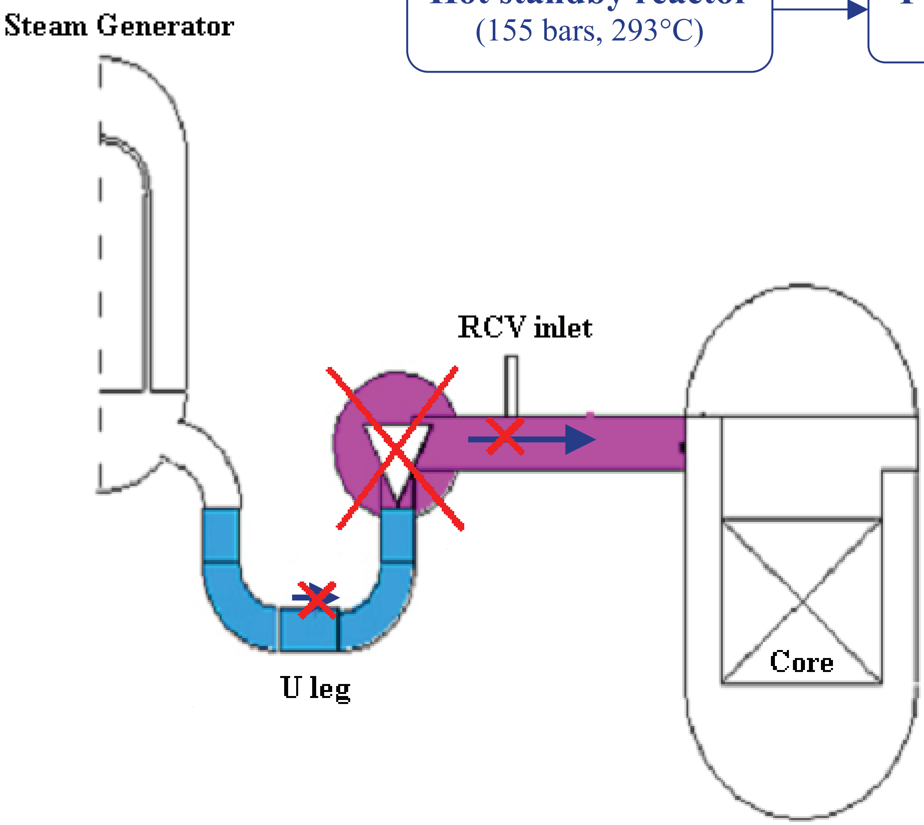
1. Introduction
   - External heterogeneous dilution accident
   - Scenario
2. Calculations with *Code_Saturne*
   - Mesh
   - Parameters
3. Results/Discussion
   - Dependence on physical parameters
   - Dependence on numerical parameters

External heterogeneous dilution accident



- ❑ Pump stops
  - ➢ Formation of a boron depleted slug in the primary circuit via RCV
  - ➢ When the pump restarts the slug will move to the core
    - ➢ Peak reactivity
      - ➢ Power surge => Core damage

Scenario (1/3)



Hot standby reactor (155 bars, 293°C) → **Fast dilution by RCV**

Lost external electrical power → **Stop of the primary pumps** → **Stop of the natural circulation if residual power is not sufficient**

Formation of a slug via RCV

Start of a primary pump

External heterogeneous dilution accident

Scenario (2/3)

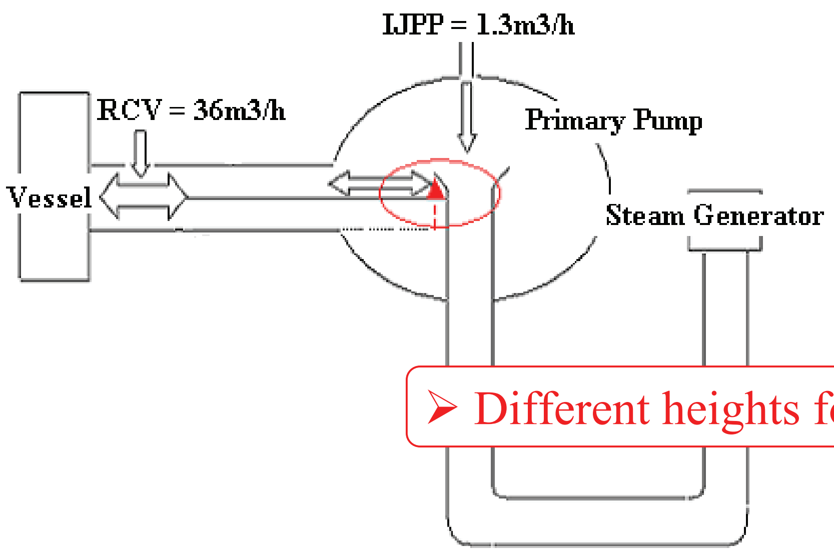
- Failure of the PAD (Anti-dilution protection)

Additional protection: « Manual stop of the dilution » = 72 minutes

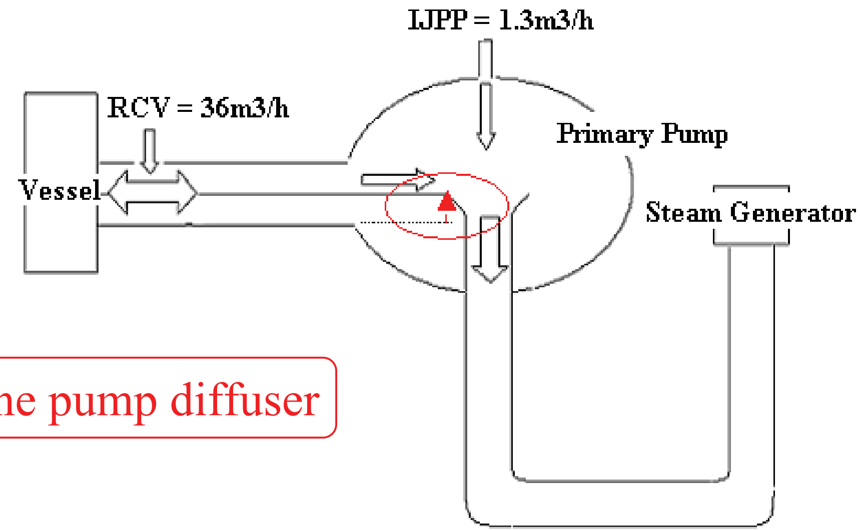
➢ Operator delay before the stop of natural circulation by the injection of cold water at primary pumps joints (IJPP) and formation of a slug via RCV

Operator delay = time to fill the horizontal part of the loop seal, 1.6m^3, by IJPP flow rate of 1.3m^3/h, i.e 72mn *(the delay for the formation of the slug by RCV (36m^3/h) is short)*

Scenario (3/3)



PWR 900MWe



PWR 1300MWe

➢ Different heights for the pump diffuser

IRSN question: « How is EDF sure that the boron depleted water from the RCV does not overflow towards the loop seal? » => Goal of the study

Objectives of the simulation

- Answer to IRSN: It has to be determined if the delay for the manual stop of the dilution is changed by the possible overflow of the water from the RCV towards the loop seal

- Exploratory study: better understanding of the phenomena

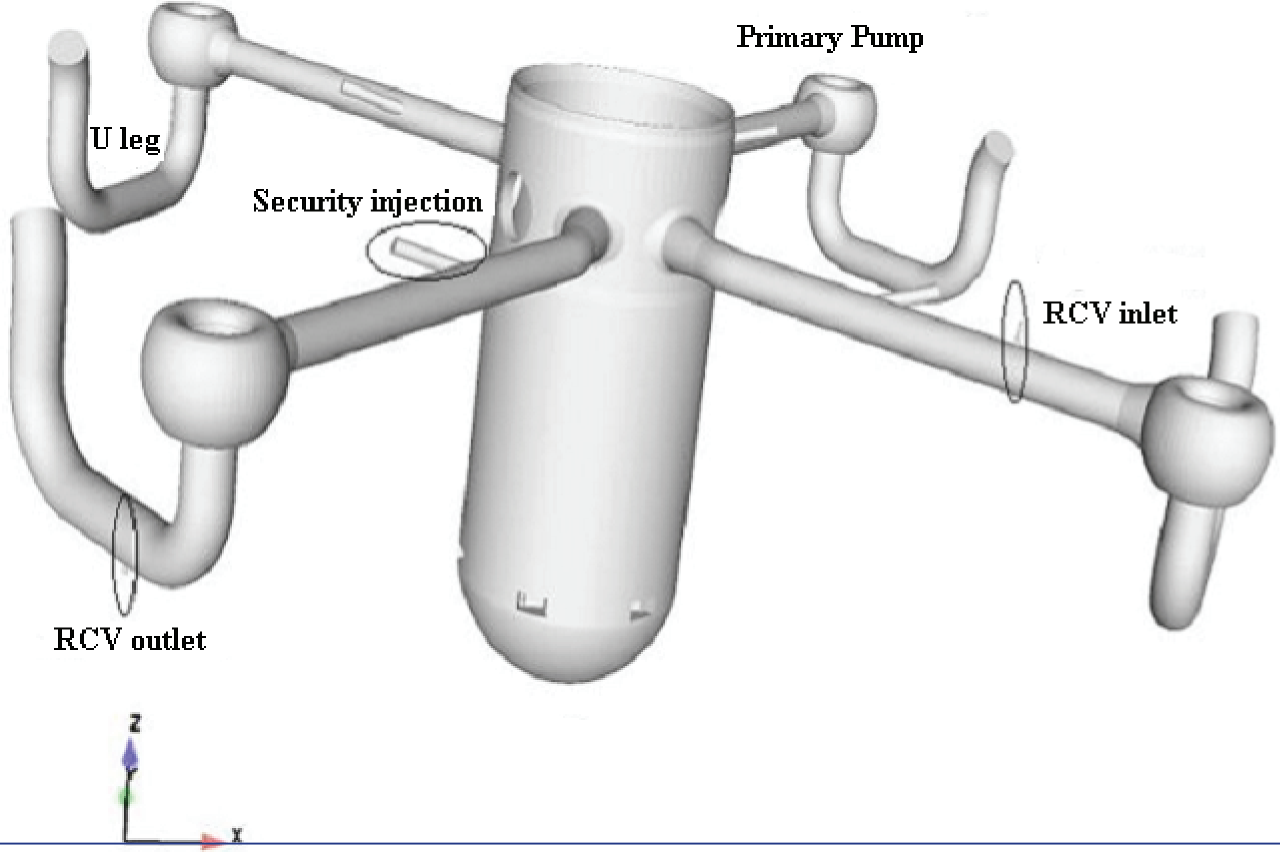
  => there are no experiments modeling the scenario and CATHARE calculations are not adapted

Code_Saturne calculations

- Physical parameters:
  - Thermosiphon flow rate
  - Temperature difference between water from RCV and water in the cold leg
- Numerical parameters:
  - Turbulence model (k-ε, k-ω, R_{ij})
  - Mesh
  - Time step

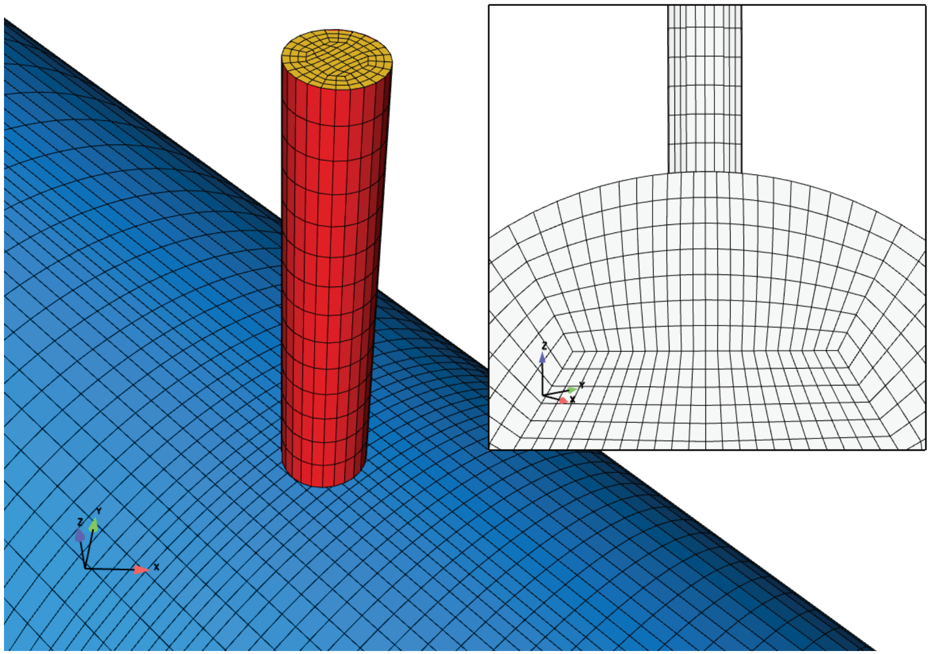
Mesh (1/2)

- Made by INCKA with SIMAIL V6.5 (more than 1 million cells)
- Vessel mesh existing + 4 cold legs, 4 U legs, 4 Primary Pumps, RCV inlet/outlet

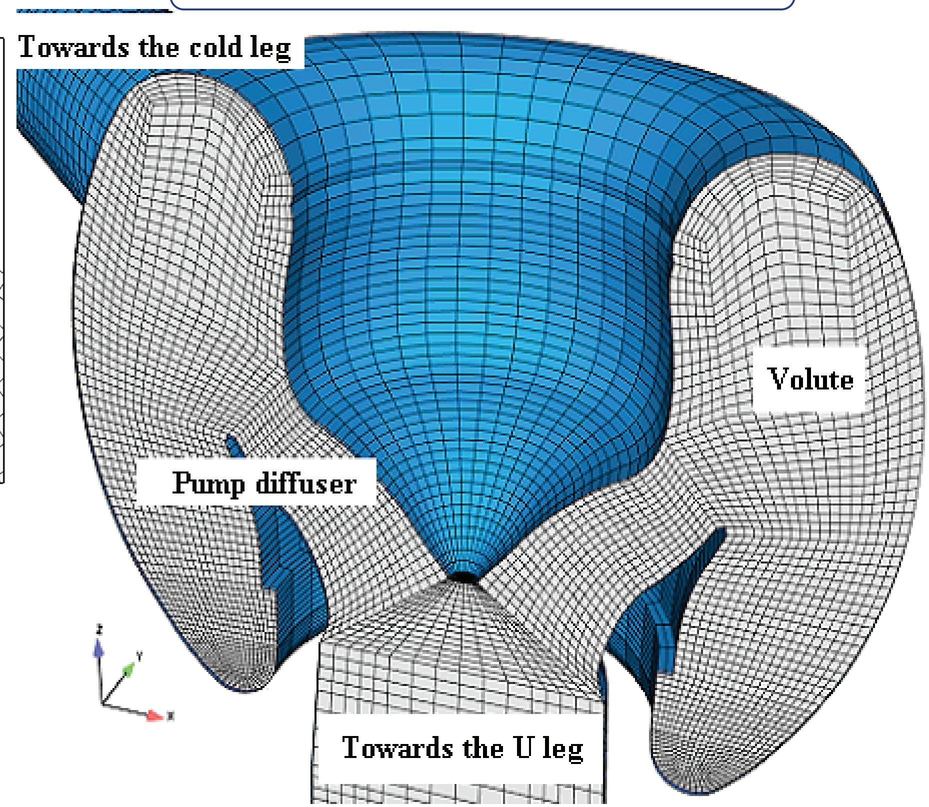


Mesh (2/2)

RCV inlet



Primary pump volute



Rotor and pales not represented

➢ Parameters are specified in the *Code_Saturne* programs

❖ Physical parameters

- ❑ Water: 155 bars and 293°C (cold leg water)
- ❑ ρ ($kg.m^{-3}$) depends on the temperature (linear by pieces)
- ❑ ρ variation ($kg.m^{-3}$) with boron concentration neglected

❖ Numerical parameters:

- ❑ Time step constant in time and space
- ❑ Turbulence model: k-ε model (regular model for industrial applications)
- ❑ Numerical scheme: centered (2^{nd} order) in space

Boundaries conditions

RCV inlet Entrance of the geometry : v, T, CB

Core Inlet Free inlet/outlet: Dirichlet condition on pressure, free outlet condition for velocity, zero flux for scalars

IS, RCV outlet and walls Walls: friction law on velocity, zero flux for scalars

Steam Generator
- Thermosiphon : inlet condition
- Without thermosiphon: free inlet/outlet condition

Initial conditions

- Initial velocity equals 0 everywhere
- Fluid temperature in cold leg: 293°C
- Scalar value representing borated water initialized at 1 everywhere
- Turbulence

Cases studied

❖ Thermosiphon values:

No thermosiphon ***(0kg/s)*** *(beyond the scope of the study)*
Realistic value : thermosiphon characterized with SIPACT ***(330kg/s)***
Search for critical flow rate (170kg/s, 100kg/s, 30kg/s)

❖ Temperature values for the water from the RCV inlet:

50°C: not heated water (by the RCV outlet)
282°C: temperature characterized with SIPACT
(247°C: maximal discharge)

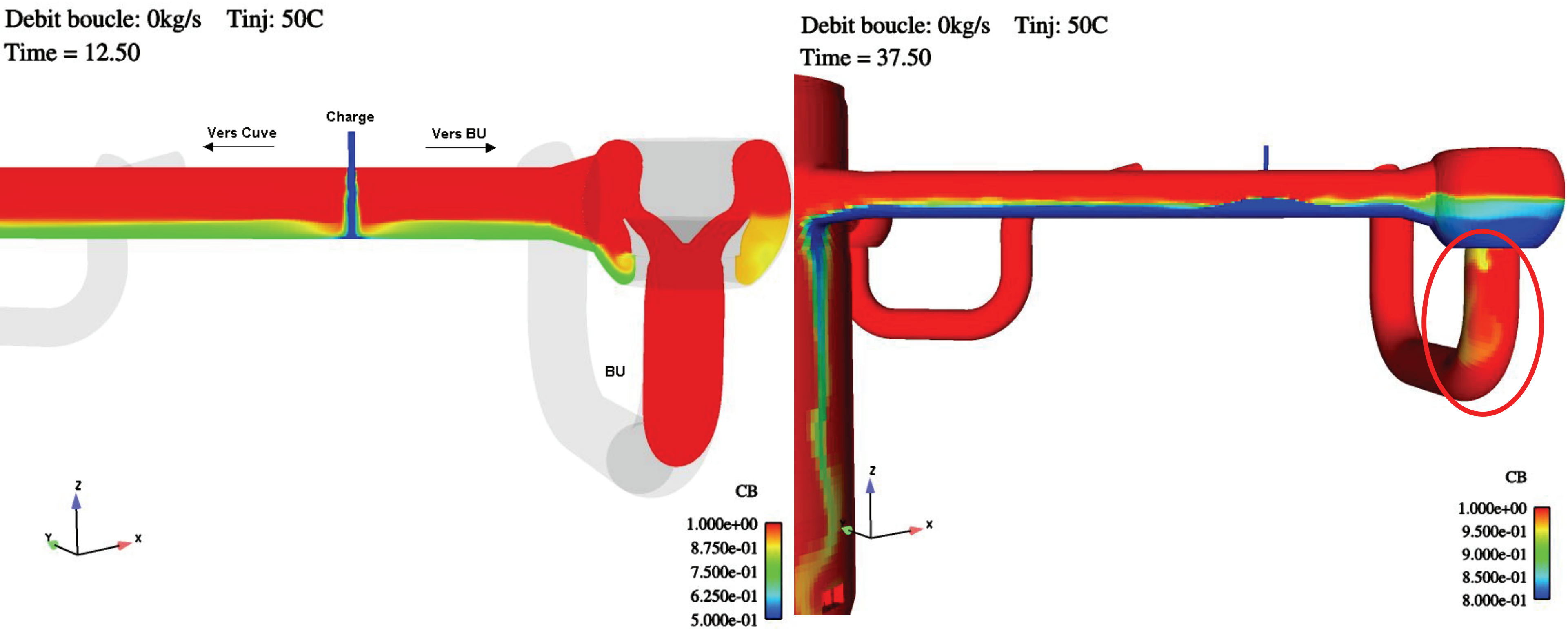
❖ Dependence on physical parameters

❖ Dependence on numerical parameters

3 Results

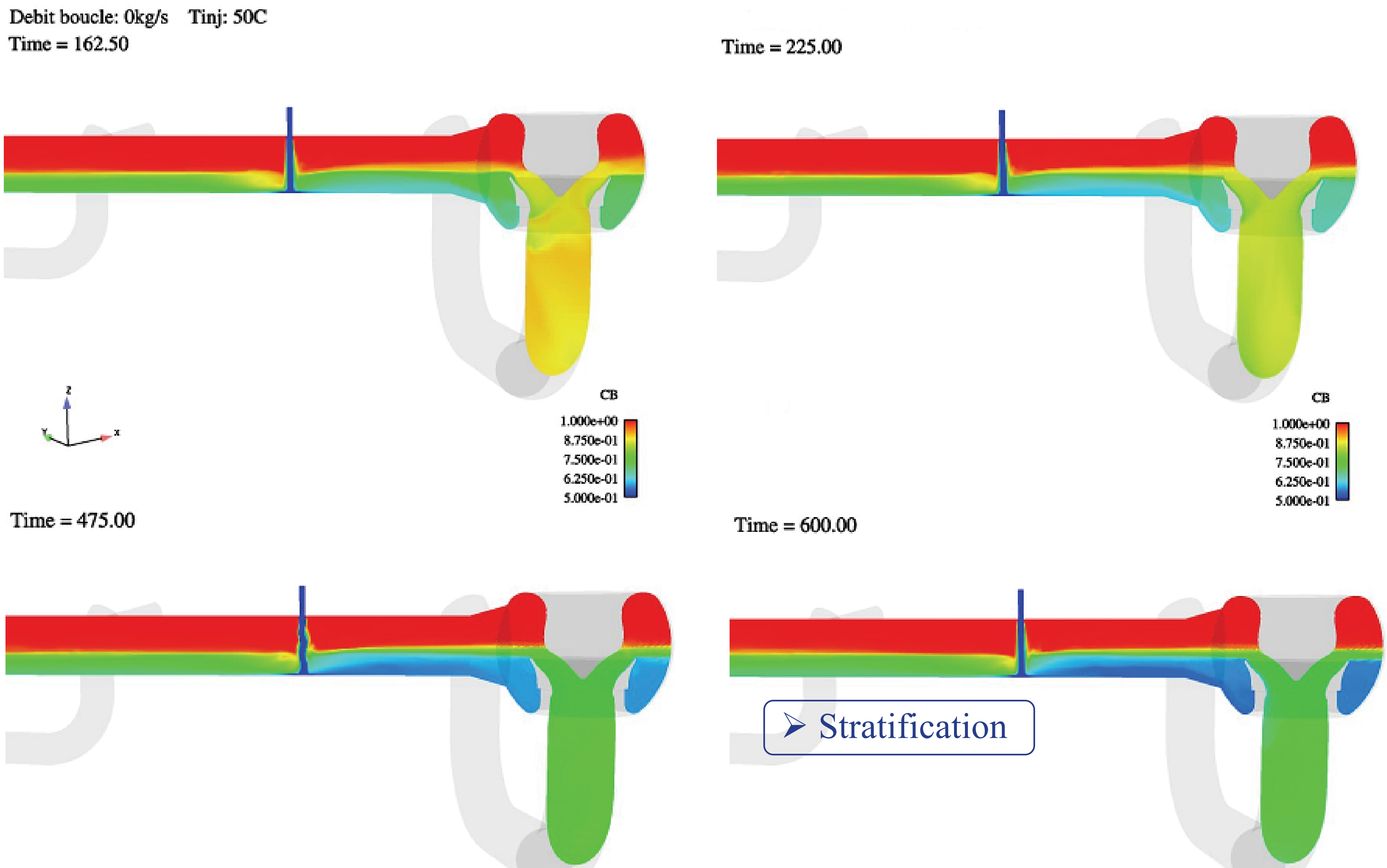
Case 0kg/s, 50°C

200h of calculations = 600s of physics

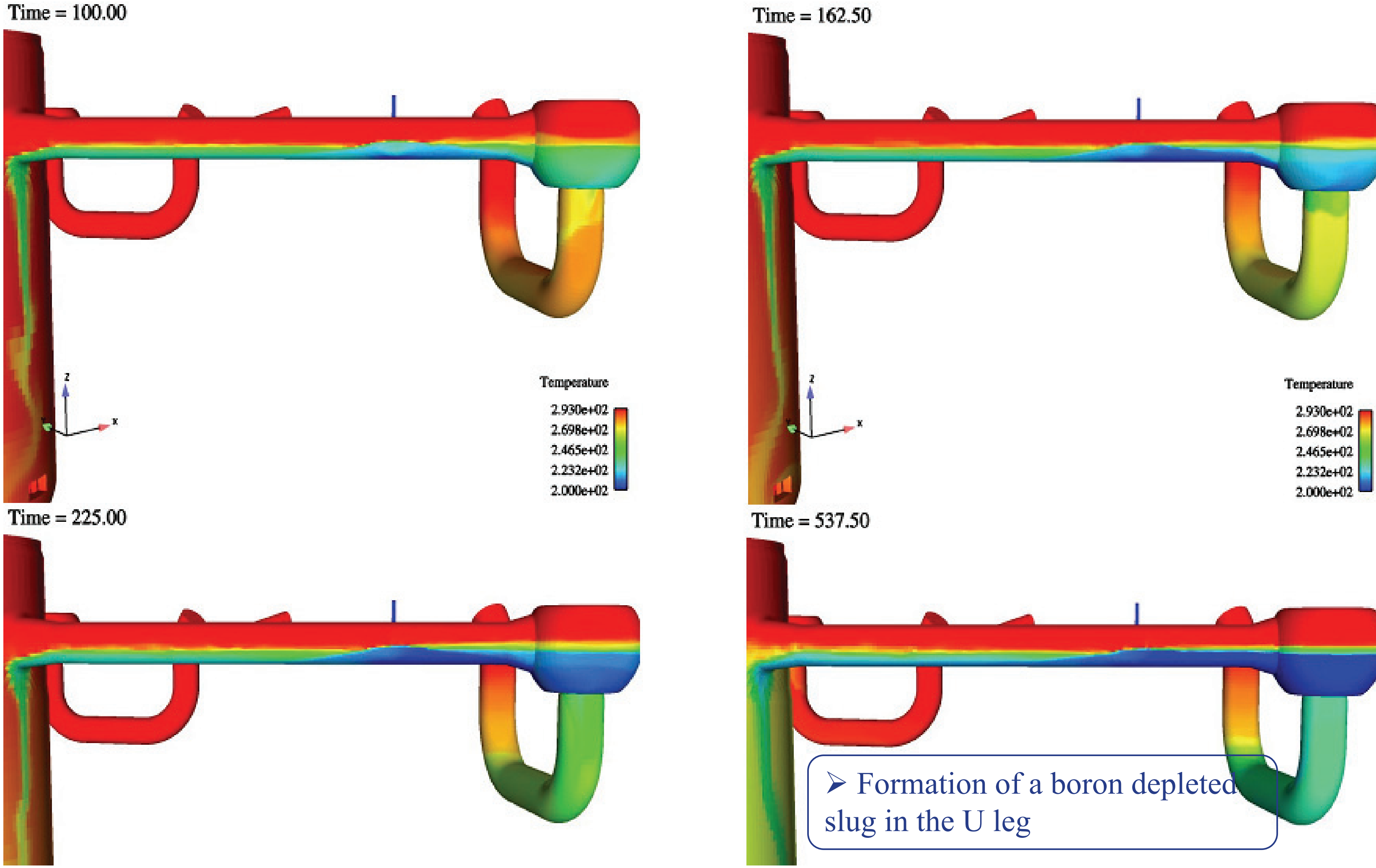


➢The water from RCV inlet overflows in a few seconds

Case 0kg/s, 50°C

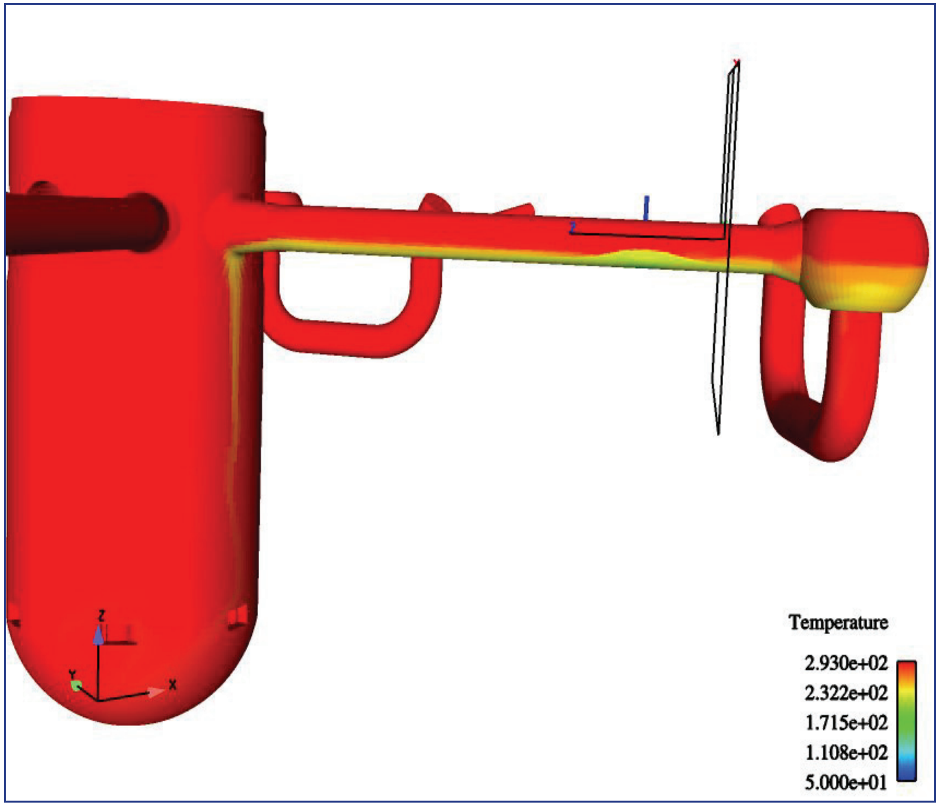


Case 0kg/s, 50°C



- Formation of a boron depleted slug in the U leg

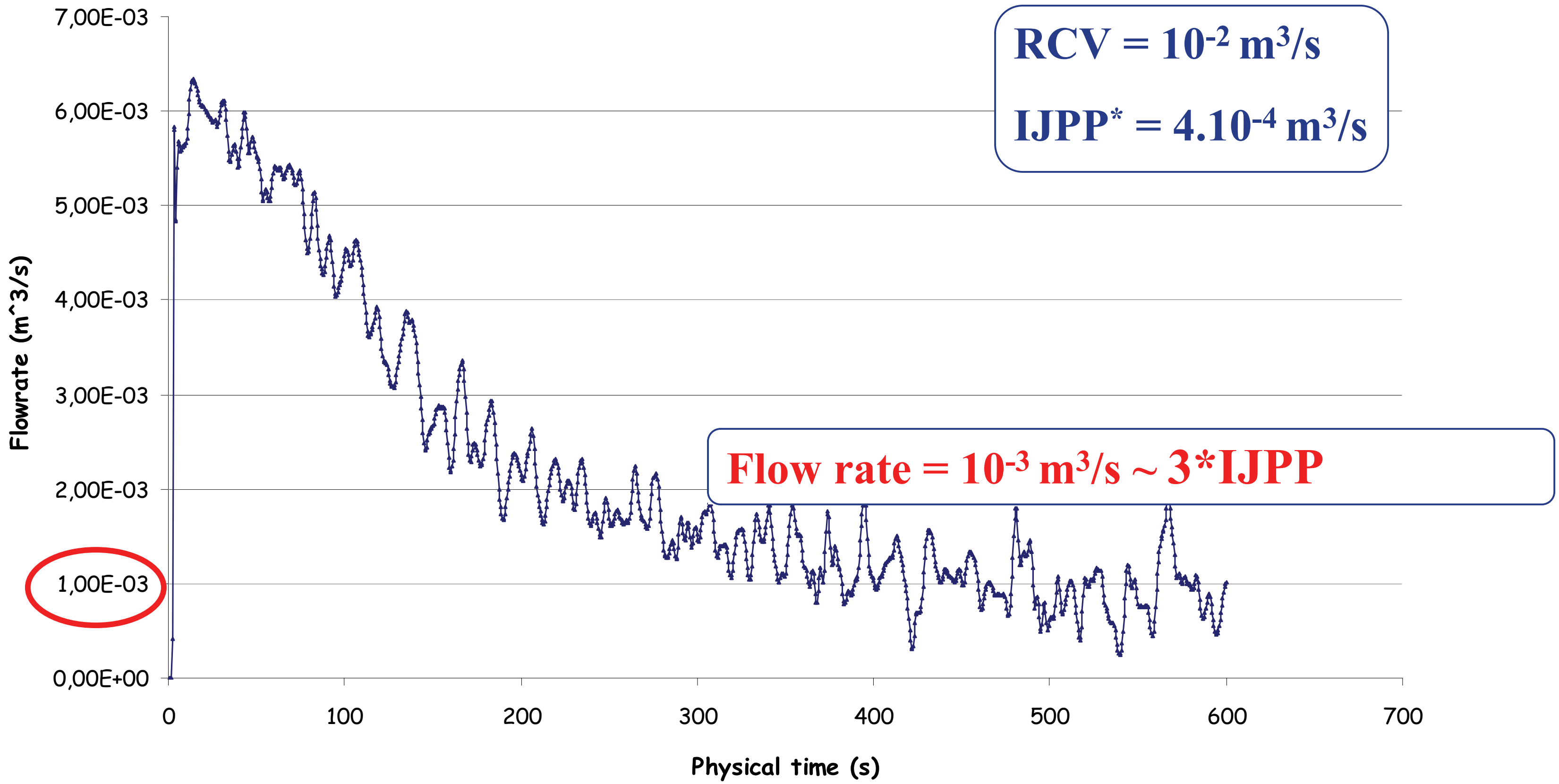
Cross section to determine the boron depleted water flow rate going to the loop seal



3 Results

Case 0kg/s, 50°C

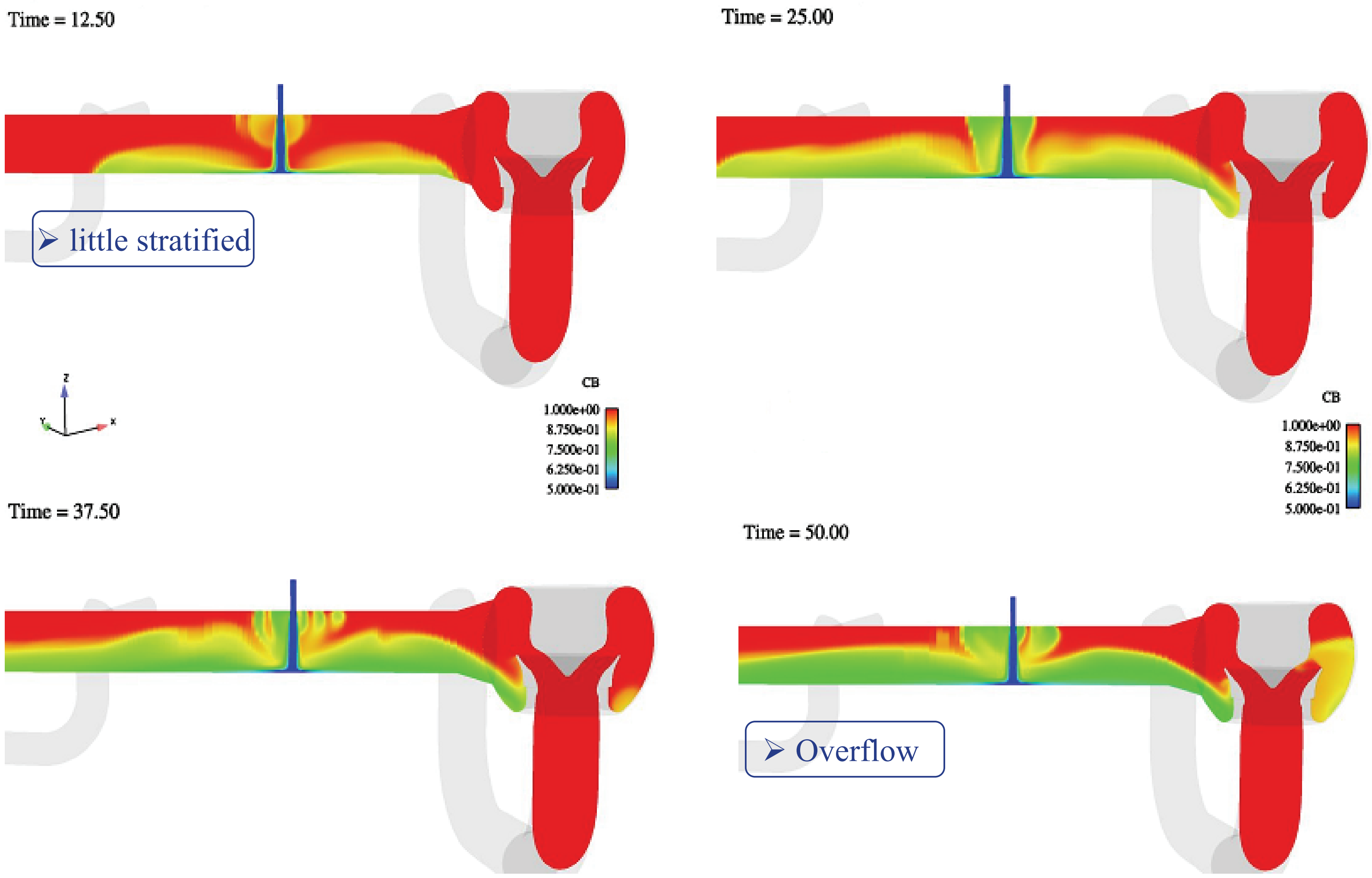
Evolution of the boron depleted water flow rate through the plane



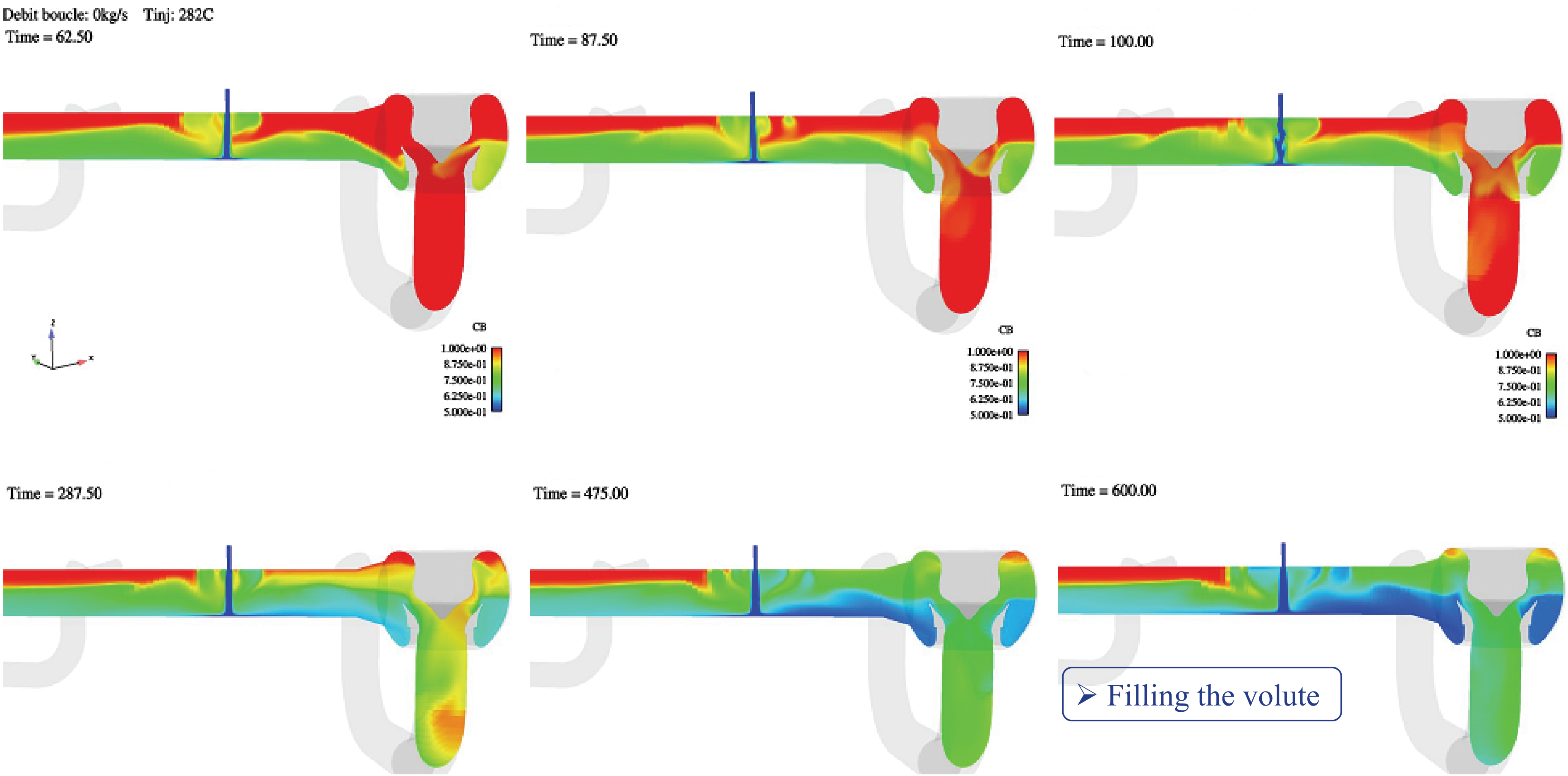
* Injection of cold water in the primary pumps joints

3 Results

Case 0kg/s, 282°C

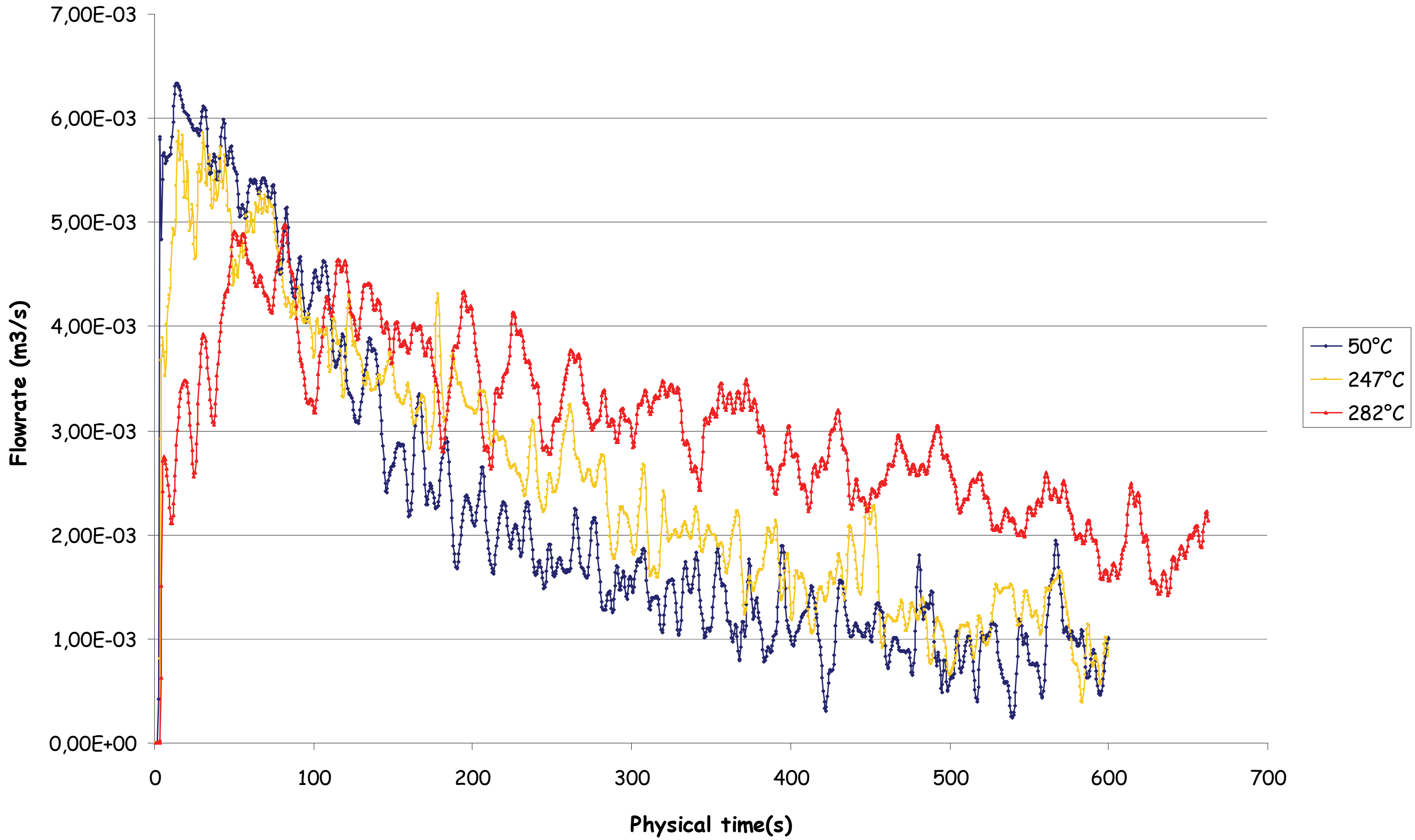


Case 0kg/s, 282°C

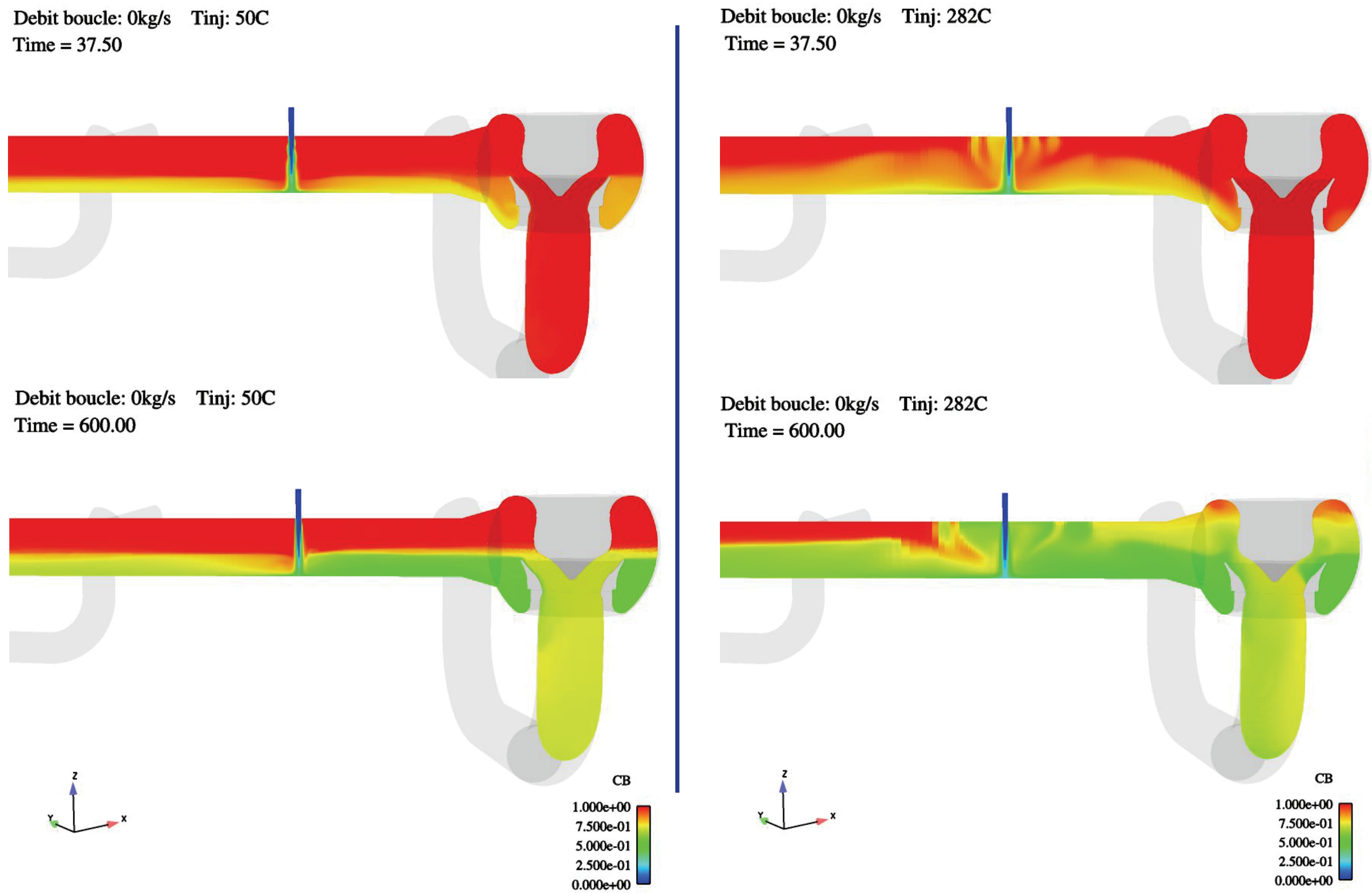


- Filling the volute

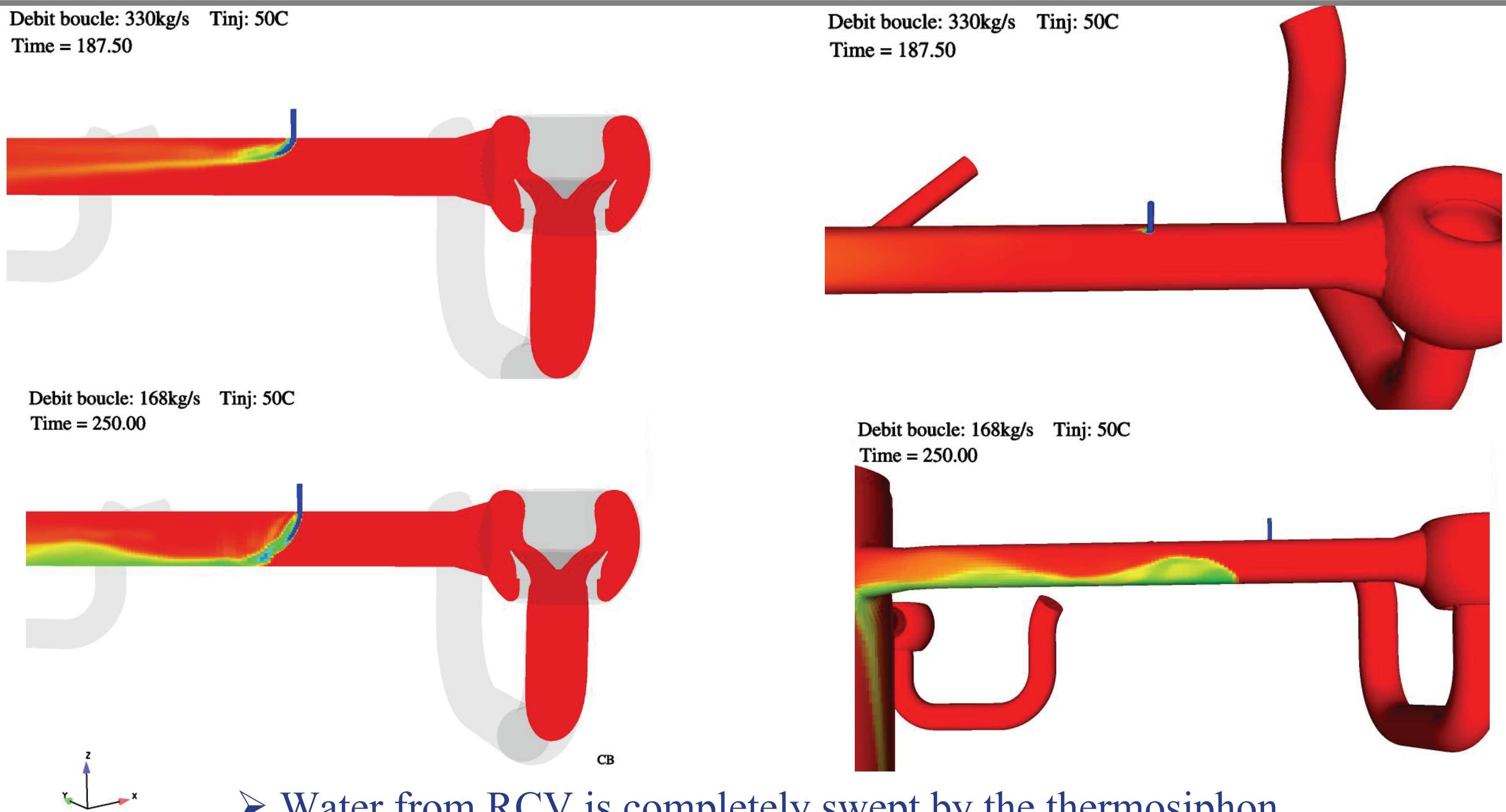
Comparison of cases 50°C, 247°C and 282°C



Comparison 50°C and 282°C

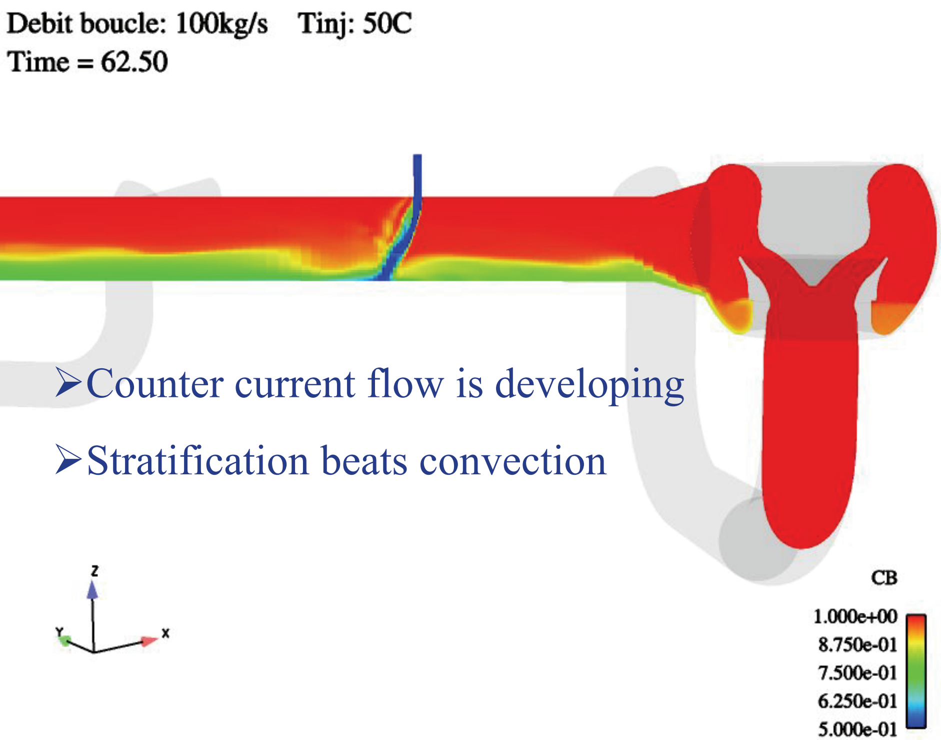


Case 330kg/s, 170kg/s

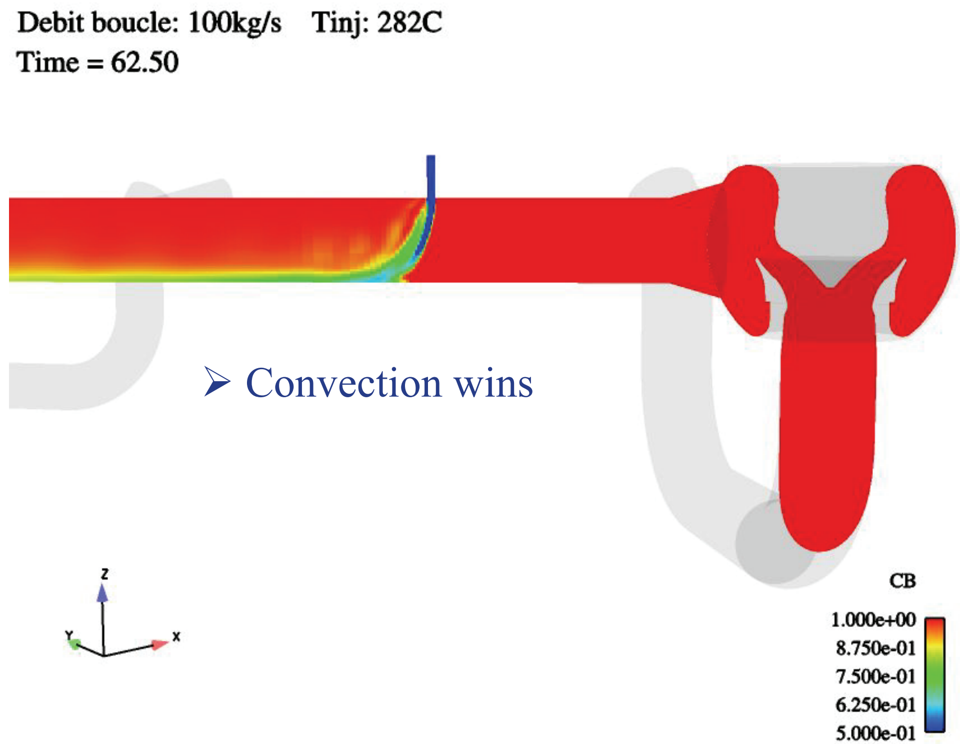


- Water from RCV is completely swept by the thermosiphon

Case 100kg/s



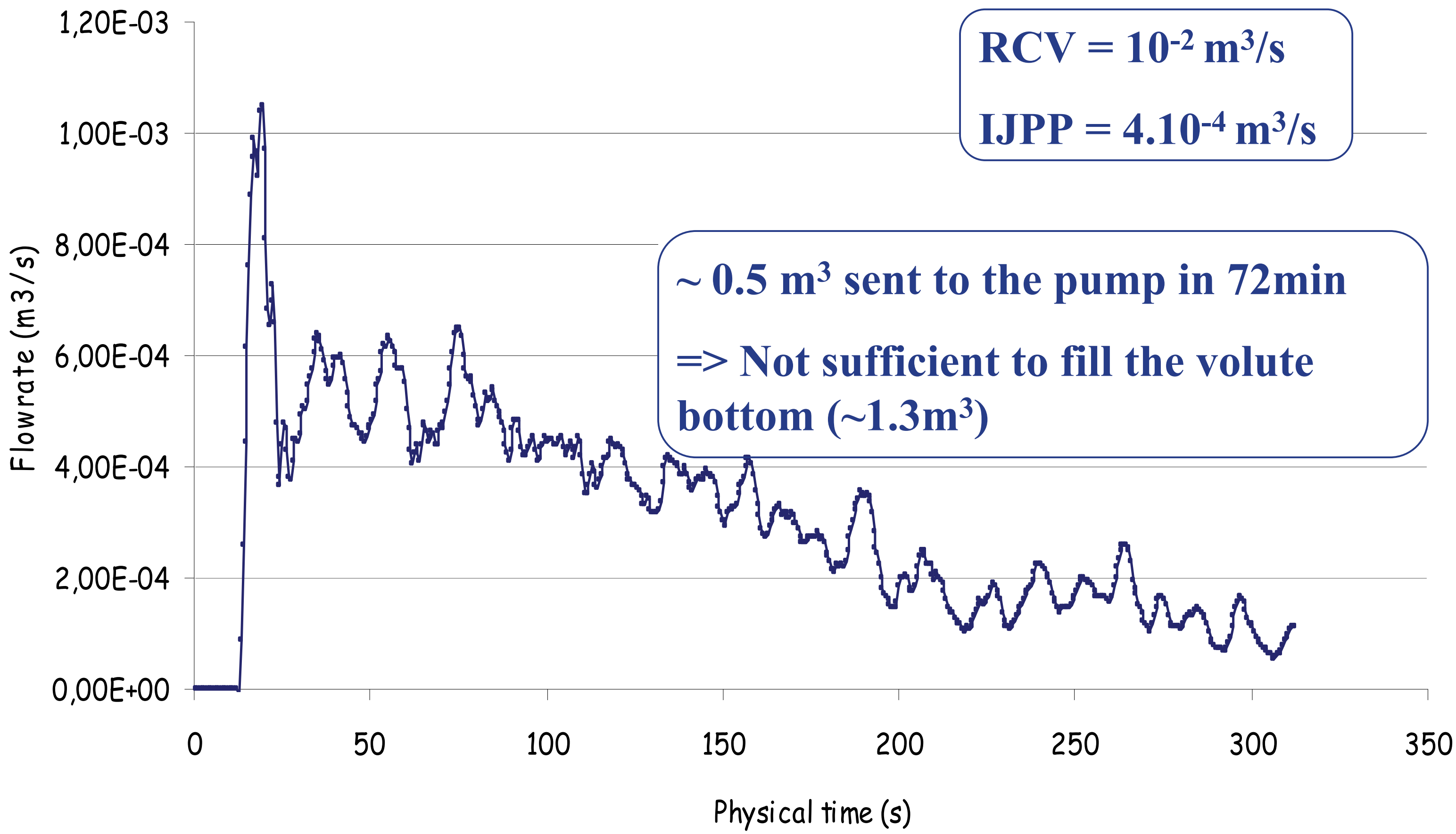
- Counter current flow is developing
- Stratification beats convection



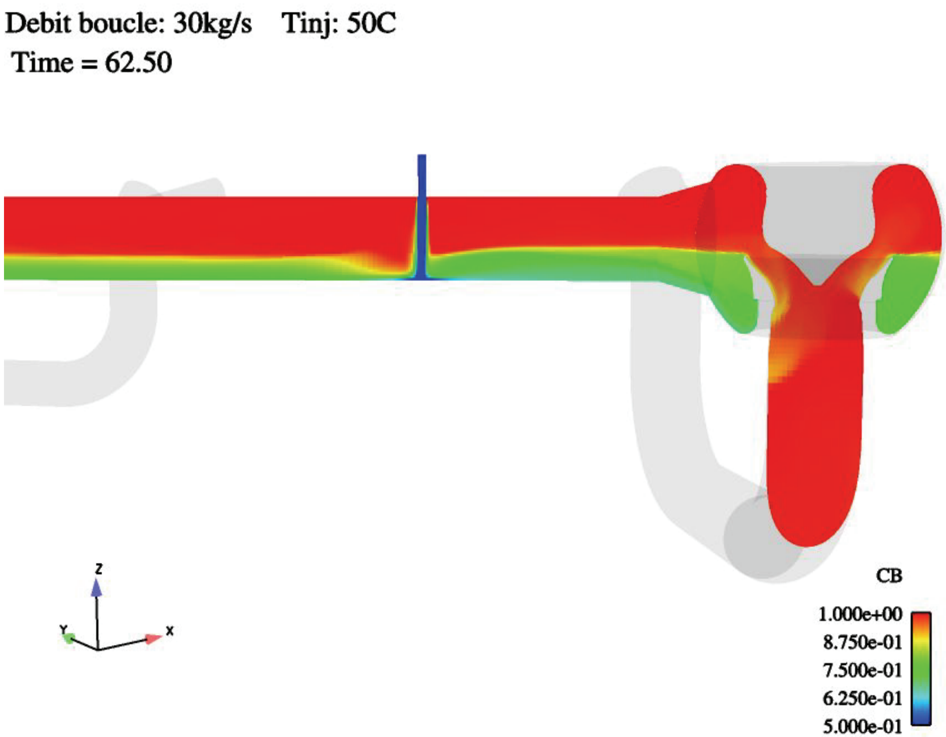
- Convection wins

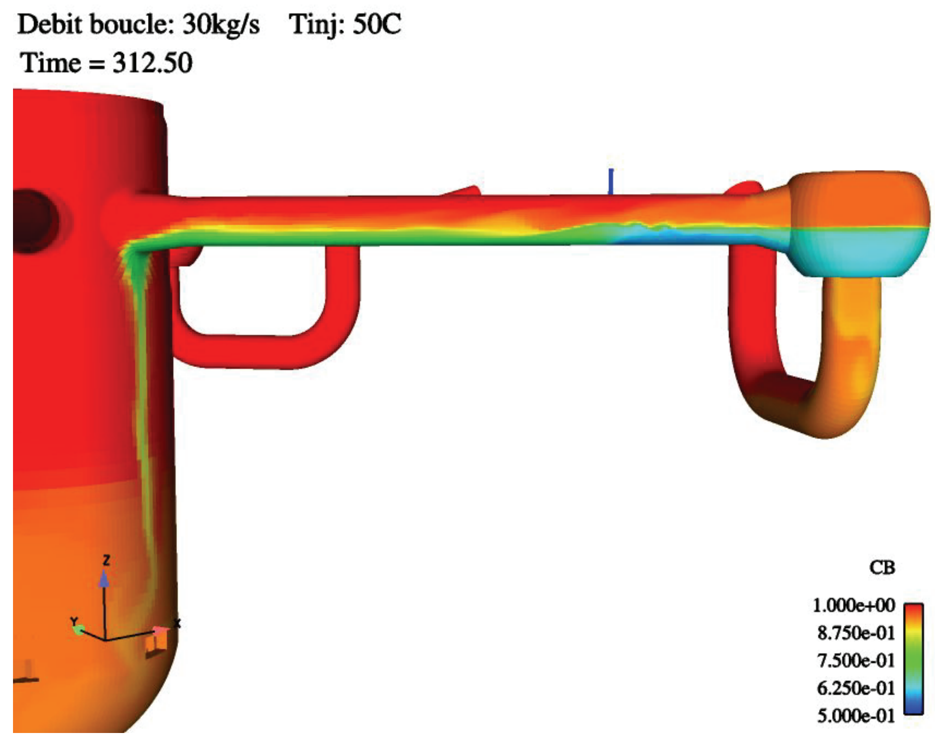
> Different behavior due to the variation of temperature

Case 100kg/s, 50°C



Case 30kg/s, 50°C



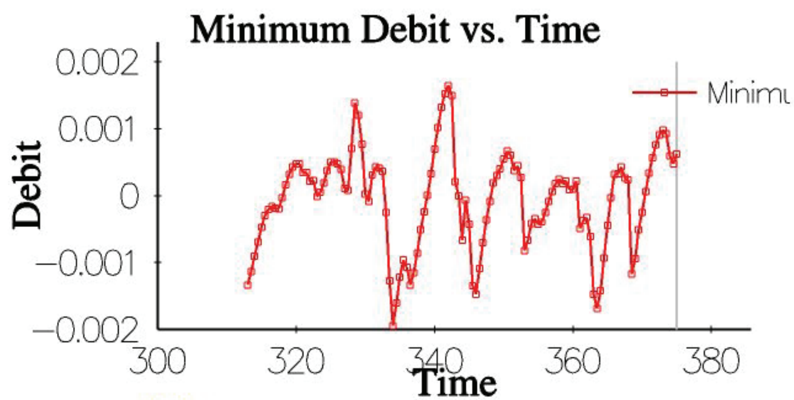


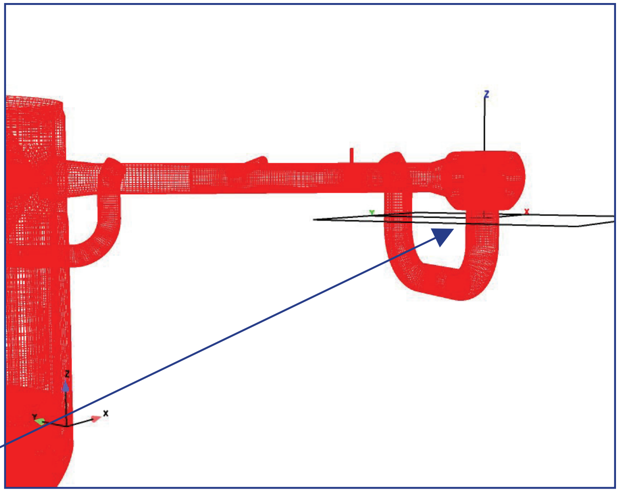
➢ Overflow in a few minutes

3 Results

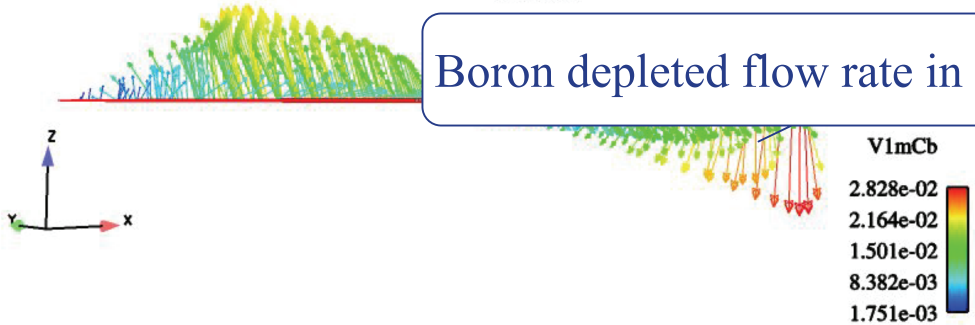
Case 30kg/s, 50°C

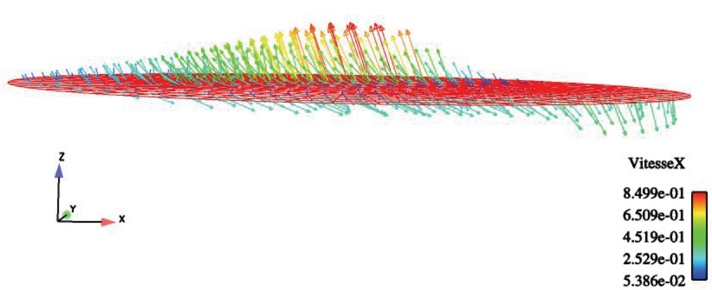
Representative part of the flow





Boron depleted flow rate in the loop seal : ~ $5.10^{-5} m^3/s$ ~12.5%IJPP





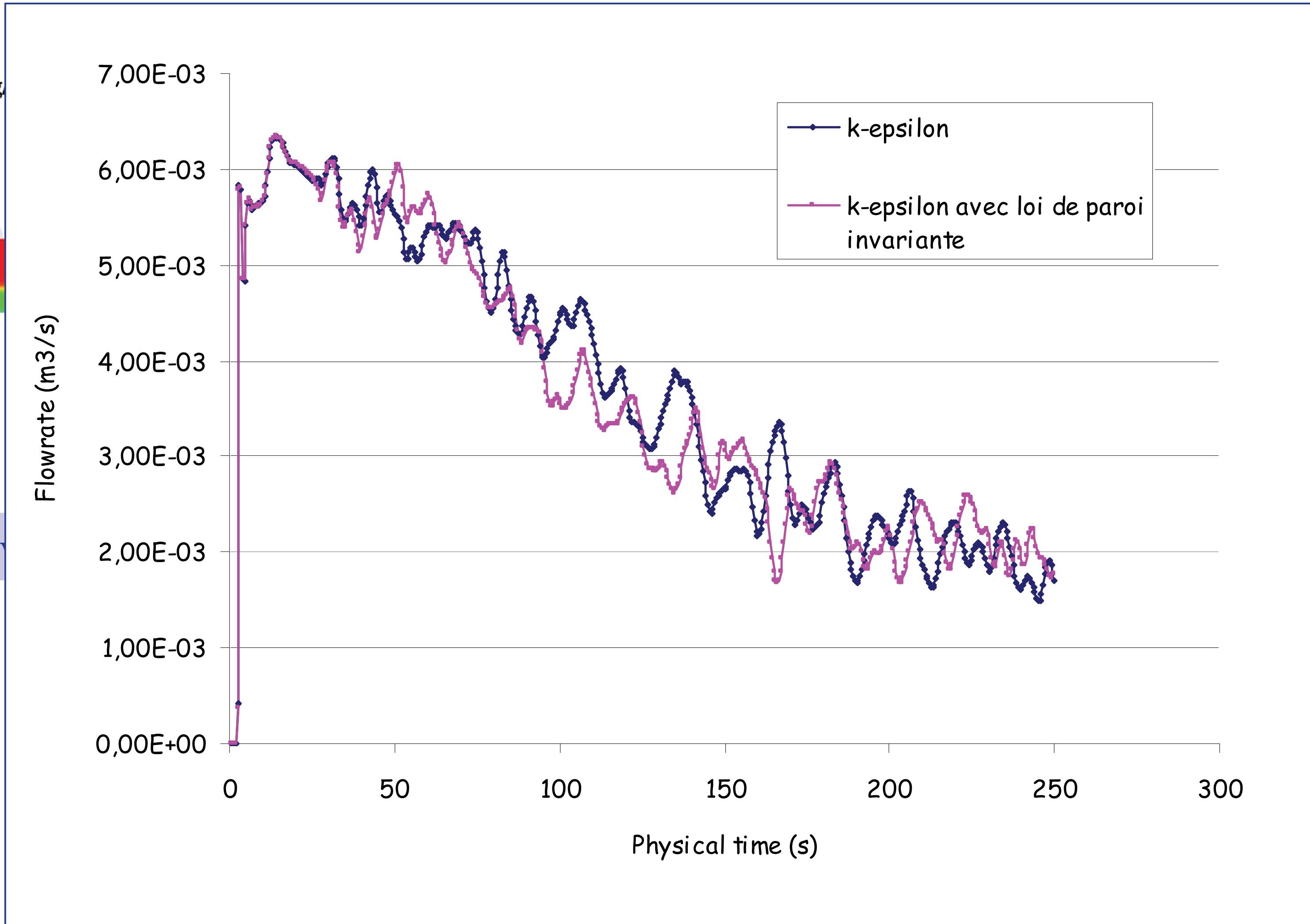
3 Results

- **Very weak thermosiphon (30kg/s):** overflow towards the U leg
- **Realistic thermosiphon (above 100kg/s):** no overflow of the RCV water
  - **Operator delay (72min) preserved**

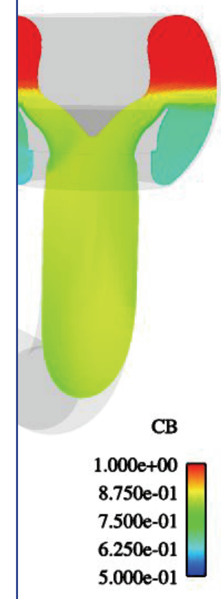
- ✓ Physical parameters
- ❖ Numerical parameters

k- ε model versus k-ε with invariant wall law model *(0kg/s, 50°C)*

Debit boucle: 0kg
Time = 225.00

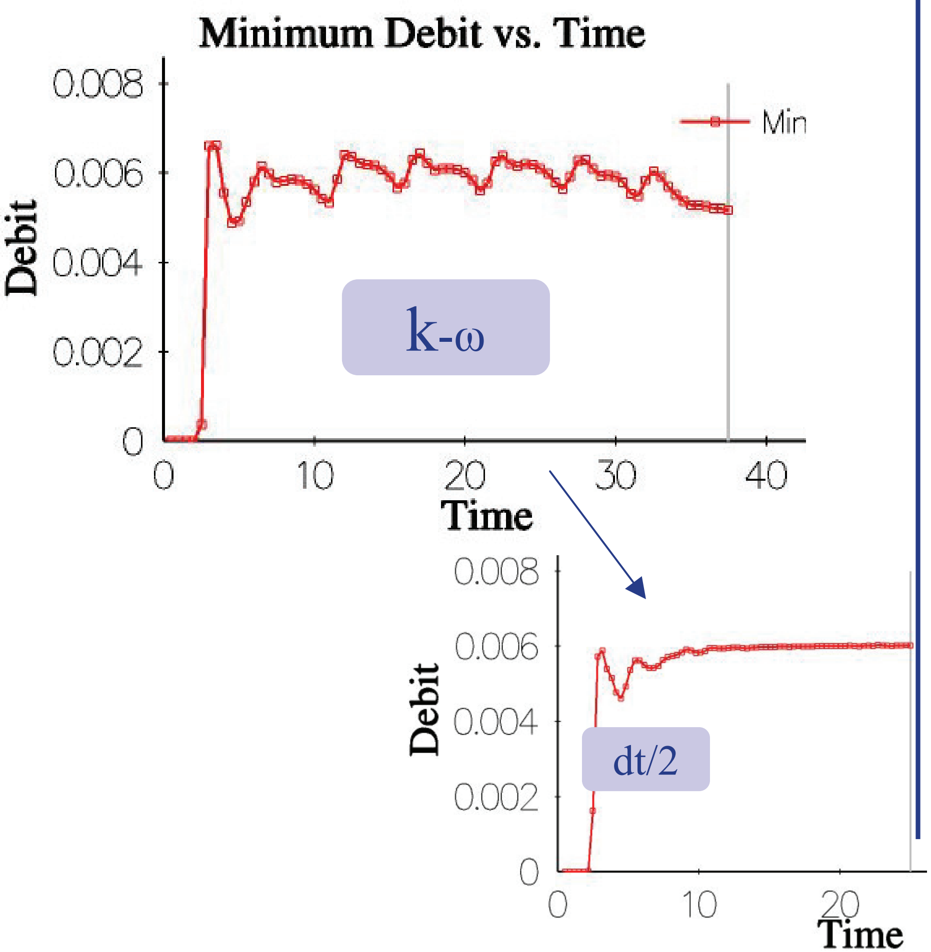


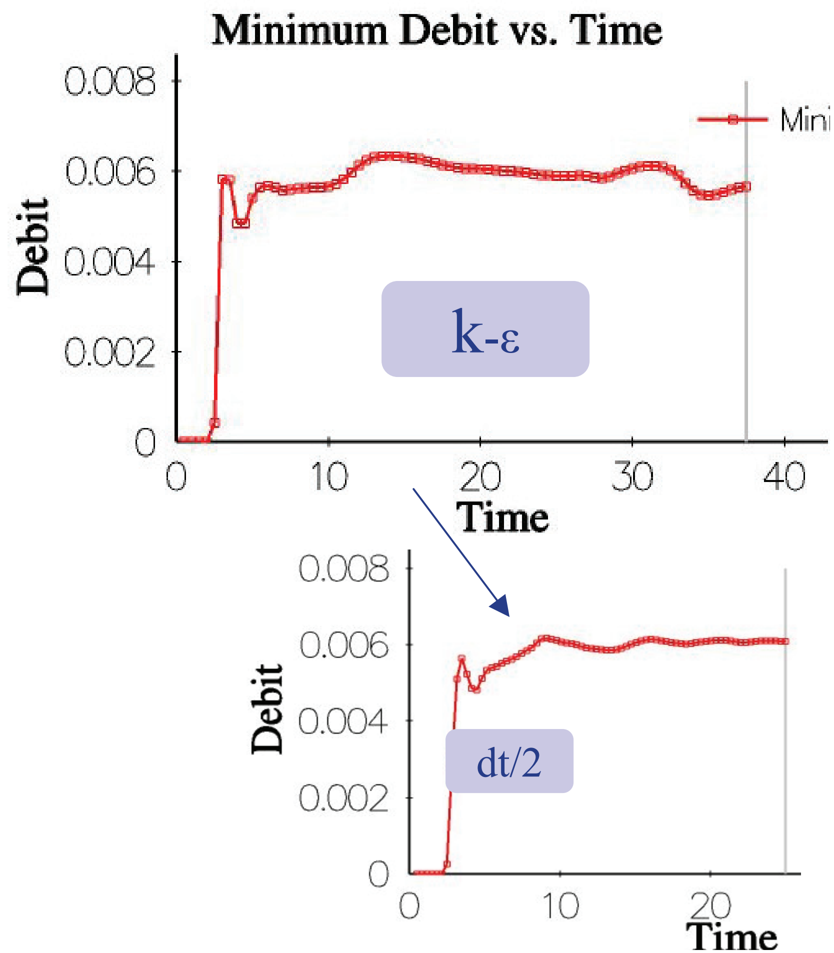
k- ε



- Same study with the other cases (330kg/s, 100kg/s)
- k-ε model gives good results even if some mesh points are too close to the wall

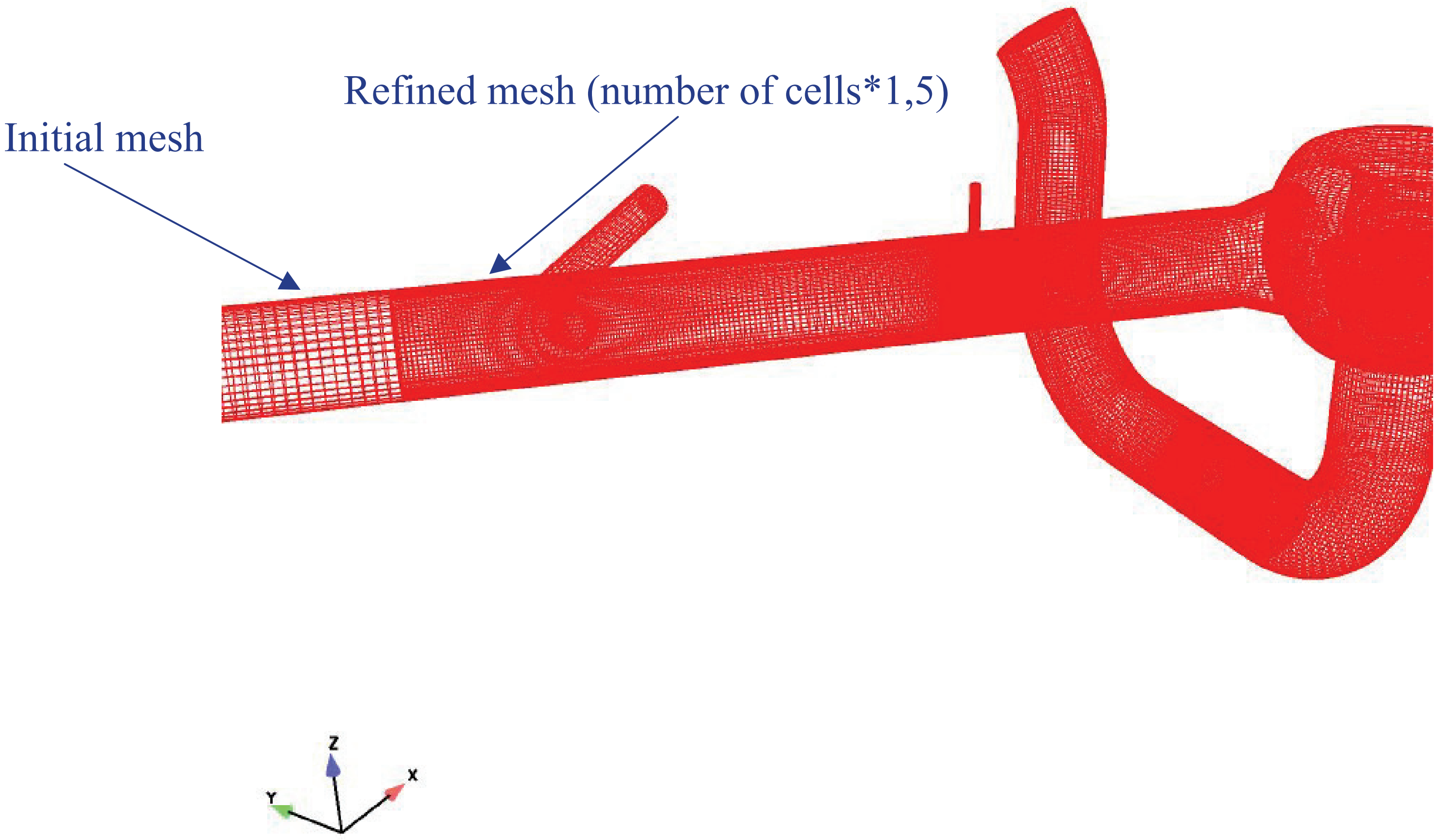
k-ω SST model versus k-ε model *(case 0kg/s)*



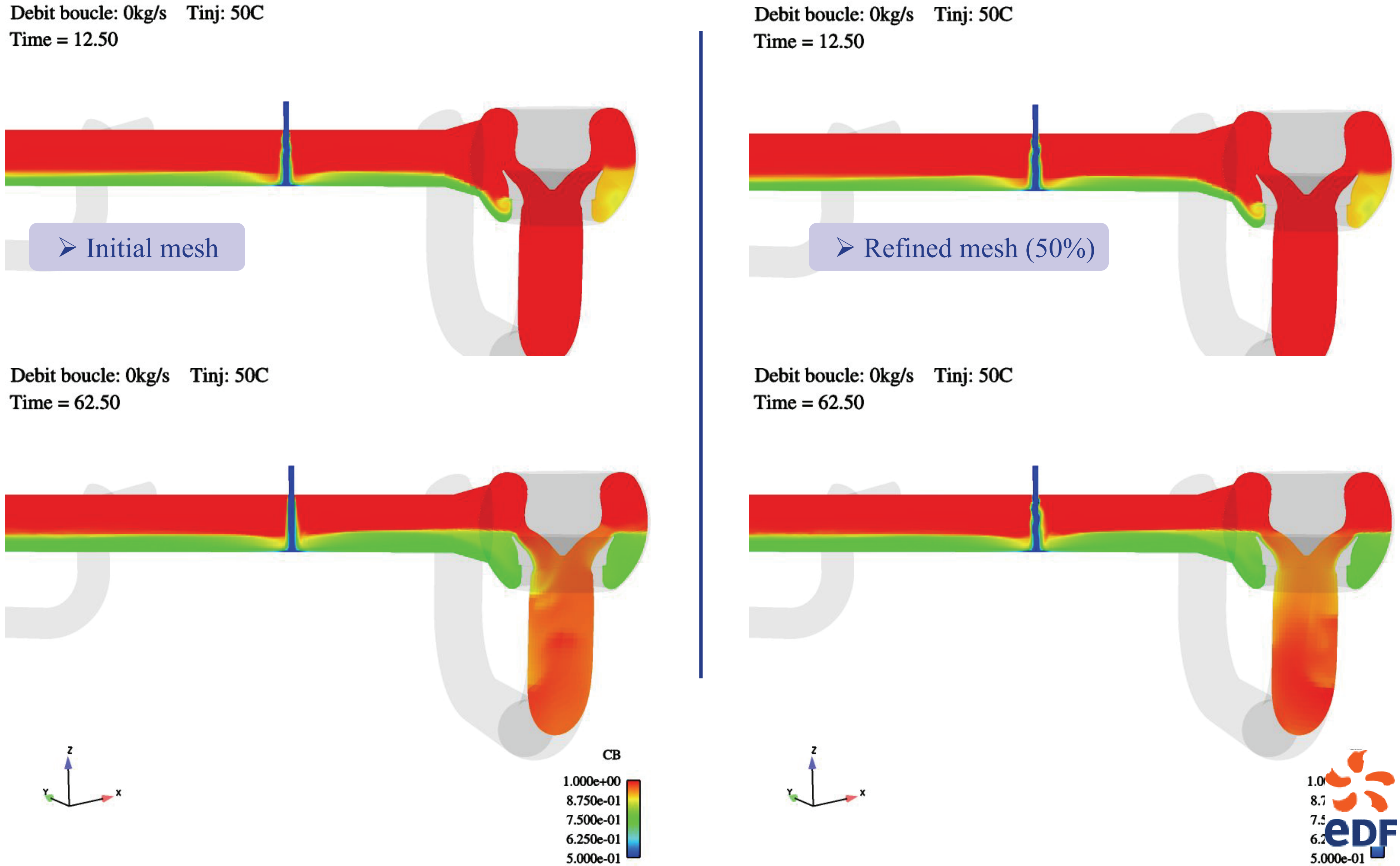


- ✓ R_{ij}- ε model (30kg/s, 0kg/s)
- ✓ Coherent results in function of the turbulence model
- ✓ Results independent of the time step

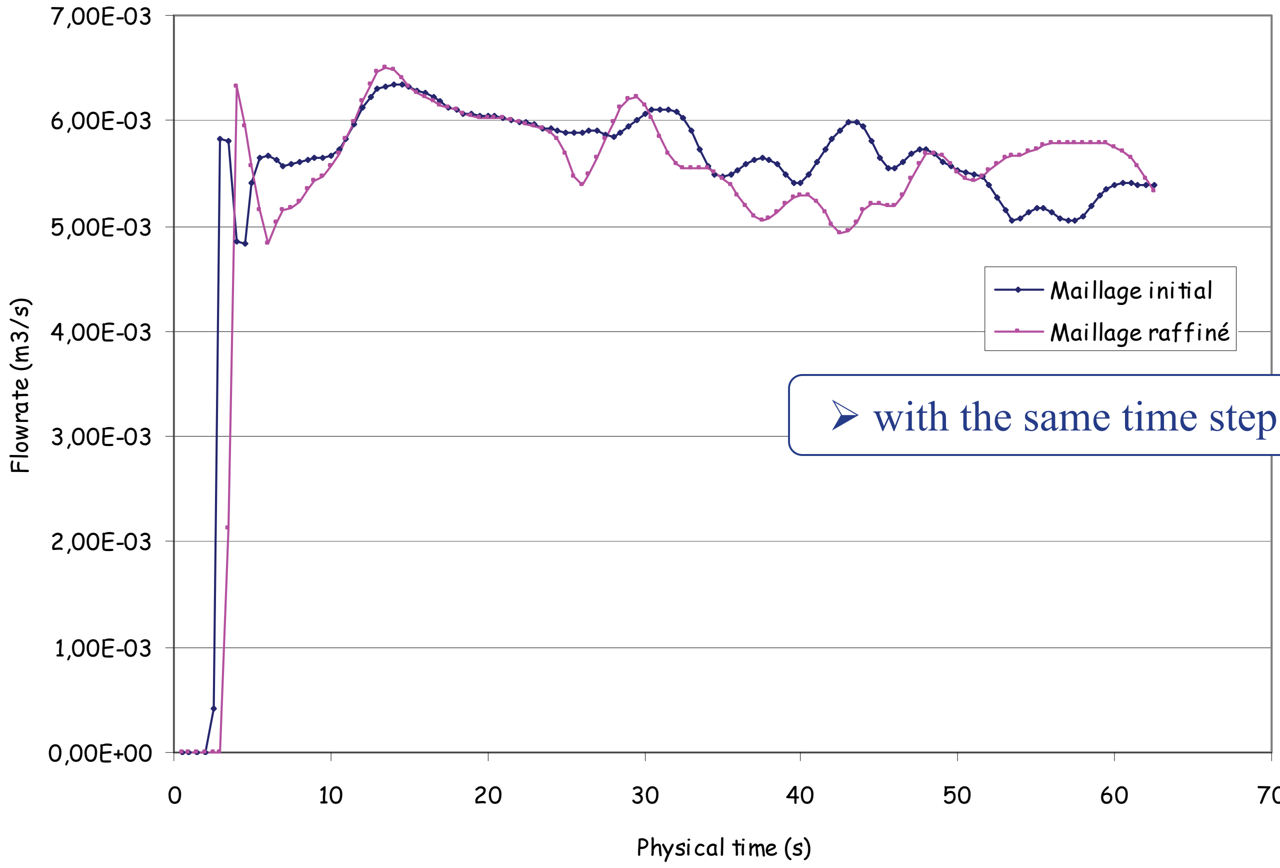
Refined mesh



Refined mesh



Refined mesh



➤ with the same time step

Conclusion

- Physical parameters
  - **Weak thermosiphon (<100kg/s):** overflow towards the loop seal with significant flow rate
  - **Realistic thermosiphon :** no overflow
    - **Delay preserved**

- Numerical parameters
  - Turbulence model modify results but the conclusions above are preserved
  - Convergence in mesh
  - Results independent of the time step