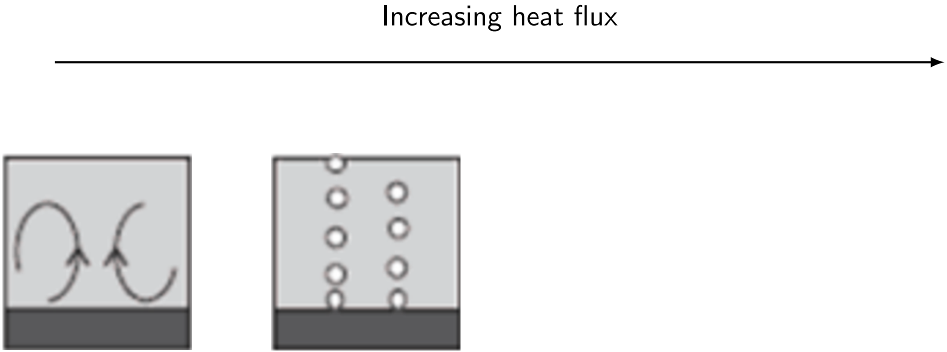
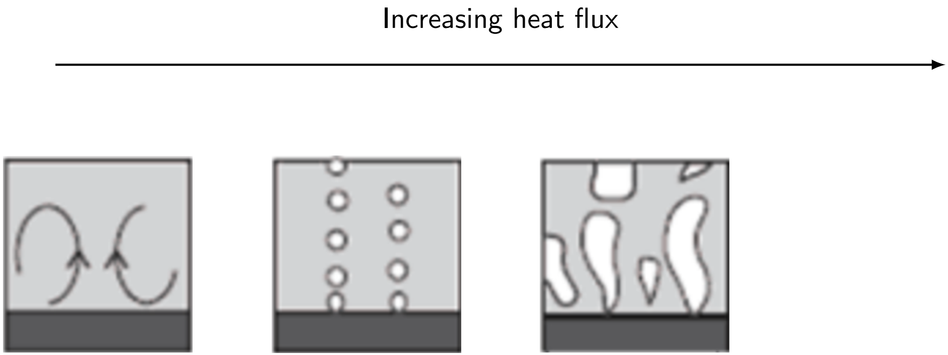
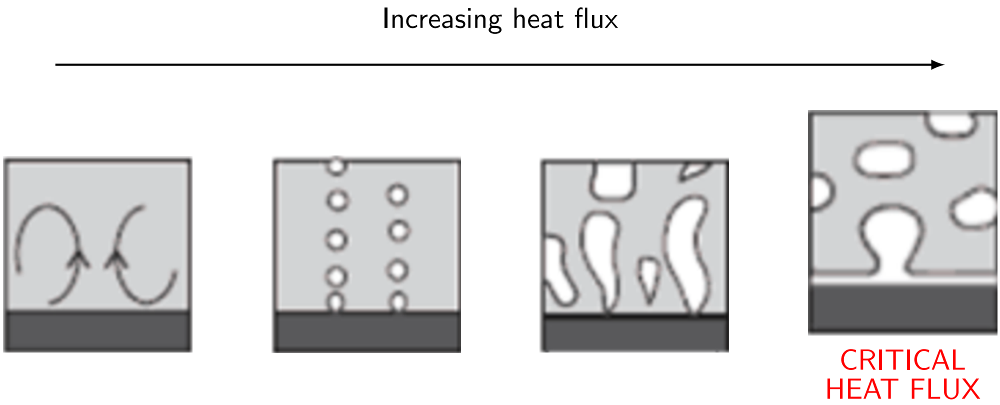
Increasing heat flux

Increasing heat flux


Increasing heat flux

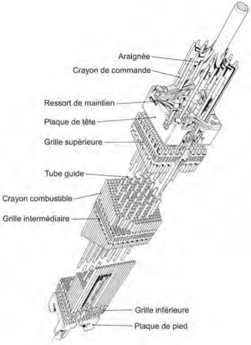

Increasing heat flux


Increasing heat flux
CRITICAL
HEAT FLUX

Heating in a nuclear reactor

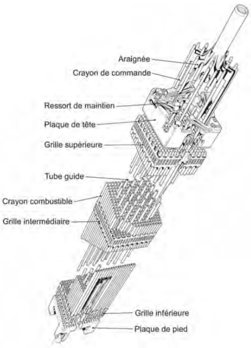
Heating in a nuclear reactor

Complex geometry

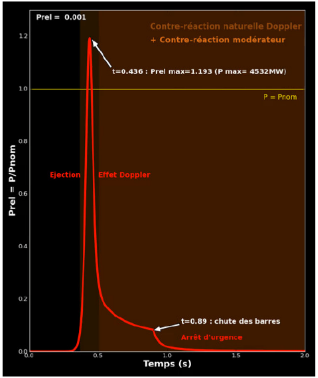


Heating in a nuclear reactor

Complex geometry



Transient power



Available experiments

Geometry	Stationnary	Transient
Pipe	DEBORA	PATRICIA
Assembly	OMEGA, KATHY	

Available experiments

Geometry	Stationnary	Transient
Pipe	DEBORA	PATRICIA
Assembly	OMEGA, KATHY	Need code Objective of PhD

JEFS

C. Reiss

Building a Boiling-Flow Multiphase CFD Framework for Nuclear Reactor Conditions

Journées Écoulements et Fluides de Saclay

Corentin Reiss, corentin.reiss@cea.fr

Tutors : C. Colin, A. Gerschenfeld

DM2S/STMF/LMEC

26/06/2023

Ingredients of TrioCMFD

- Numerical framework $\rightarrow$ TRUST platform
- Conservation equations
- Selection and implementation of closure laws
- Step-by-step validation

Conservation equations for each phase

Mass conservation :

$$\frac{\partial \alpha_k \rho_k}{\partial t} + \nabla \cdot (\alpha_k \rho_k \vec{u_k}) = \underbrace{\Gamma_k}_{\text{Changement de phase}}$$

Momentum conservation :

$$\alpha_k \rho_k \frac{\partial \vec{u_k}}{\partial t} + \nabla \cdot (\alpha_k \rho_k \vec{u_k} \otimes \vec{u_k}) - \vec{u_k} \nabla \cdot (\alpha_k \rho_k \vec{u_k}) = -\alpha_k \nabla P + \nabla \cdot [\alpha_k \mu_k \nabla \vec{u_k} - \underbrace{\alpha_k \rho_k \overline{u_i' u_j'}}_{\text{Turbulence}}] + \underbrace{\vec{F}_{ki}}_{\text{Forces interfaciales}} + \alpha_k \rho_k \vec{g}$$

Energy conservation :

$$\frac{\partial \alpha_k \rho_k e_k}{\partial t} + \nabla \cdot (\alpha_k \rho_k e_k \vec{u_k}) = -P \left(\partial_t \alpha_k + \nabla \cdot (\alpha_k \vec{u_k})\right) + \nabla \cdot [\alpha_k \lambda_k \nabla T_k - \underbrace{\alpha_k \rho_k \overline{u_i' e_k'}}_{\text{Turbulence}}] + \underbrace{q_{ki}}_{\text{Condensation}} + \underbrace{q_{kw}}_{\text{Chauffage paroi}}$$

Undisputed terms

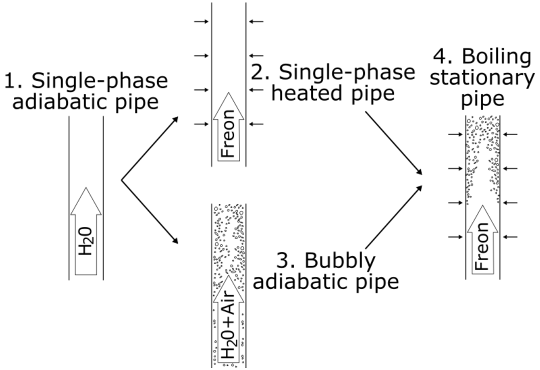
Terms that need to be modeled

Selected baseline models

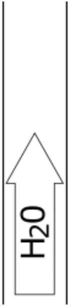
Model type	Selected model	Effect
1ϕ turbulence	$k - \omega$	
Adaptive wall law	Reichardt	
Interfacial forces	Tomiyama drag	Sets relative velocity
	Sugrue lift	Bubbles sent to wall or core
	Burns turbulent dispersion	Spreads bubbles
	Lubchenko wall correction	Pushes bubbles from wall
	Constant-coeff virtual mass	Increases bubble inertia
Wall heat flux partition	Kurul-Podowski	Liquid heats or vapor forms ?
Condensation	Zeitoun	

N.B. : mostly come from experiments on single bubbles at P_{atm} *or from a purely theoretical analysis* $\rightarrow$ *Valid in PWR's ?*

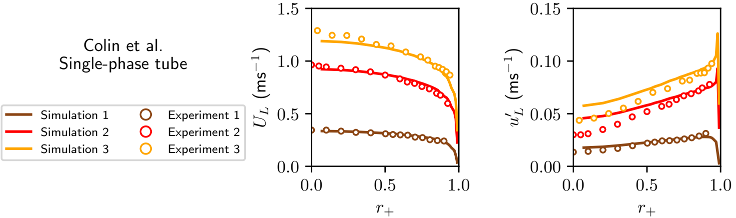
Validation stages



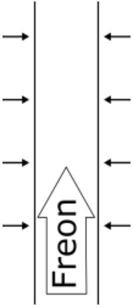
1. Single-phase adiabatic pipe flow

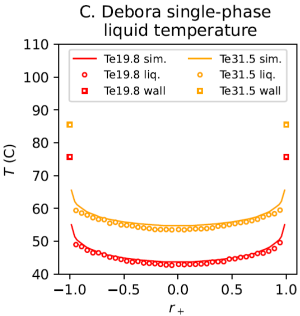


Colin et al.
Single-phase tube

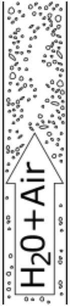


2. Single-phase heated pipe flow

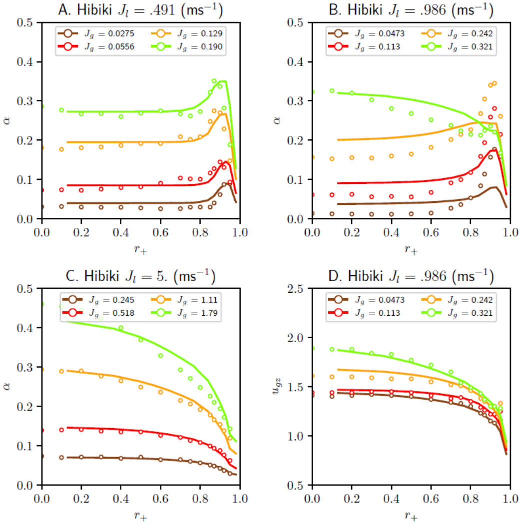




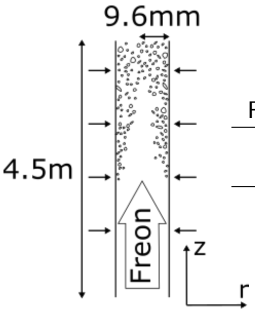
3. Bubbly adiabatic pipe flow



We enforce the experimentally measured bubble diameter



4. Boiling pipe flow in PWR similarity



DEBORA experiments

Run number	1	2	3
Pressure similarity	Boiling Water Reactor	Pressurized Water Reactor	Pressurized Water Reactor
Liquid velocity	Maintenance ∼2m/s	Maintenance ∼1m/s	Normal operation ∼3m/s

4. Boiling pipe flow in PWR similarity

How to close the bubble diameter in boiling flow simulations:

Historical approach:

1. Build and IATE to predict diameters
2. Validate the model on atmospheric-pressure adiabatic stationary flows with momentum closures
3. Add boiling and condensation terms

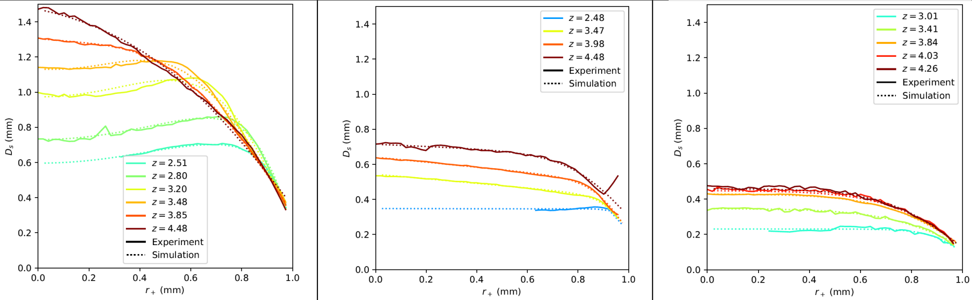
Our approach:

1. Select energy and momentum closures
2. Enforce 3D map of experimental bubble diameter
3. Validate the closures in PWR-similarity conditions
4. Future work: model bubble diameters in PWR conditions

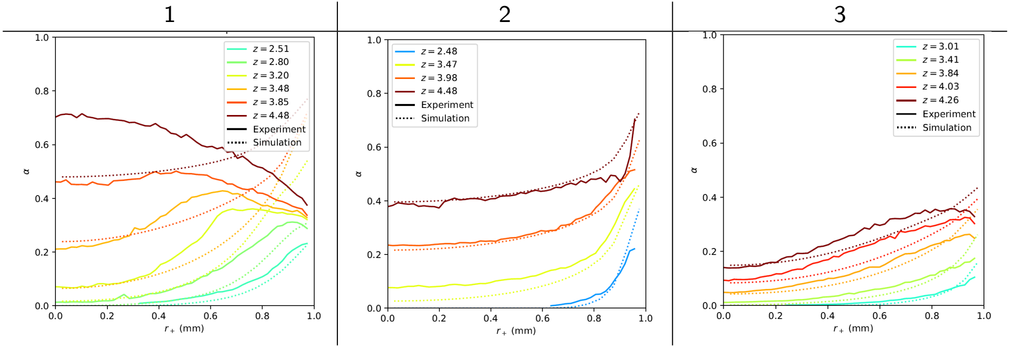
4. Boiling pipe flow in PWR similarity

Diameter interpolation

1	2	3



4. Boiling pipe flow in PWR similarity



Atmospheric-pressure closure models are not adapted to nuclear reactor-condition boiling flows

For $u_{\mathrm{bulk}} > 2m/s$ something pulls the bubbles away from the wall $\rightarrow$ lift force along $-\vec{u_r}$

Lack of separate-effect experimental data: still many closure terms to adjust

4. Boiling pipe flow in PWR similarity

Choice to concentrate on PWR operating conditions.

- Deformable Ishii-Zuber drag force (independent of bubble diameter)
- $C_l = -0.03$: negative constant lift coefficient
- No wall correction : unnecessary thanks to lift force

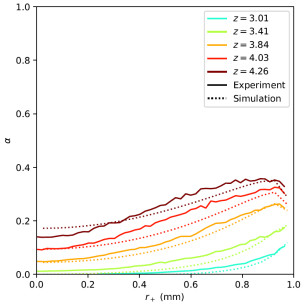
$\rightarrow$ Selected momentum closure terms are independant of bubble diameter

4. Boiling pipe flow in PWR similarity

Choice to concentrate on PWR operating conditions.

- Deformable Ishii-Zuber drag force (independent of bubble diameter)
- $C_l = -0.03$: negative constant lift coefficient
- No wall correction : unnecessary thanks to lift force

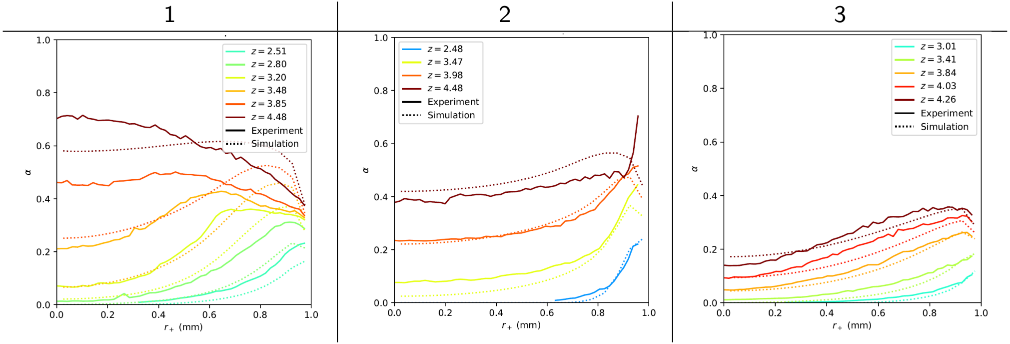
$\rightarrow$ Selected momentum closure terms are independant of bubble diameter



NB: the selected closures work on ∼10 unpublished PWR-operating conditions

4. Boiling pipe flow in PWR similarity

Modifying the models to improve PWR in operation case (3) impairs the others



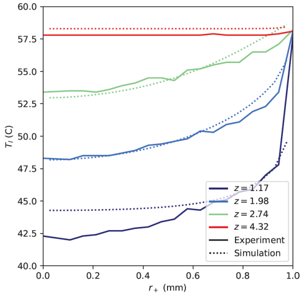
JEFS

C. Reiss

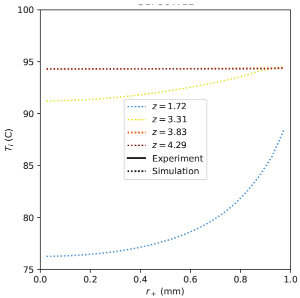
4. Boiling pipe flow in PWR similarity

The liquid is at saturation temperature at the wall at the top of the tube in all simulations

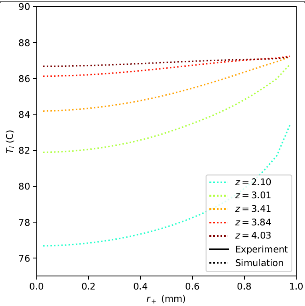
1



2



3



$\rightarrow$ CHF criterion on evacuation of void fraction from the wall and not energy ?

Conclusion

Take-home messages :

- We simulate boiling flows by enforcing the **experimental diameter**
- Atmospheric-pressure closure models are not adapted to **nuclear reactor-conditions**

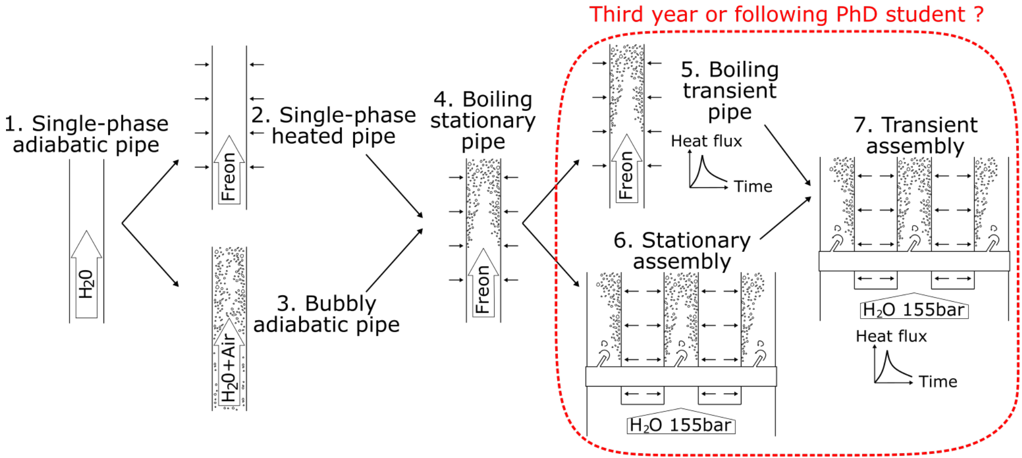
Next steps :

- Finalize the choice of a set of **momentum and energy** closures that is adapted to reactor conditions
- Model the bubble diameter in reactor conditions
- Simulate the physical properties at the wall near the critical heat flux

JEFS

C. Reiss

Conclusion



References

TRUST and TrioCFD platforms

- https://github.com/cea-trust-platform
- https://triocfd.cea.fr/
- https://github.com/cea-trust-platform/TrioCFD-code

Thanks to

Elie Saikali

Yannick Gorsse

Antoine Gerschenfeld

Catherine Colin