NUCLEAR PRODUCTION OPTIMIZATION UNDER SEVERE WINTER CONDITIONS

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Cooling system availability for production under frazil ice risk

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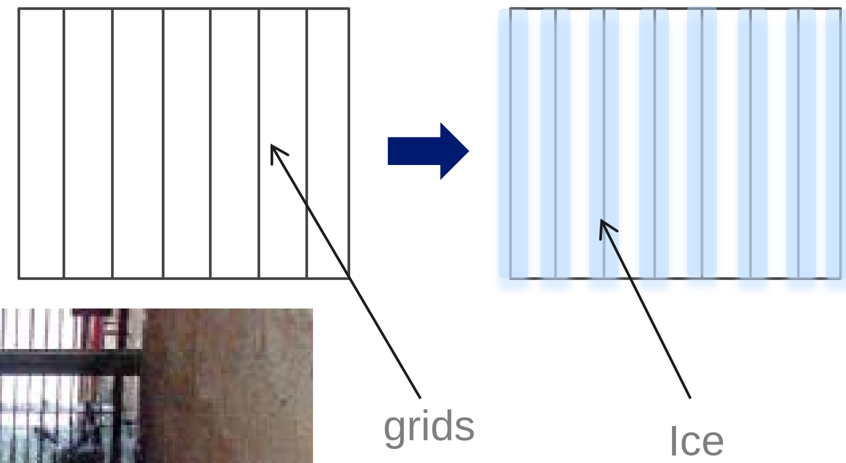
CONTEXT
OPTIMIZATION OF WINTER NPP PRODUCTION

- **Frazil ice risk for NP**
  - Ice formation on grids can lead to stop the production because of partial loss of cold source



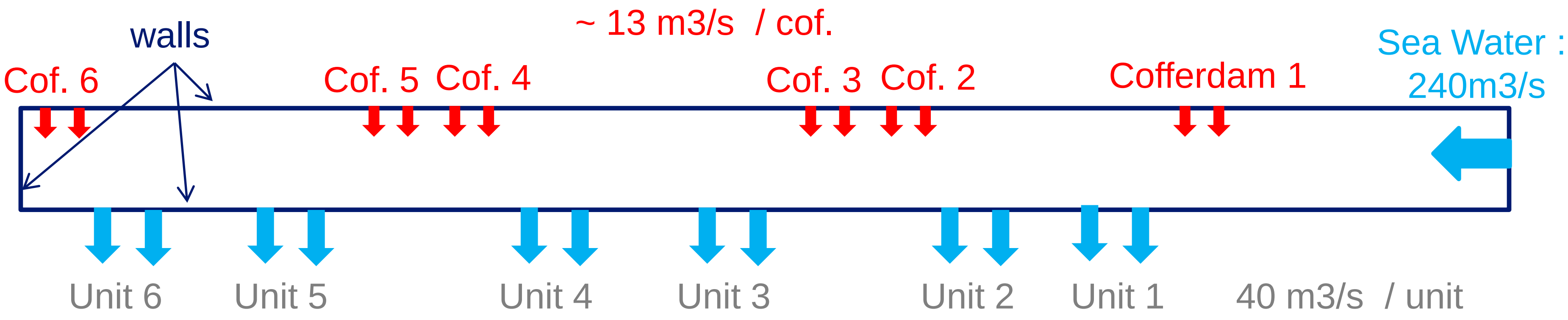
- **Engineering centre ask for a generic study of typical NPP under severe winter event**

- **Stategy to avoid frazil ice risk : hot water injection in the NPP channel**

SITE

TYPICAL NUCLEAR POWER PLANT DEFINITION

- **Choice of a typical seaside NPP channel + typical water levels (tides)**



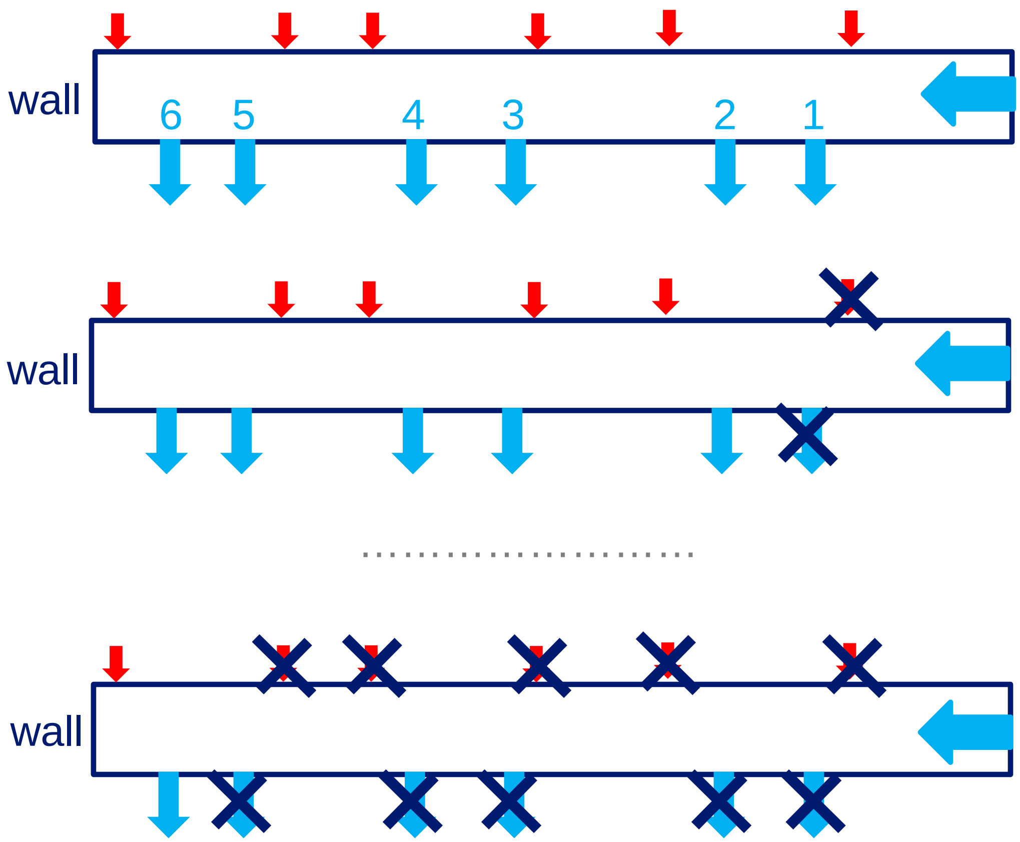
- **« Cofferdam » system to inject hot water**
  - 2 groups of 3 for each unit
  - Upstream/downstream pumps
  - Above Sea Water Level (SWL) or submerged (depending on tides !)
  - Hot water taken from waste heat of the NPP

- **Goal of the study**
  - How many units can be protected by this cofferdam system ?
  - Methodology definition for real sites.

OBJECTIVES

HOW MANY UNITS CAN BE PROTECTED FROM FRAZIL ICE ?

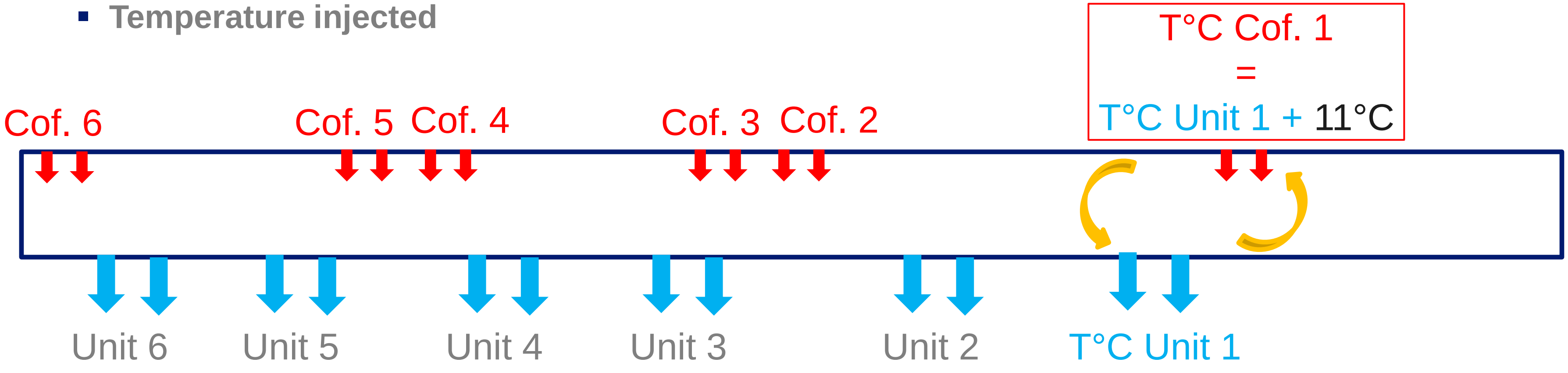
- **Methodology used here :**
  - **Initial T°C in the channel : 0°C.**
  - **Different SWL**
  - **Physical time : 2h**
  - 6 units in production
    - If unit 1 is not protected then
  - 5 units in production
    - If unit 2 is not protected then
  - 4 units in production
    - If unit 3 is not protected then
  - 3 units in production
    - If unit 4 is not protected then
  - 2 units in production
    - If unit 5 is not protected then
  - 1 unit in production



- **Protection if ΔT°C > 2°C**
  - Criterion to guess how many units could be protected
  - Anyway the study had to be performed for any configuration (1 to 6 units in production)

INPUT/OUTPUT TEMPERATURES

- **Temperature injected**



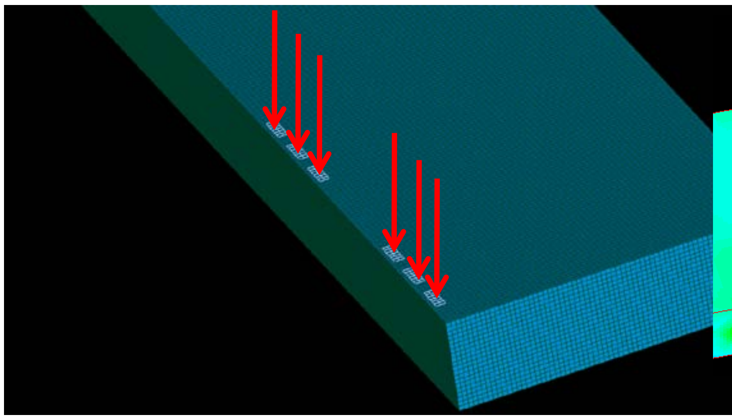
- ***Code_Saturne* user routines**
  - **cs_user_module.f90** : Definition and allocation of a table to stock the temperature of the production unit pumps.
  - **cs_user_extra_operation.f90** : Computation of mean temperature at pumps : « T unit » (time step n)
  - **cs_user_boundary_conditions.f90** : affectation of temperature at cofferdams : « T unit + 11°C » (time step n+1).

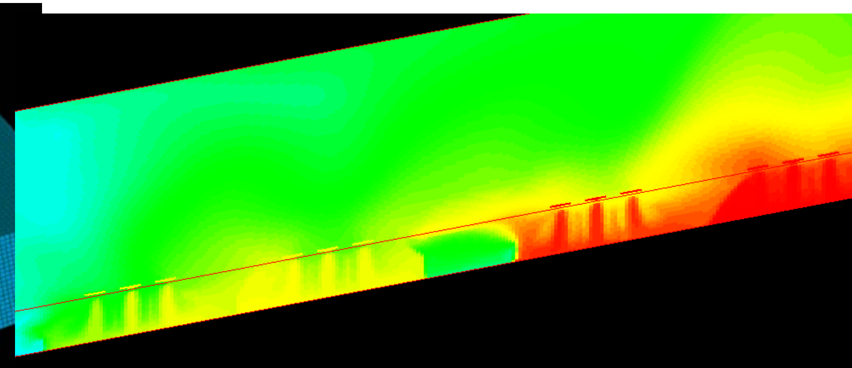
SWL CHOICE

DEFINITION OF 3 LEVELS

- **2 main stream configuration can be imagined for this site**
  - Case 1 : the SWL is lower than the cofferdam and then the hot water will fall from the cofferdam to to the channel : vertical injection
    - Need to estimate the vertical velocity
    - Low level of stratification (depending on the SWL)

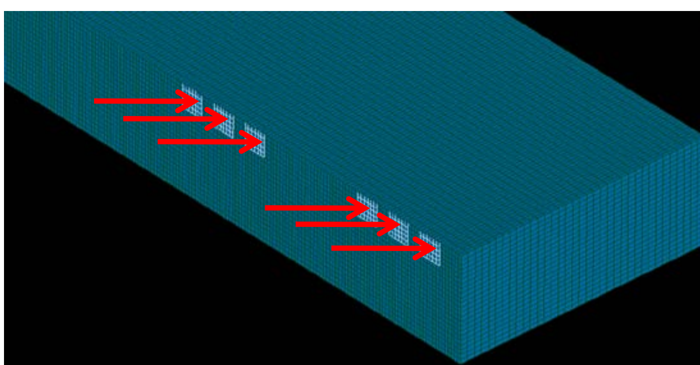
Low water level
Mean water level

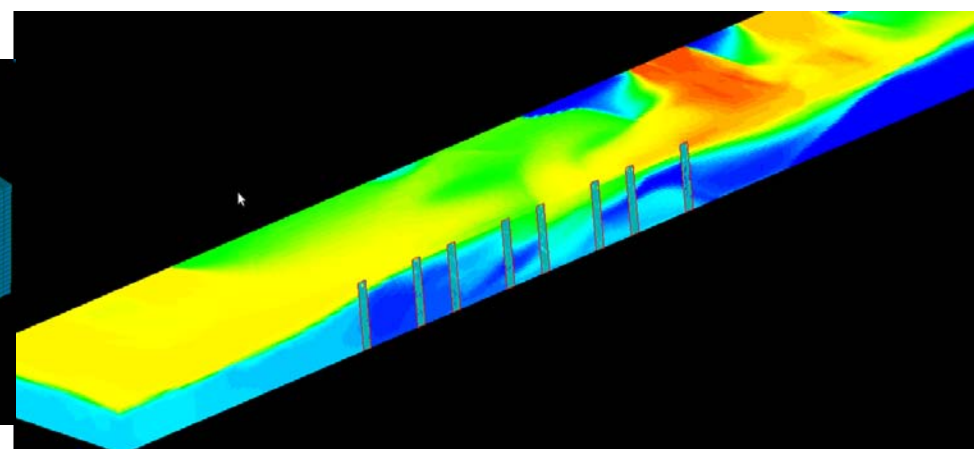




  - Case 2 : the SWL is as high as the cofferdam : horizontal injection
    - High level of stratification

High water level

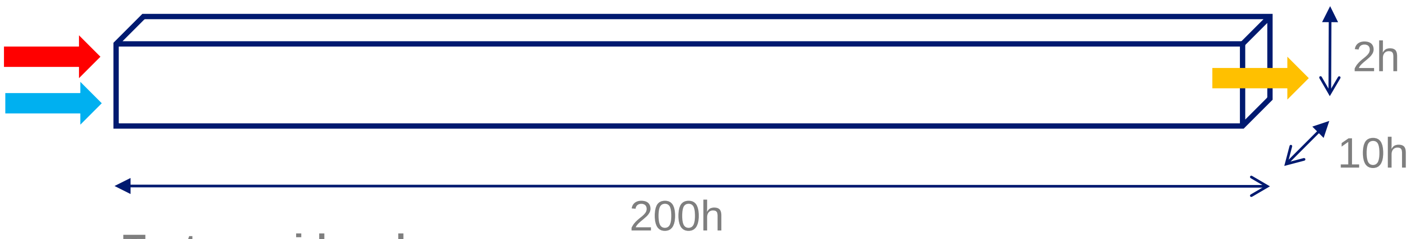




VALIDATION

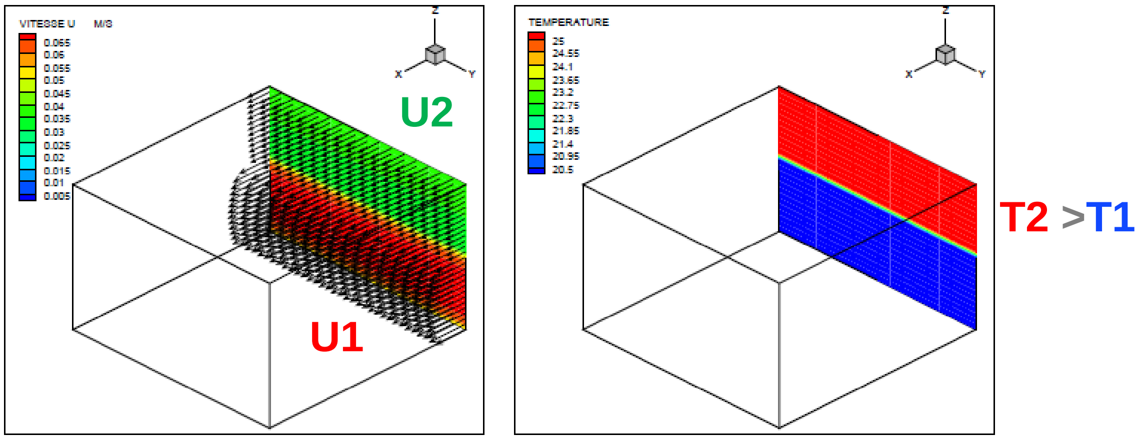
TEST CASE 1 : VIOLLET'S EXPERIMENTS (1980)

- **Geometry**



- **Test considered :**
  - $U2=3cm/s < U1=6cm/s$
  - $T2=25°C > T1=20°C$
  - Stable
  - h=0.1m
  - Fr = 0.9

$$F_r = \frac{|U_2 - U_1|}{\sqrt{gh\frac{\Delta\rho}{\rho}}}$$



(a) Profil de vitesse

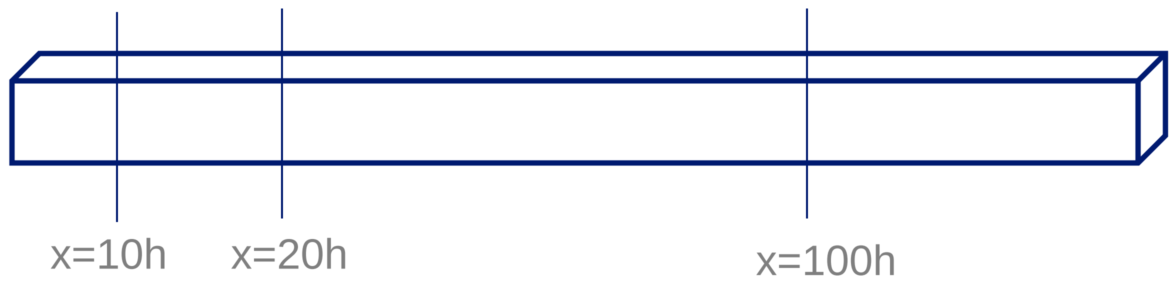
(b) Profil de température

- **Numerical study done by Martin Ferrand with TELEMAC CFD system (2009)**
  - Stable & instable simulations
  - Good correlation between k-ϵ model and experiments

VALIDATION

TEST CASE 1 : VIOLLET'S EXPERIMENTS

- **Code_Saturne results**
  - Velocity/Temperature profiles for different sections
  - k-ε model - standard version
  - Option **IPHYDR=0**
  - Differences for x=100h

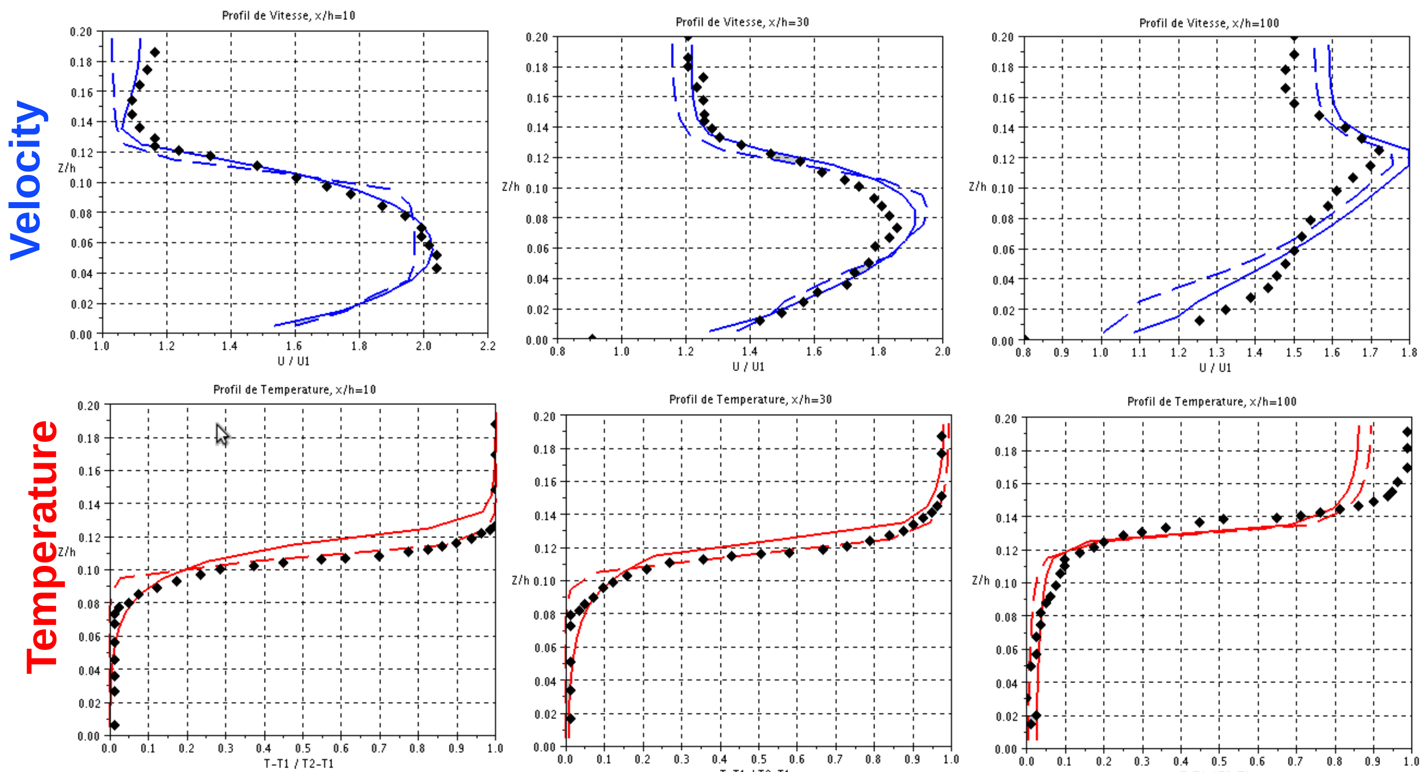


Velocity profile at boundary

No profile

Velocity profile at boundary

No profile



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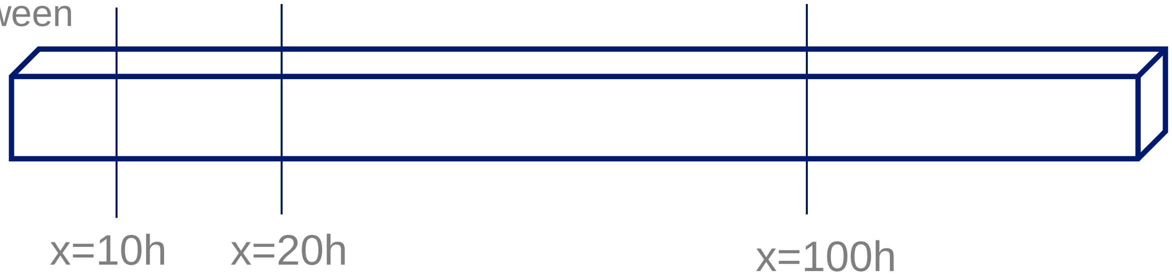
VALIDATION

TEST CASE 1 : VIOLLET'S EXPERIMENTS

- **Code_Saturne results**
  - Change of option for balance between pressure gradient and gravitiy
  - Option IPHYDR=1
  - **You can trust the documentation !**

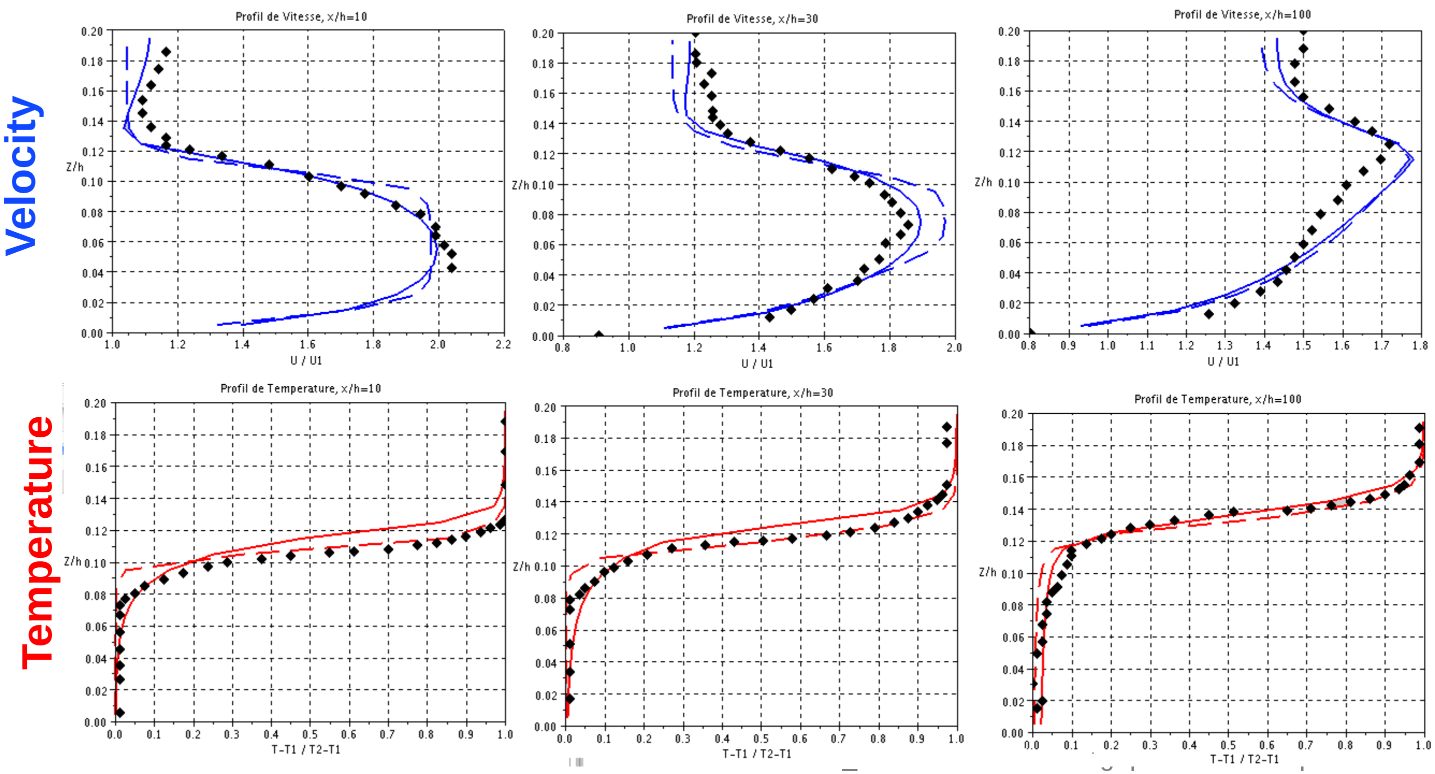


Velocity profile at inlet

No profile

Velocity profile at inlet

No profile



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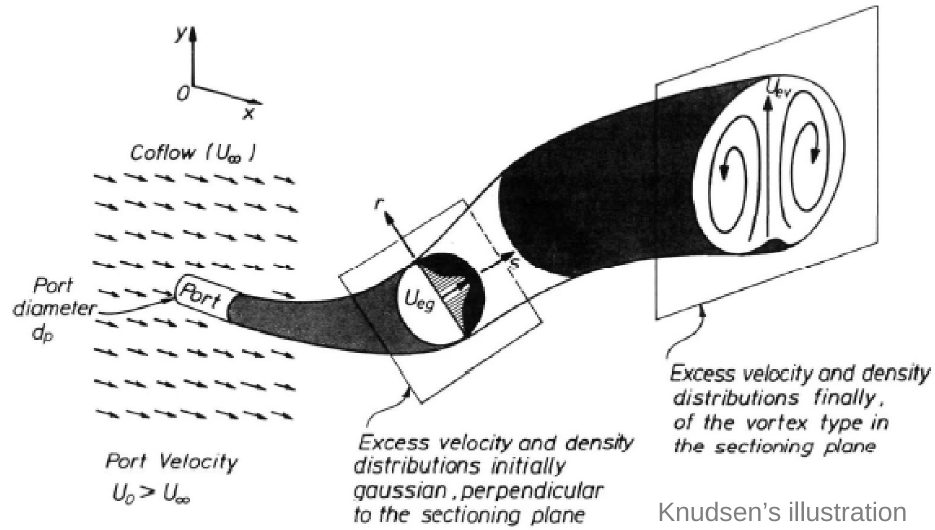
VALIDATION
TEST CASE 2 : DAVIDSON'S EXPERIMENT (1991)

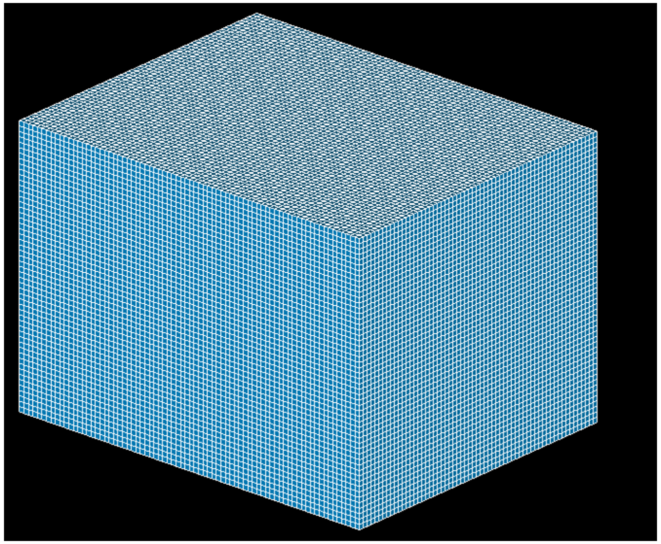
- **Buoyant flow in a coflowing ambiant fluid**
  - Many tests performed for different ambiant flows
- **Selected case**
  - Ambiant flow velocity : 0
  - Buoyant flow velocity : Uo=0.343m/s
  - Section : 2.25e-4 m2
  - ΔT=20°C
  - Fr = 10 (~1/R)

$$F_r = \frac{U_0}{\sqrt{\frac{\Delta\rho}{\rho} g d_p}}$$

  - Re=2250
    (regarded as turbulent)
- **Mesh**
  - Refined mesh of a cubic domain
  - 2M cells (inflow section = 4 faces)



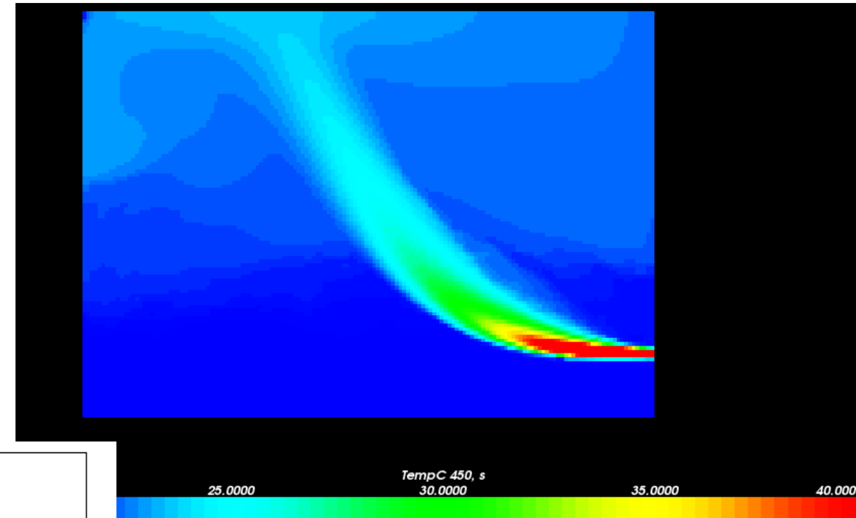
Knudsen's illustration

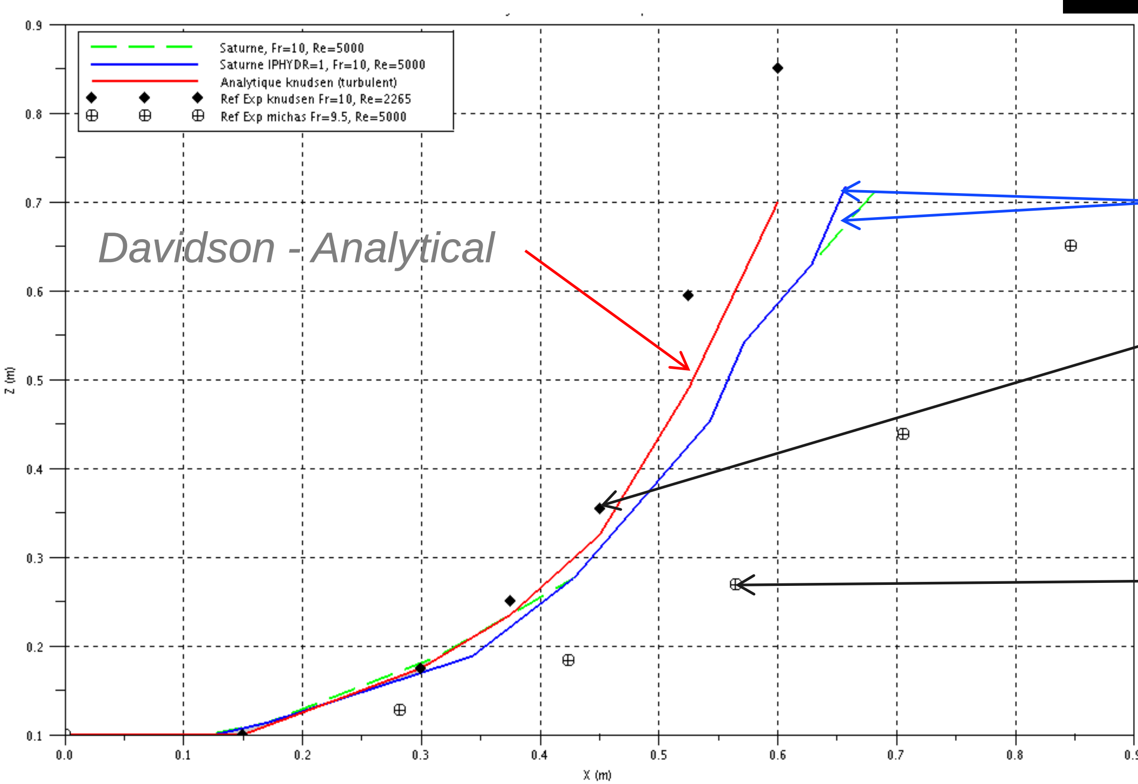


VALIDATION

TEST CASE 2 : DAVIDSON'S EXPERIMENT

- ***Code_Saturne* results**
  - Trajectory of the buoyant jet (max T°C)
  - Good general agreement with experiments and analytical model by Davidson
  - Limited impact of IPHYDR option

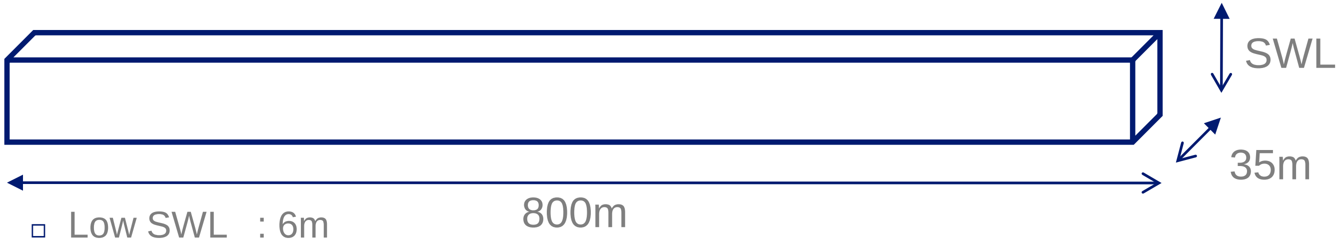




BACK TO THE NPP

GEOMETRY AND MESH USED

- **Channel size**

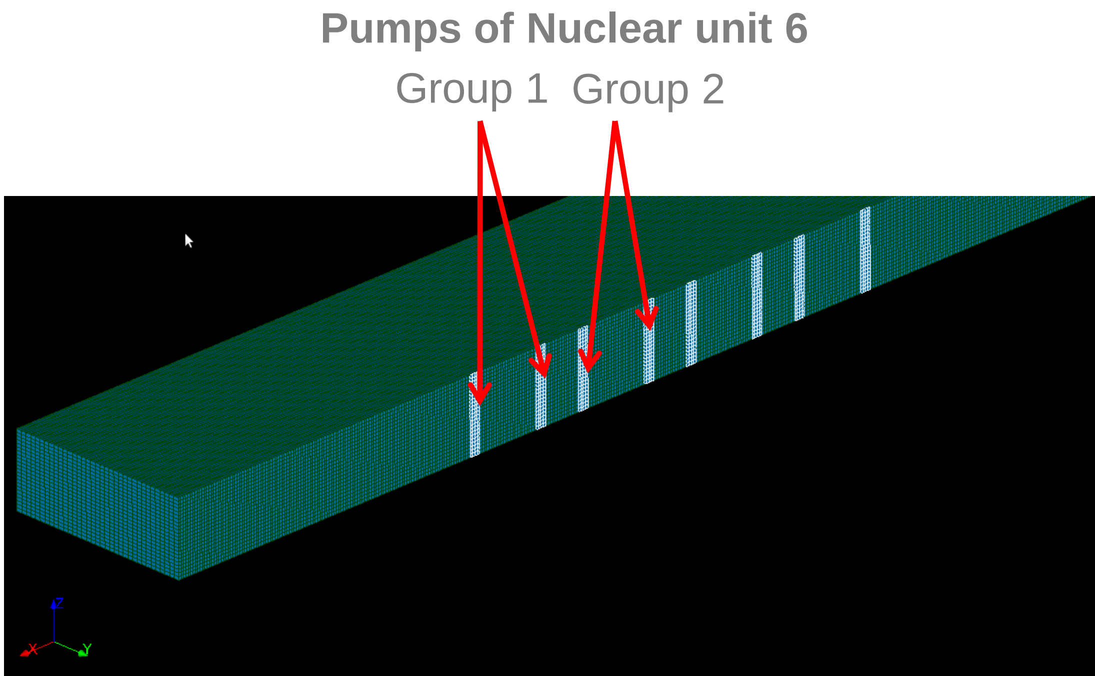


  - Low SWL : 6m
  - Mean SWL : 10m
  - High SWL : 14m

- **Geometry & mesh used for this study**
  - Regular mesh, cell typical size ~0.5m (~ 3 M cells)
  - CPU time ~ 1 to 7 days for 7200s on IVANOE cluster (96-192 procs)
  - 1 Pump ~ 100 faces
  - 1 cofferdam ~ 10/30 faces

- **k-ϵ standard**

- **IPHYDR = 1**



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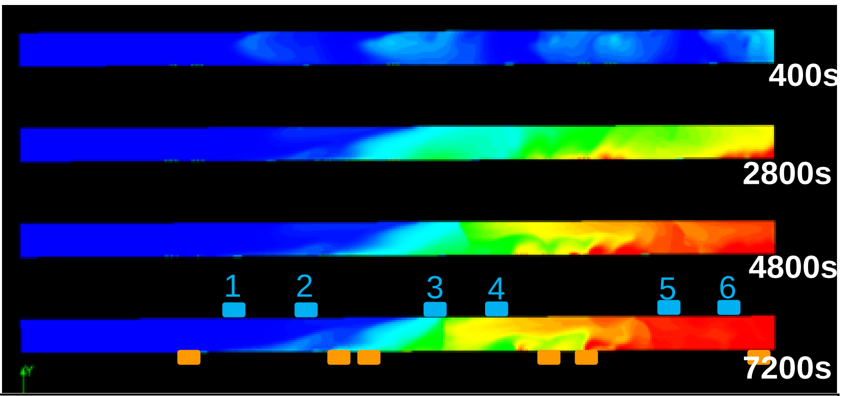
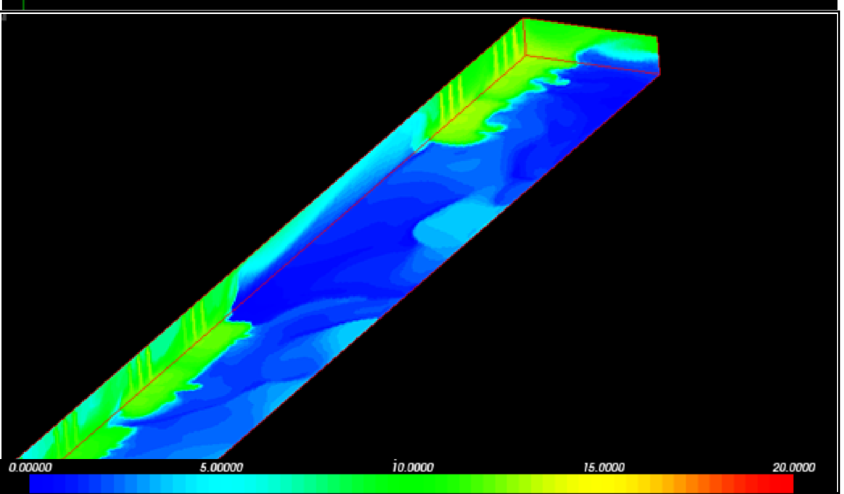
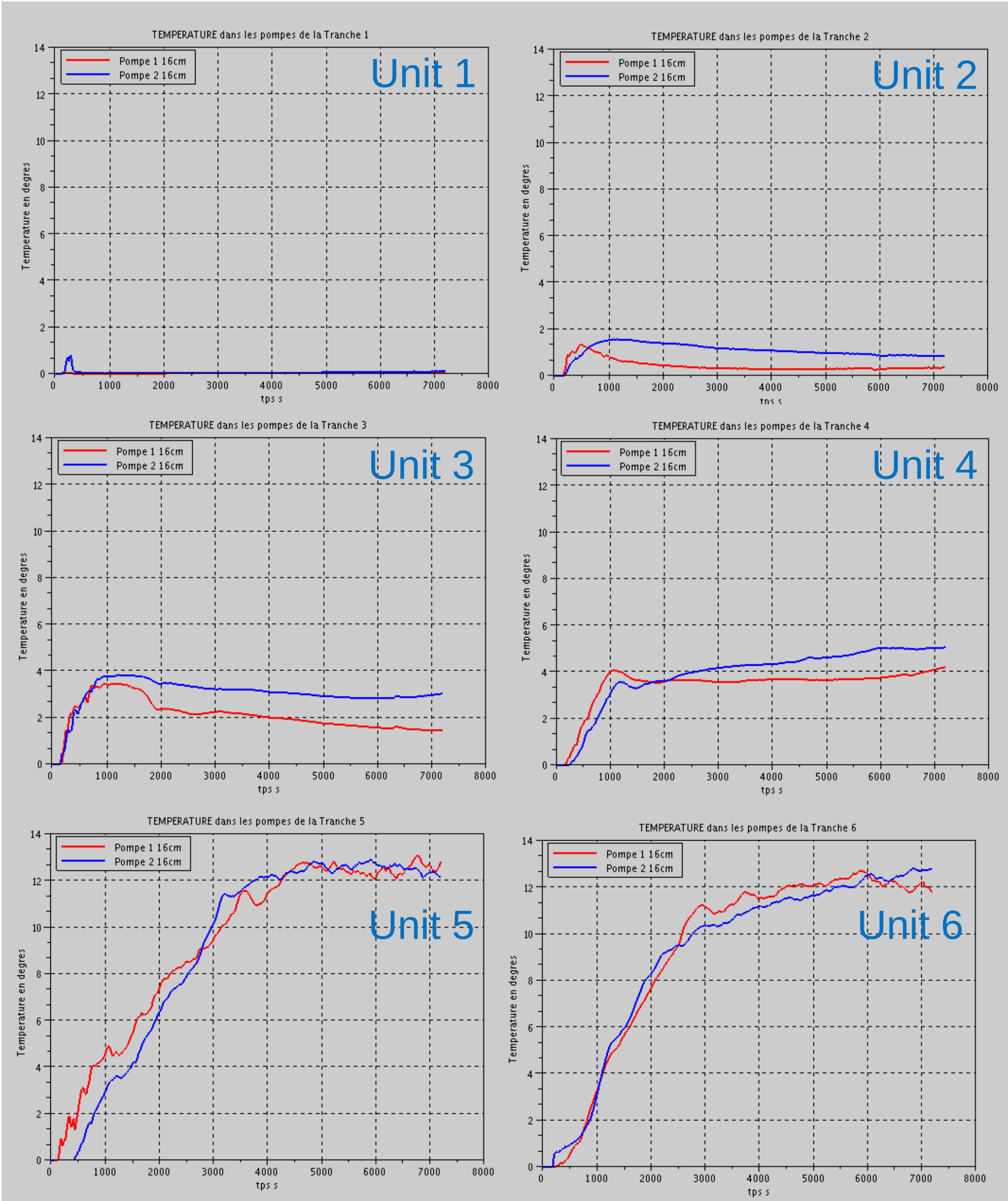
STEP 1 : MEAN WATER LEVEL

6 POWER UNITS IN PRODUCTION

- **Low temperature elevation on units 1 and 2**
- **Up to +14°C on units 5 and 6**







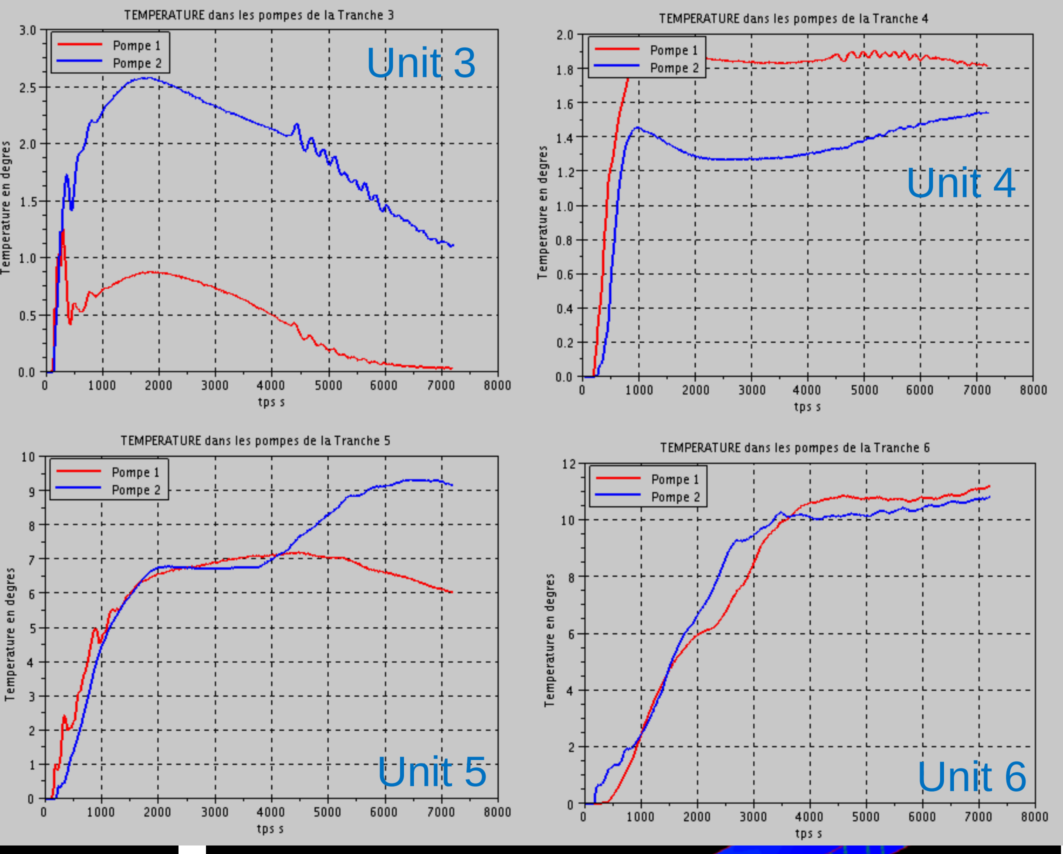
STEP 1 : MEAN WATER LEVEL

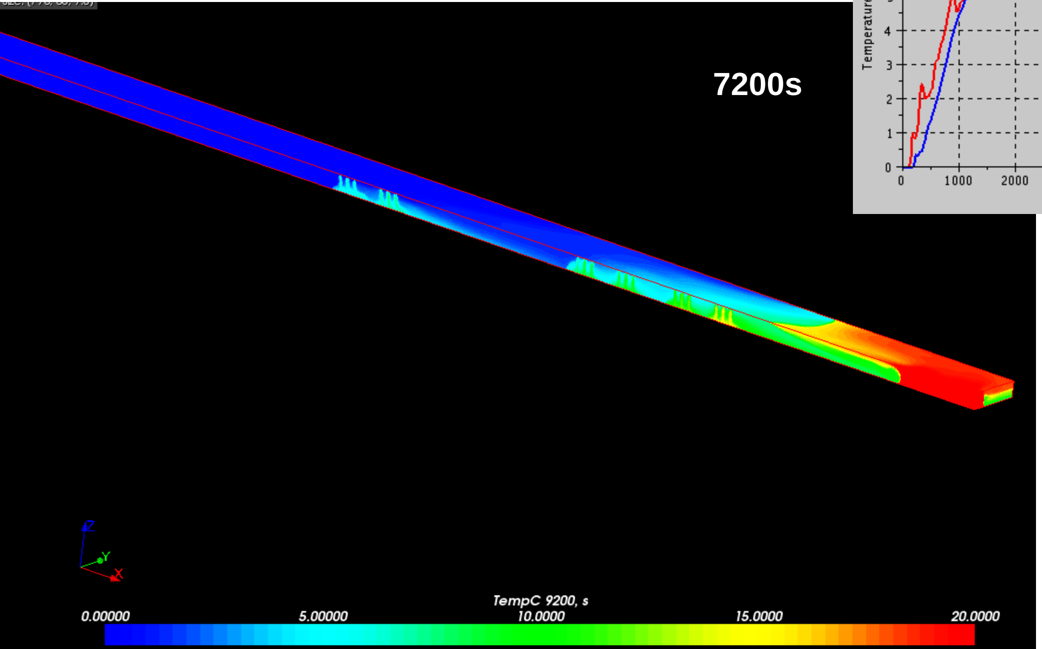
4 POWER UNITS

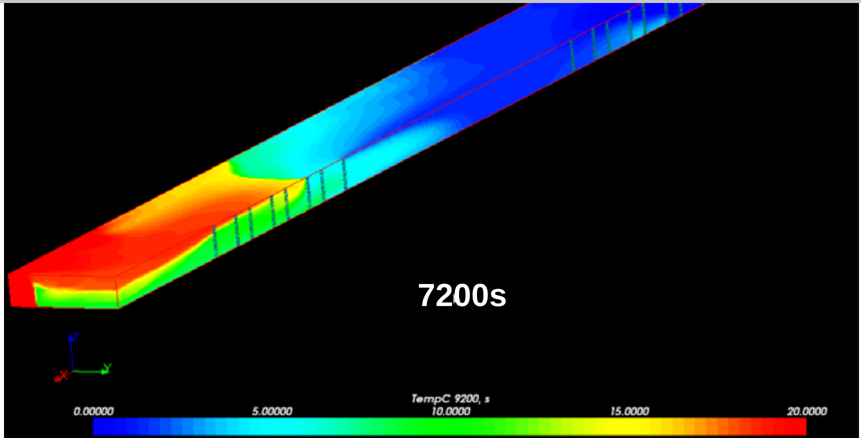
- **Vertical injected velocity**
  => no hot water on the units shore

- **Small temperature increasement for units 3 and 4**

- **+10°C for units 5 and 6**

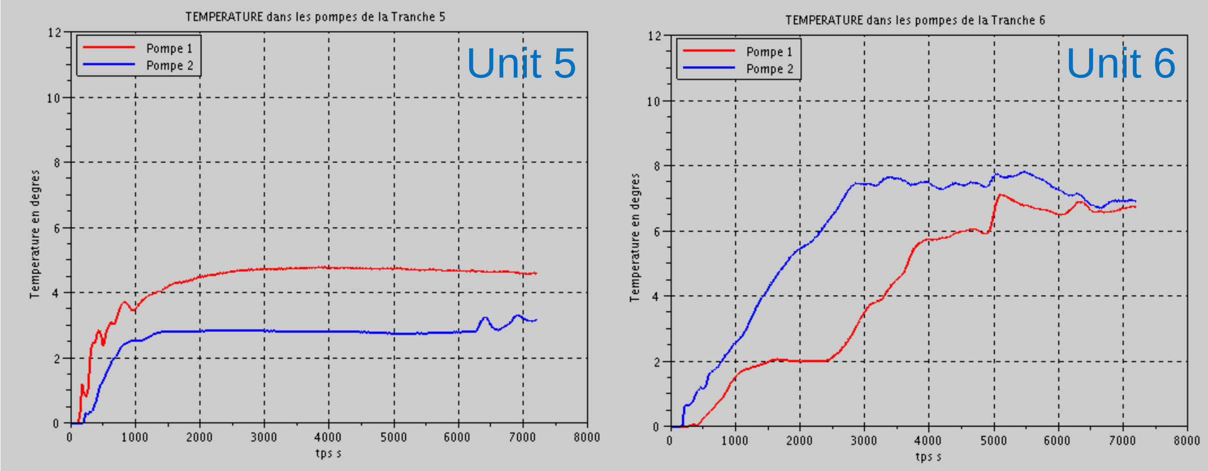


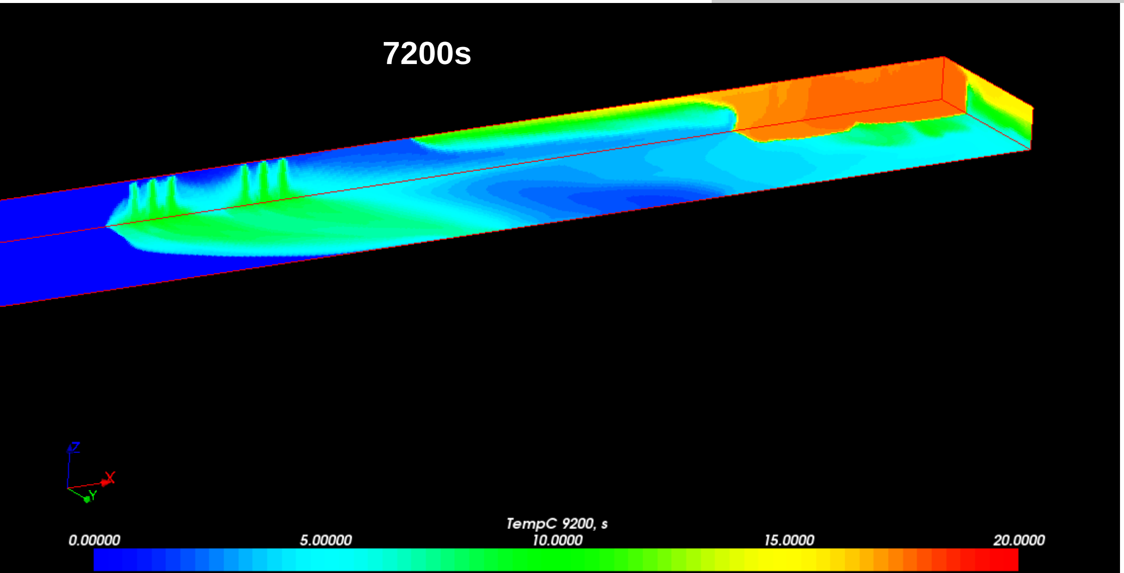




STEP 1 : MEAN WATER LEVEL
2 POWER UNITS

- **Units 5 and 6 : temperature elevation ~ 3°C to 7°C**
- **Hot water impacts the bottom**
- **Conclusion on frazil ice :**
  Units 5 and 6 are regarded as protected
- **Need to verify for other SWL**

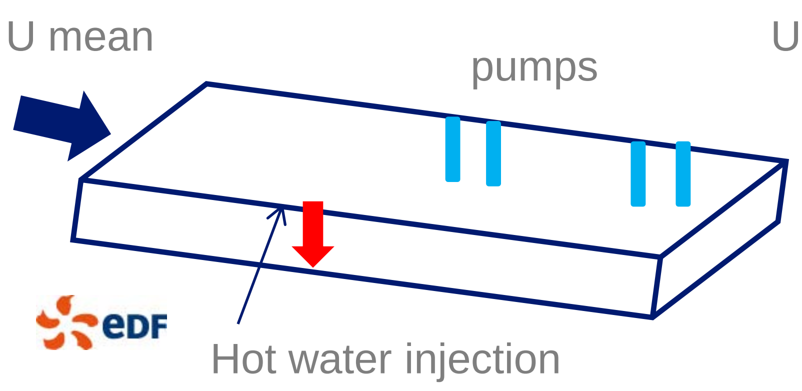


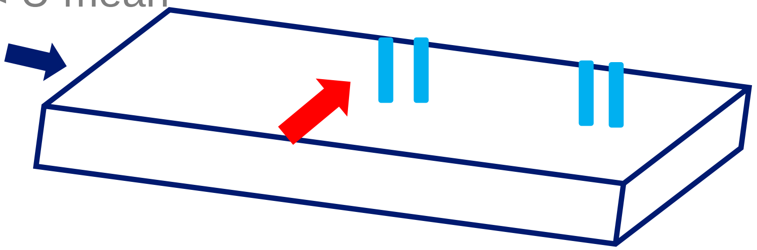


STEP 2 : HIGH WATER LEVEL

CONFIGURATION

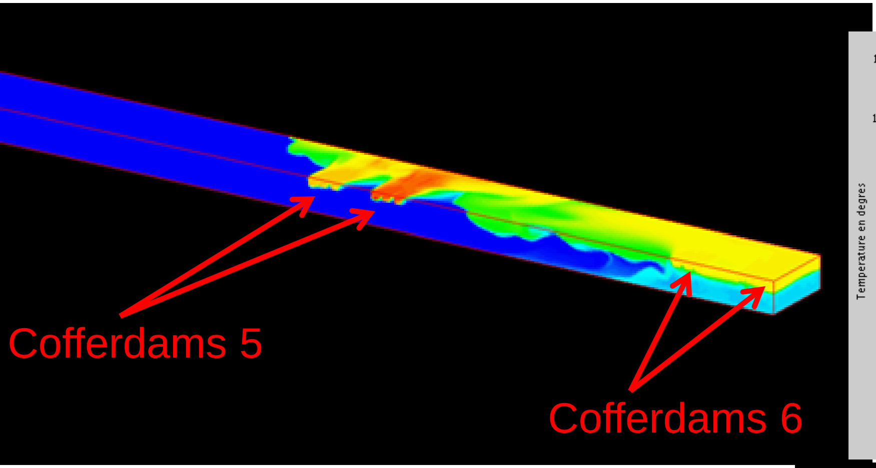
- **Water depth : 14m**
- **Simulations were performed for 1 to 6 units in production**
- **Focus on « units 5&6 in production case »**
  - Velocity in the channel for mean water level : Q/S = 0,15 m/s
  - Velocity in the channel for high water level : Q/S = 0,11 m/s
  - => hot water less convected by the main flow
- **Horizontal injection**
  - => hot water reach the units shore more efficiently
  - Temperature difference between the 2 units should be lower

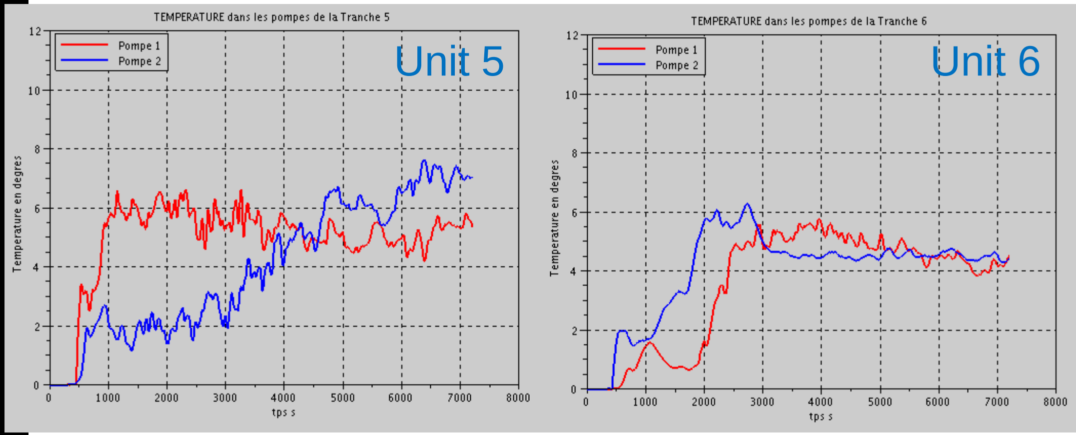




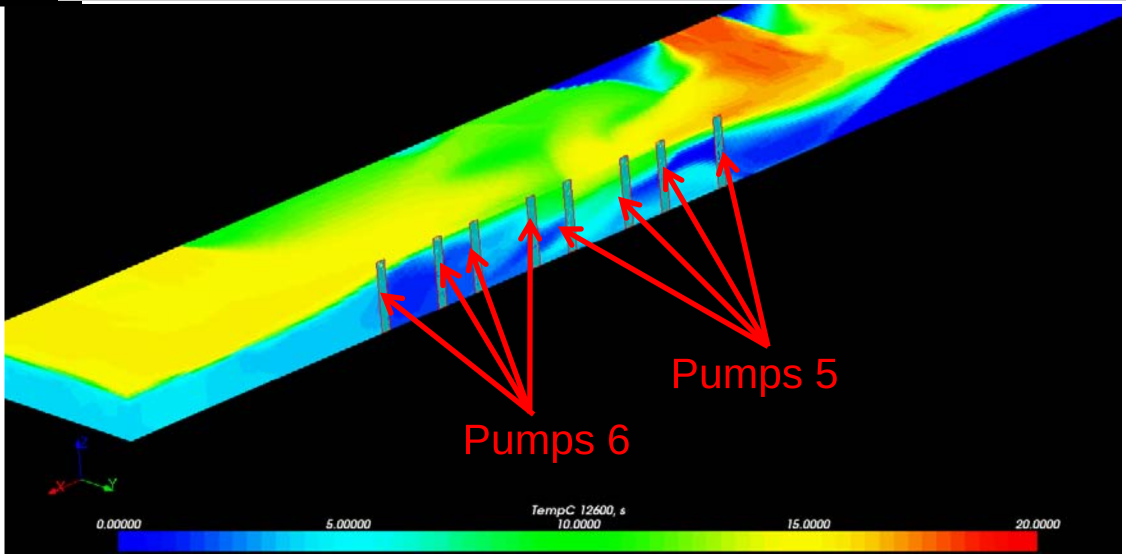
STEP 2 : HIGH WATER LEVEL

2 POWER UNITS RESULTS





- **Stratified flow as hot water is injected in the upper part**
- **Clearly see that different temperatures are injected**
- **Increase of 5°C for units 5 & 6**
- **Protection OK**

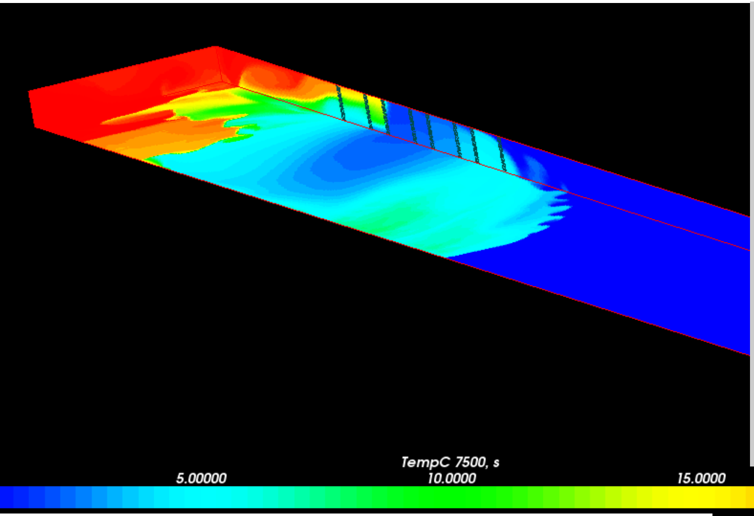


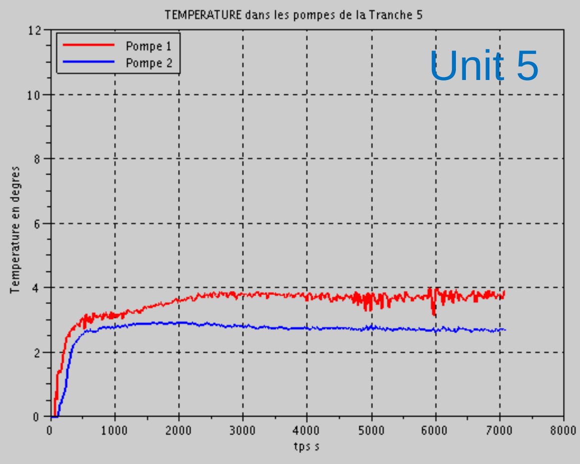
STEP 3 : LOW WATER LEVEL
CONFIGURATION

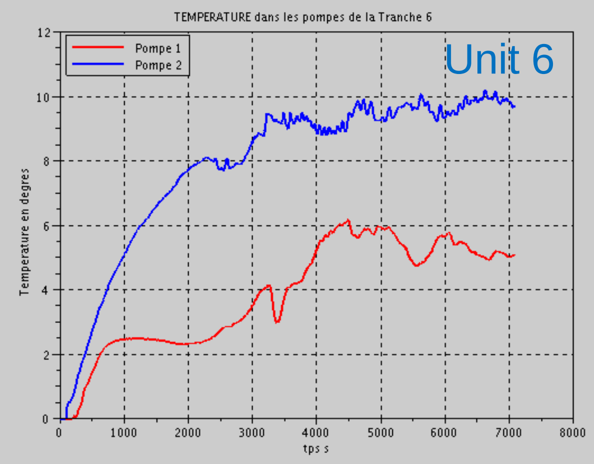
- **Water depth : 6m**
- **Simulations were performed for 1 to 6 units in production**
- **Focus on « units 5&6 in production case »**
  - Velocity in the channel for mean water level : Q/S = 0,158 m/s
  - Velocity in the channel for high water level :   Q/S = 0,110 m/s
  - => hot water less convected by the main flow
  - Temperature for unit 6 should be greater than for unit 5
- **Vertical injection**
  - Vertical velocity is higher than for mean level
  - But anyway, the hot water reached the channel bottom even for mean level
    => no significant impact expected

STEP 3 : LOW WATER LEVEL

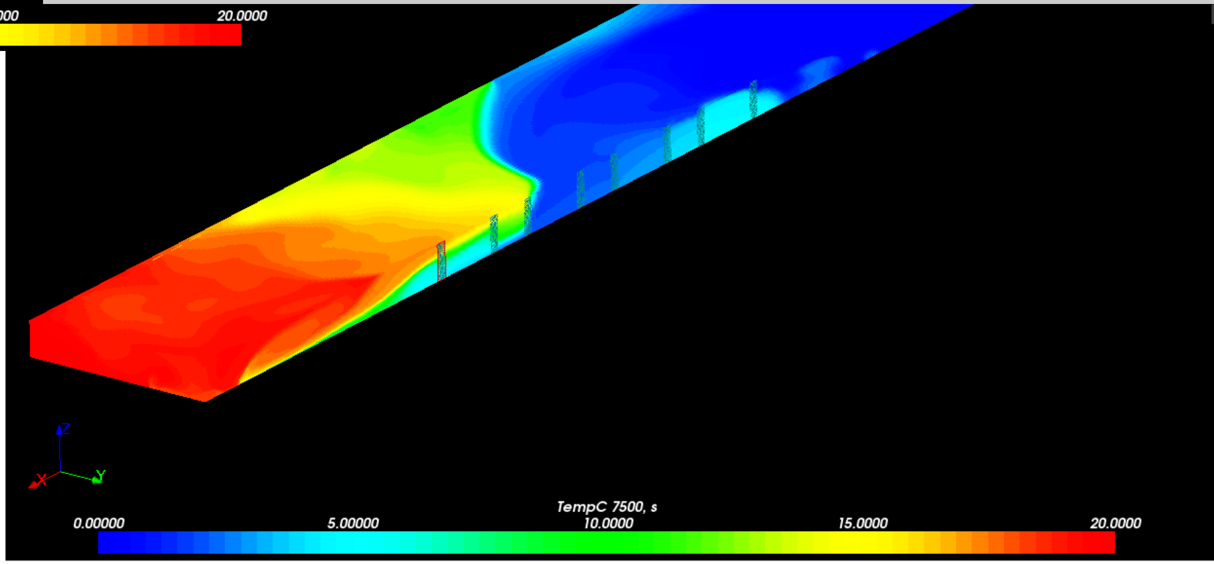
RESULTS FOR UNITS 5 AND 6







- Unit 5 : +2 to + 4°C
- Unit 6 : +5 to +10°C
- Convection effect
- Protection OK



CONCLUSION

- **Generic study showed how to use *Code_Saturne* to adress the issue of frazil ice risk**
  - Specific cofferdam solution efficiency studied
  - Validation on litterature test cases
  - Application to a realistic case : size of the domain, volumic flow rates, etc…
- **Methodology curently applied on a specific seaside site**
  - Direct input for Nuclear engineering team
  - Decision to use cofferdam solution to optimize the winter production
  - How many of them should be used / maintained
- **Need for site measurements for full validation**

- ***Code_Saturne* user routines easy to adapt for specific needs**

- **Other solutions against frazil ice to be studied , as directly heating grids**

THANK YOU FOR YOUR ATTENTION

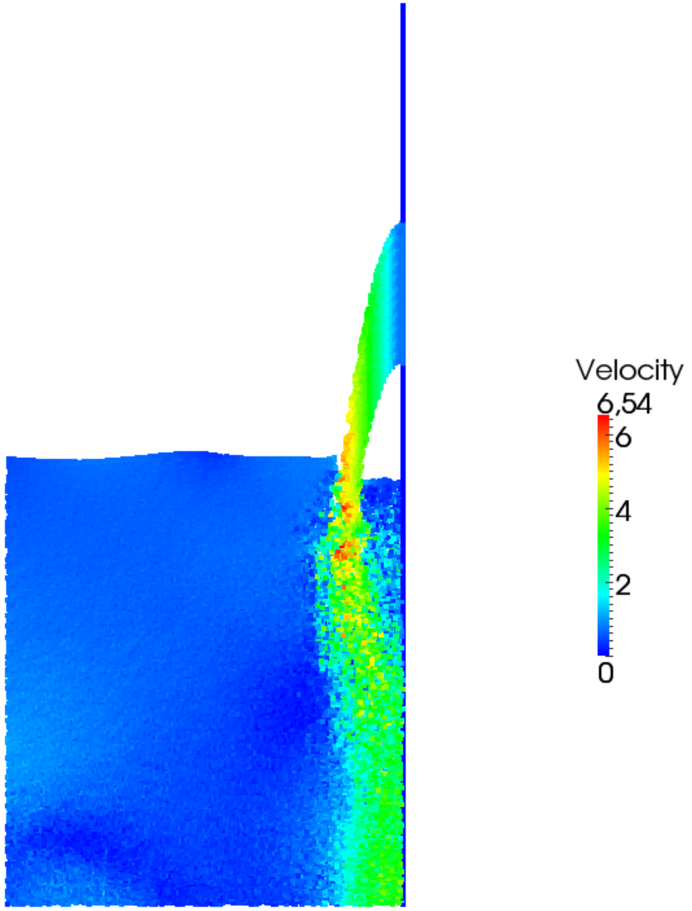
MODELISATION DES BATARDEAUX

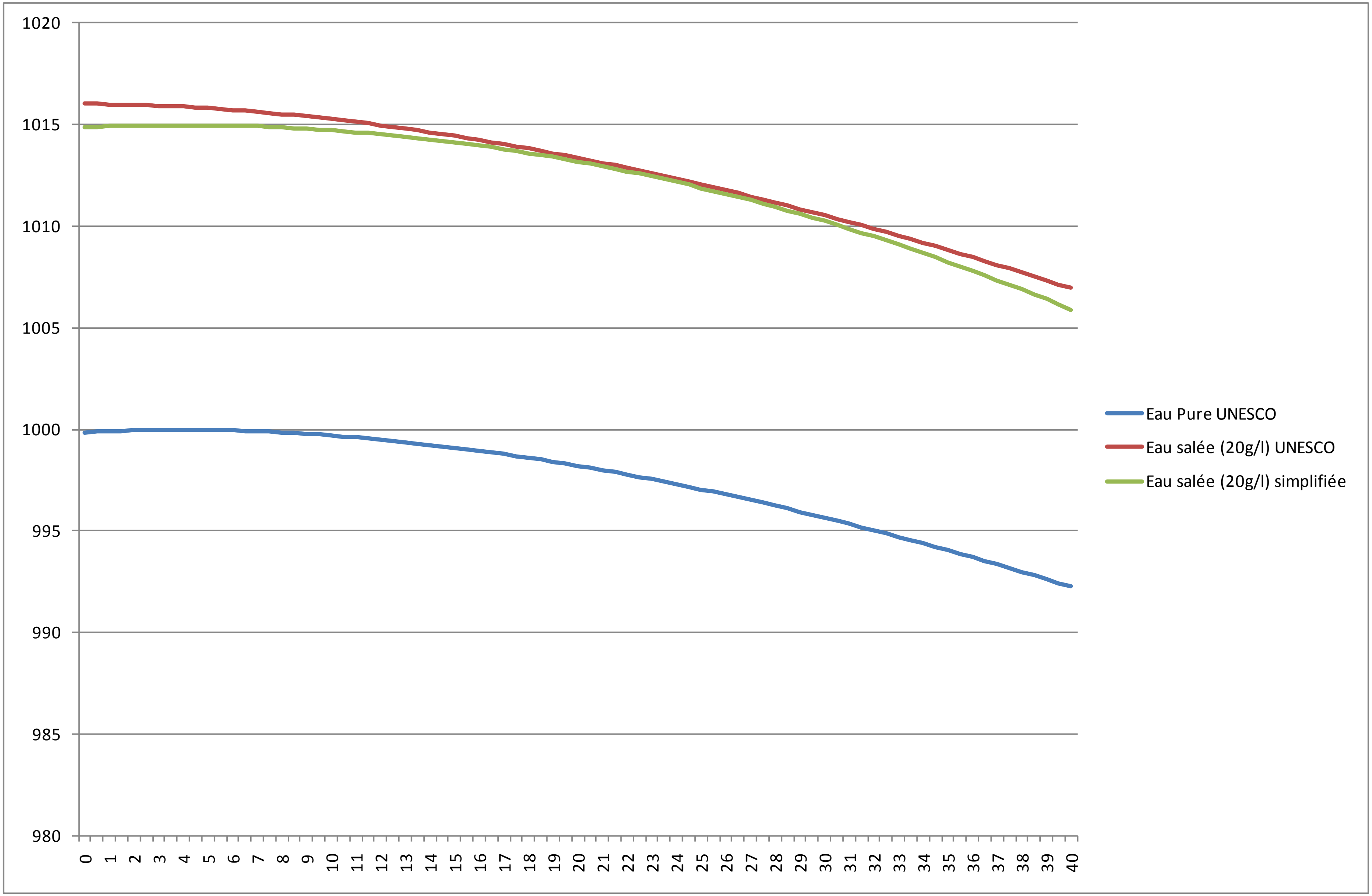
LAME D'EAU AU NIVEAU DE LA SURFACE LIBRE

- **Vitesse horizontale en sortie des batardeaux**
  - Formule des seuils épais
  - Lame d'eau ~ 1 m
  - Vitesse horizontale ~ 0.7 m/s
  - Quid de l'évolution après le seuil?

- **Cinématique de la chute d'eau**
  - Utilisation d'une approche SPH (Sphynx, Laboratoire St Venant)
  - Méthode sans maillage : fluide représenté par des particules
  - Modélisation d'écoulements complexes
  - Calculs réalisés par Agnès Leroy (Doctorante)

➡ **Vitesse verticale : 4.6 m/s**

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Eau Pure UNESCO
Eau salée (20g/l) UNESCO
Eau salée (20g/l) simplifiée