FROM RESEARCH TO INDUSTRY

THERMOHYDRAULIC TRANSIENTS IN BOILING HELIUM NATURAL CIRCULATION LOOPS

Hernán FURCI

Director: Chantal MEURIS
Supervisor: Bertrand BAUDOUY
Laboratoire de Cryogénie et Station d'Essais
SACM/IRFU/CEA de Saclay

D-DAYS 2014
IRFU

JULY 2ND AND 3RD 2014

FURCI Hernán

Nuclear Engineer, Instituto Balseiro, Argentine.

Master 2 Sciences de la Fusion, Université d'Aix-Marseille.

Second Year PhD Candidate at MIPEGE, Paris Sud.

I have been recommended to Bertrand BAUDOUY by Jean-Luc DUCHATEAU, a senior researcher at CEA and Master's professor.

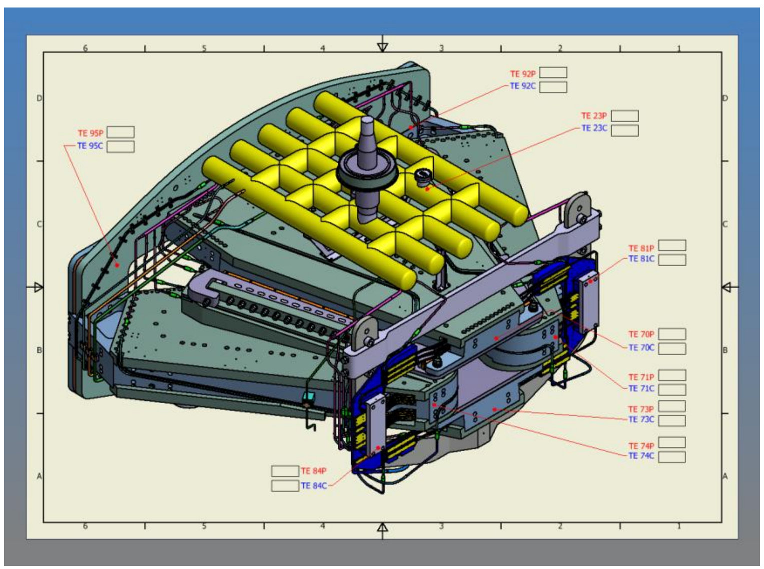
When I visited the lab, I was highly seduced by

- the experimental facility I would use and by the challenges involved in the subject,
- the contribution of this research project to bigger ones,
- the diversity and nature of the R&D at LCSE,
- the professional and human qualities of my prospective colleagues.

Thermohydraulic transients in boiling helium natural circulation loops

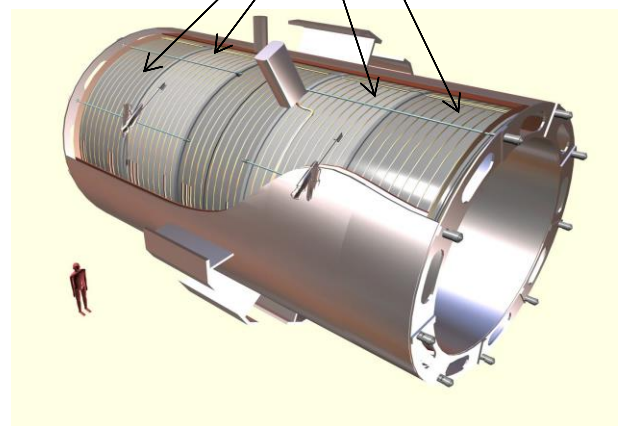
Helium natural circulation is a cooling scheme in large **superconducting magnets**

- CMS at the LHC for CERN
- R3B-GLAD for GSI
- Passive safety reasons
- Already studied in steady state
- Not thoroughly studied in transient



R3B-GLAD cooling system

CMS thermosiphon cooling pipes



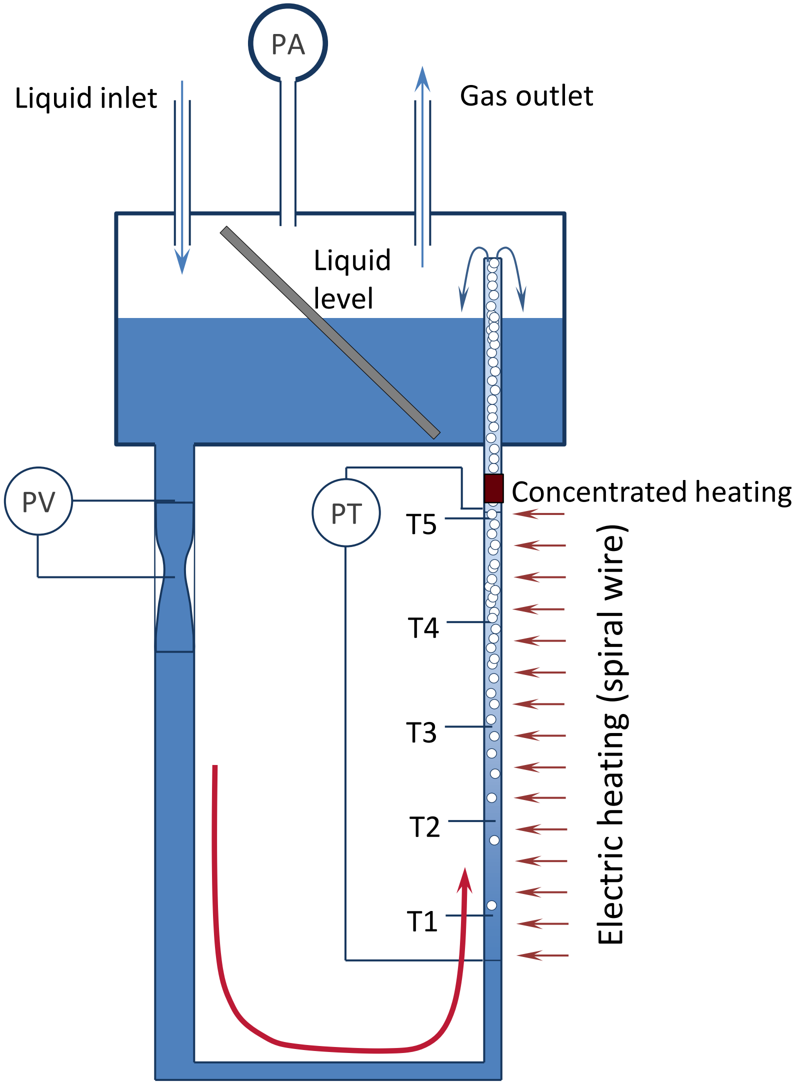
We perform **experiments** on a big size helium natural circulation facility

- To **explore the existing boiling regimes** during transients at different powers and positions of a heated section;
- To identify **heat transfer deterioration** phenomena;
- To determine ways of **mitigating its effects**.

We do **numerical simulations**

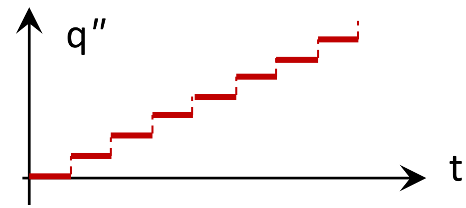
- To **understand more deeply** the phenomena
- To **extrapolate** results to other systems

EXPERIMENTAL SET-UP

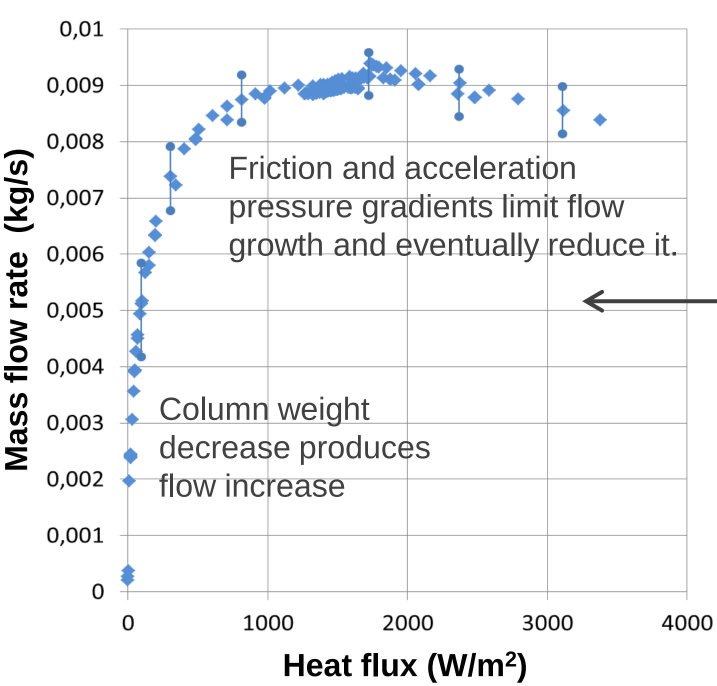


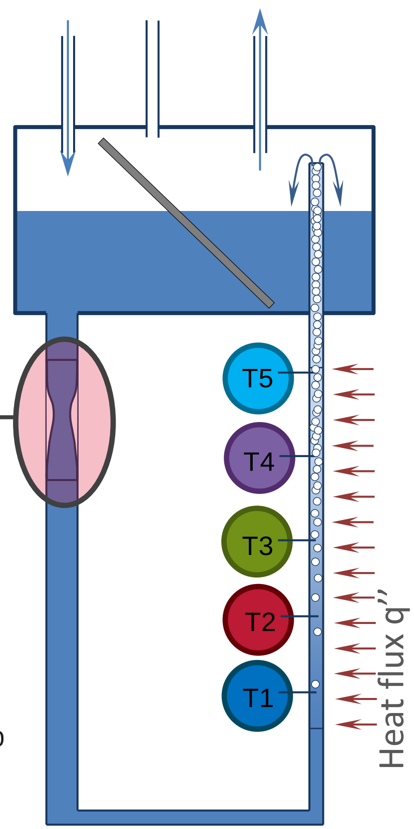
STEADY-STATE REGIME

Reference to which compare transient results.
Power is increased gradually, at steps (quasi-steady evolution)
Mass flow takes place as a result of **buoyant forces**.
Two boiling regimes take place depending on power (and position).

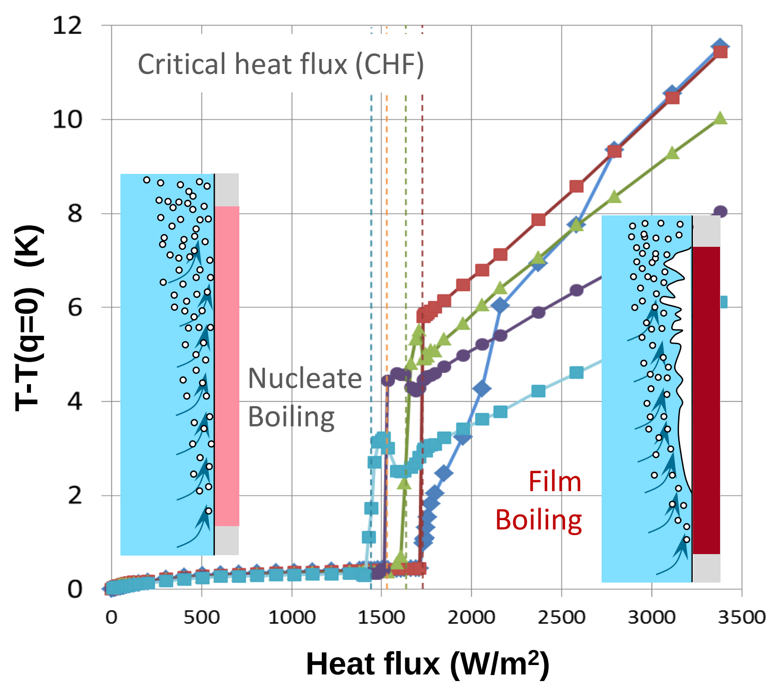


Hydraulic regimes

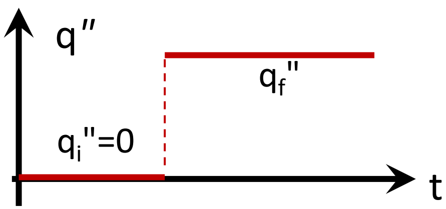


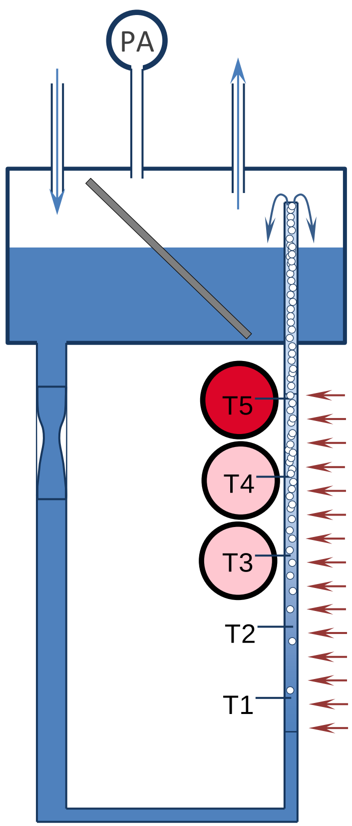


Heat transfer regimes



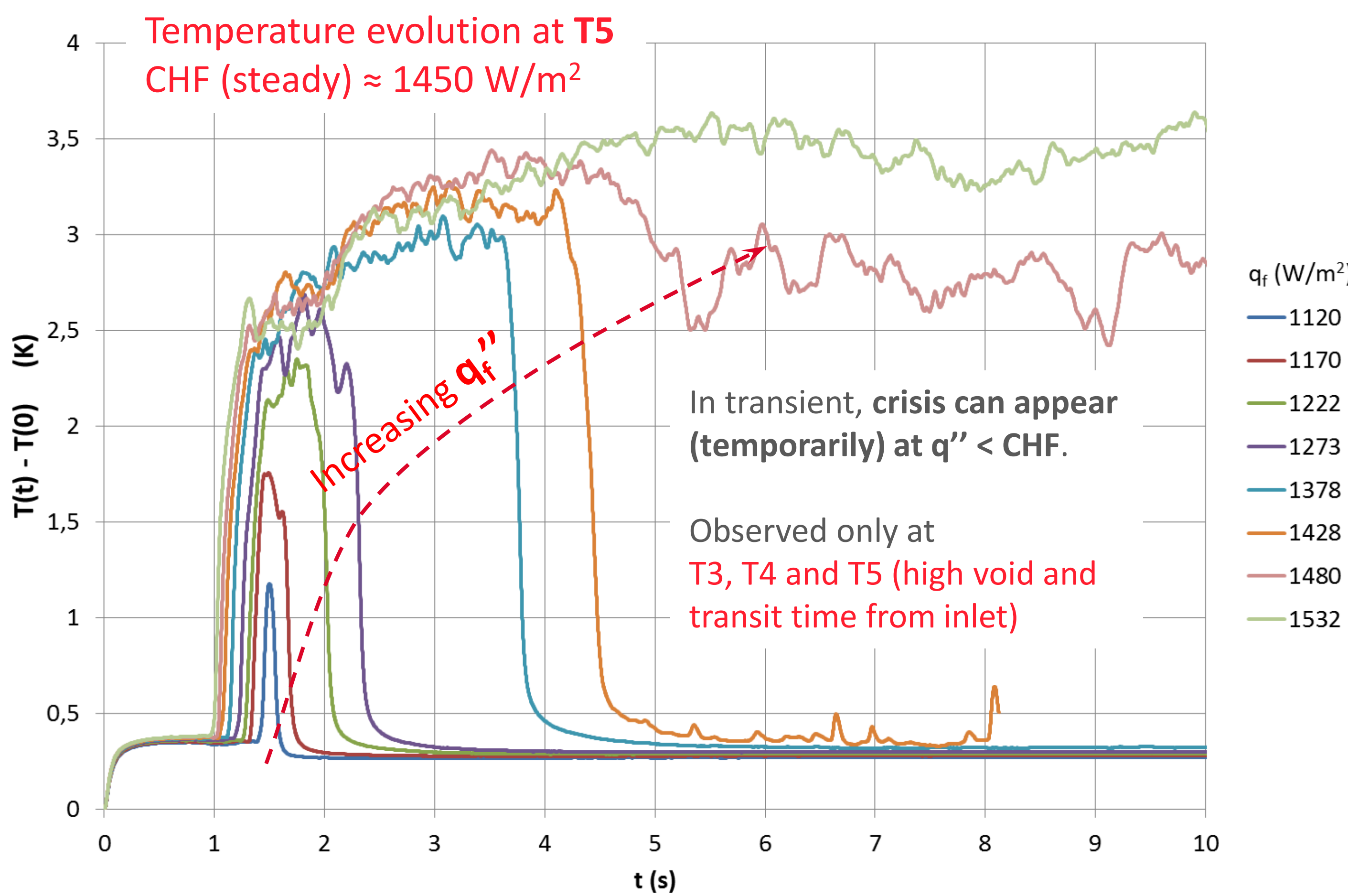
TRANSIENT CRISIS





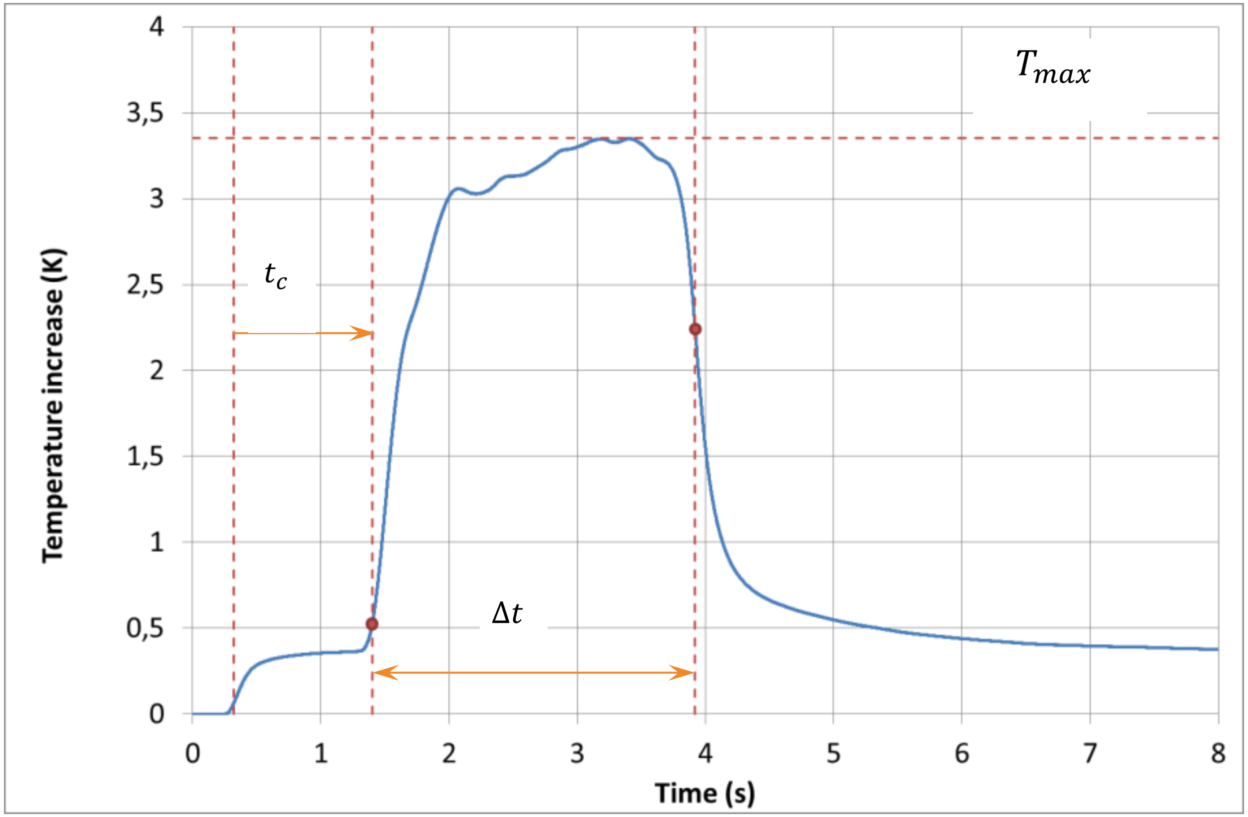
Zero initial power transients, increasing final power

We focus on high power transients only (the most critical)



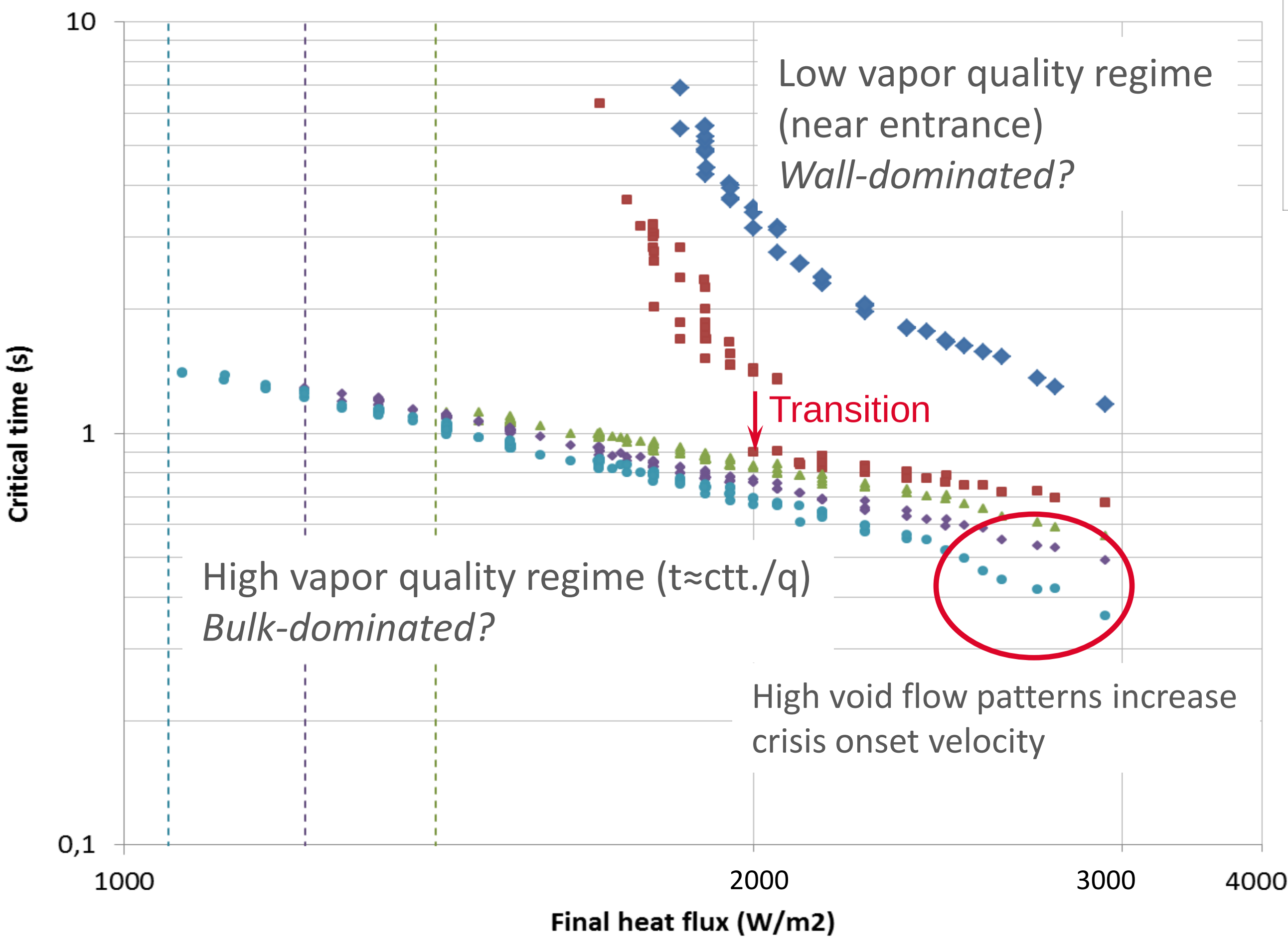
TRANSIENT BOILING CRISIS PARAMETERS

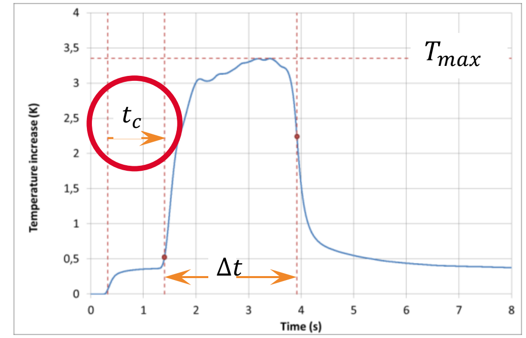
- We analyze the transients by calculating three main parameters:
  - t_c, **the critical time**: duration of nucleate boiling before crisis;
  - Δt, **the crisis duration**: time between the initiation of the crisis and its end;
  - T_{max}, the **maximum temperature** attained.

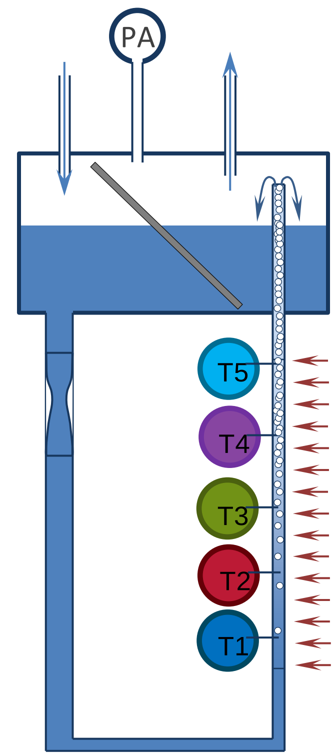


TRANSIENT CRISIS

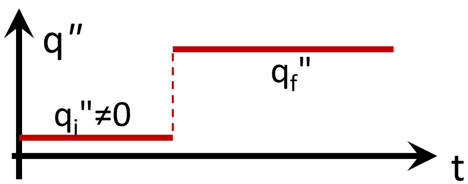
Critical time, t_c







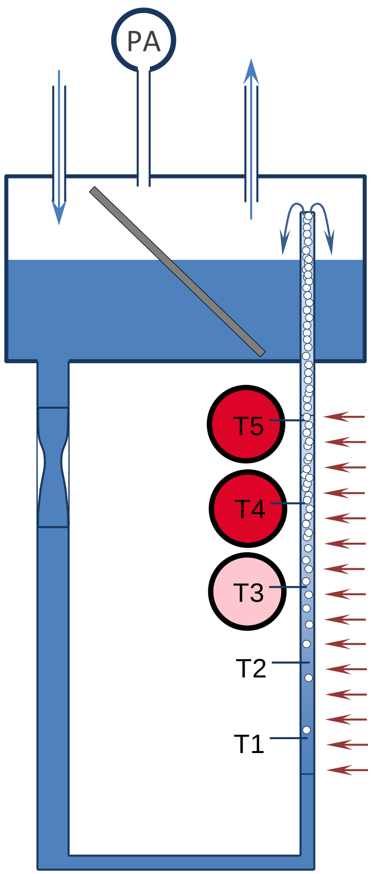
TRANSIENT PREMATURE CRISIS ATTENUATION

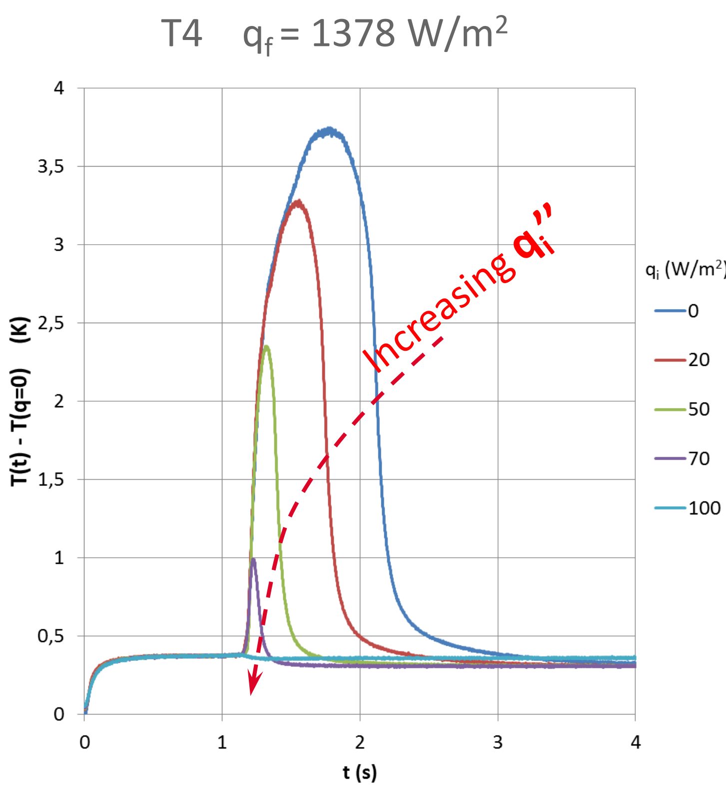


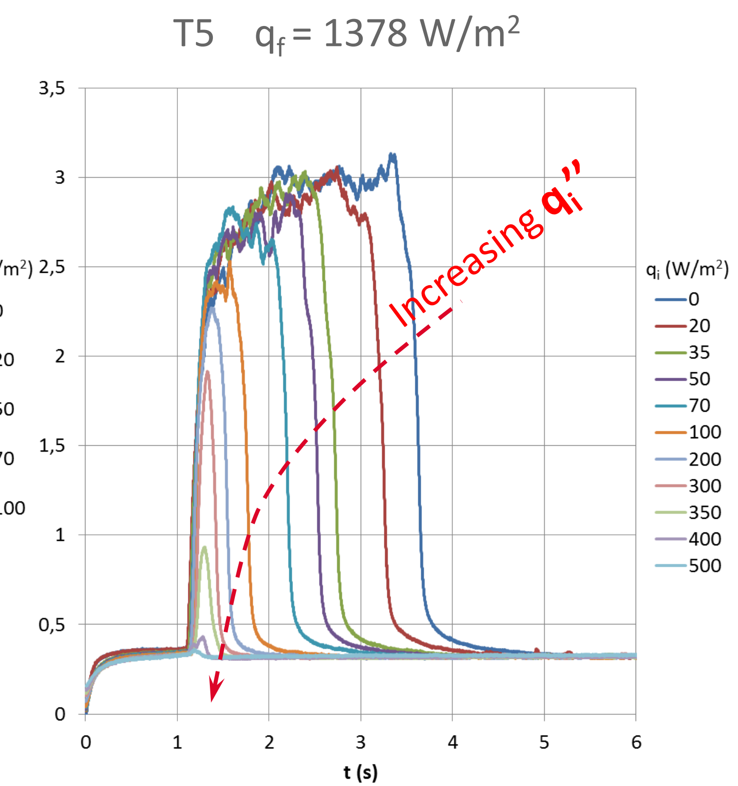
Non-zero initial power transients

Fixed final power (e. g. 1378 W/m²)

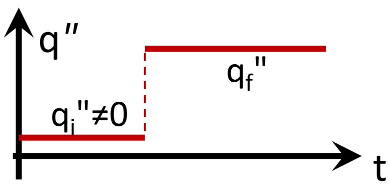
Increasing initial power q_i'' reduces duration and intensity of T excursion

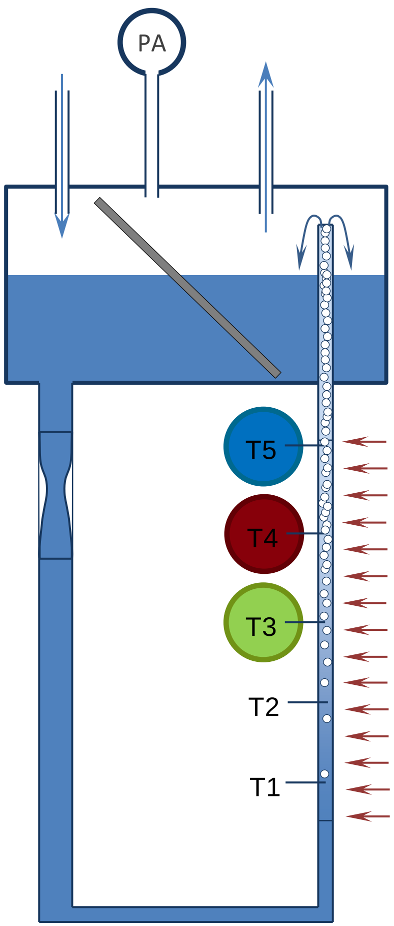




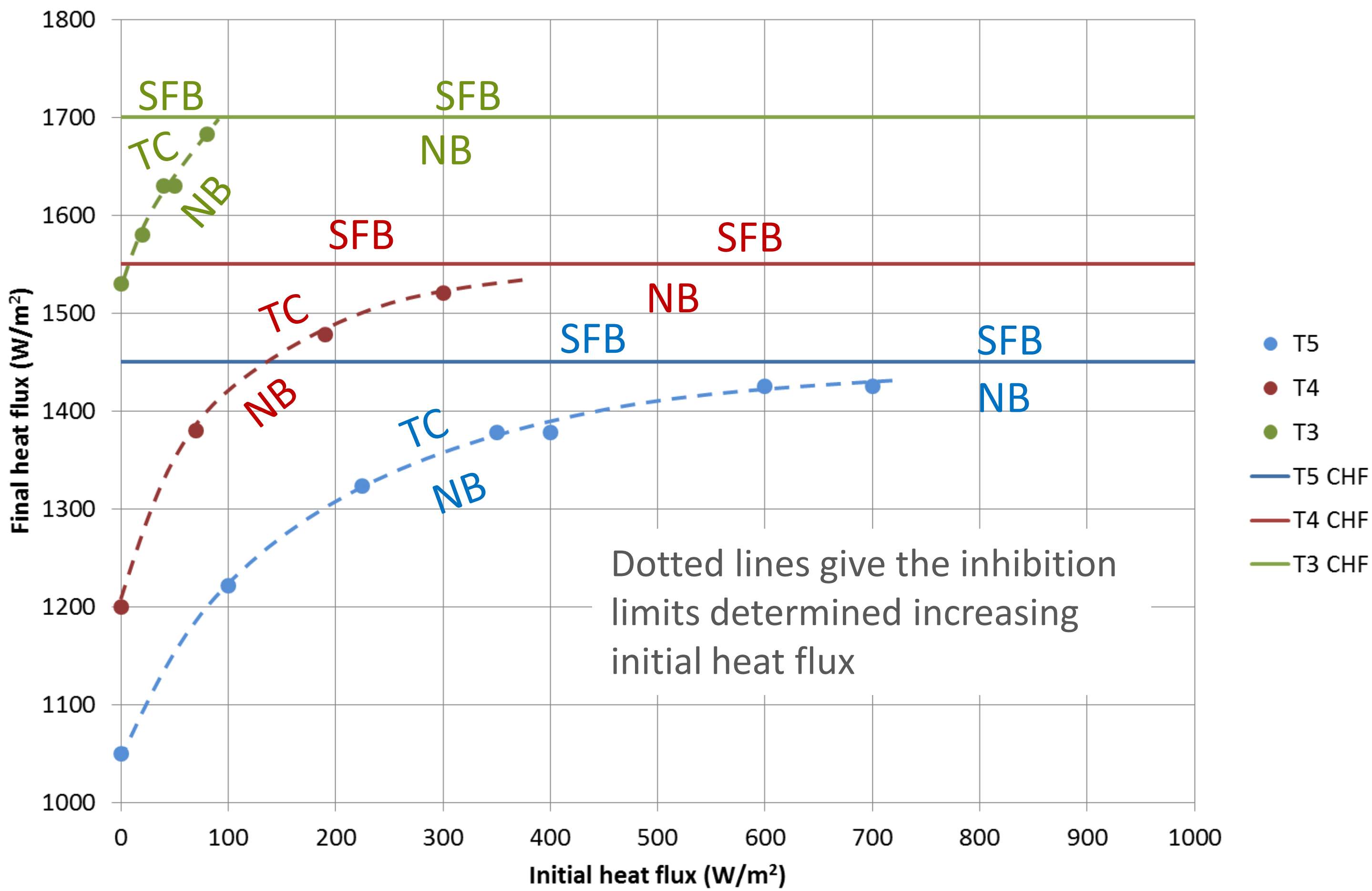


TRANSIENT PREMATURE CRISIS ATTENUATION





We could draw the limits for the three types of behavior:
Nucleate Boiling, Stable film boiling and Transient Crisis (final NB)



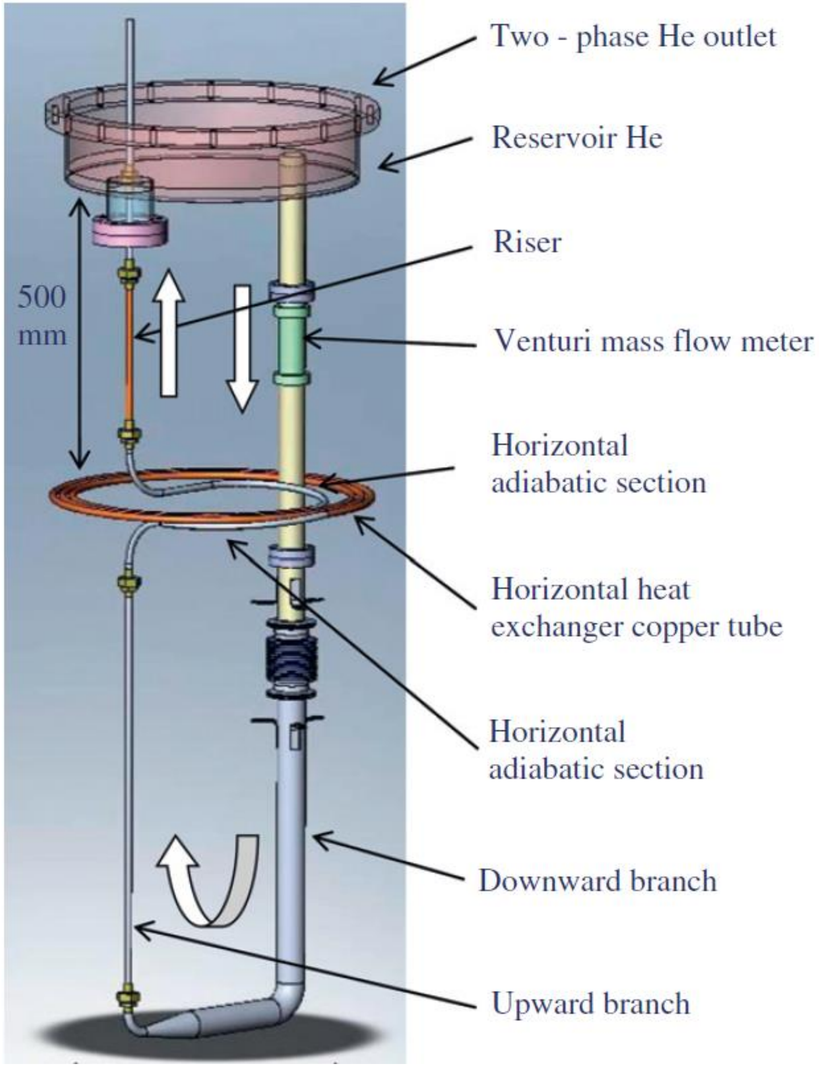
EXPERIMENTAL CAMPAIGNS

The heated section of the loop can be changed. We used three different test sections so far:

- Vertical, D = 10 mm, L = 95 cm
- Vertical, D = 5 mm, L = 102 cm
- Horizontal spiral, D = 10 mm, L = 427 cm

The results discussed in this talk concern only the **vertical, D = 10 mm, L = 95 cm** heated section experiments.

Loop with horizontal heated section has very distinct behaviour from vertical. Thermohydraulic instabilities have been observed in wide power ranges.



MODELLING – HOMOGENEOUS TWO-PHASE FLOW

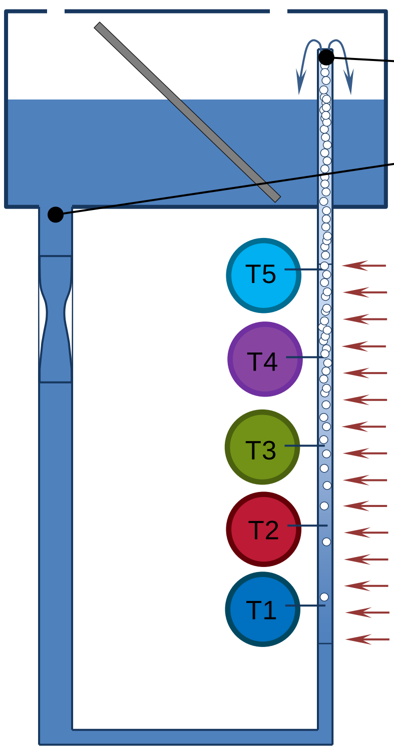
$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} = 0$$

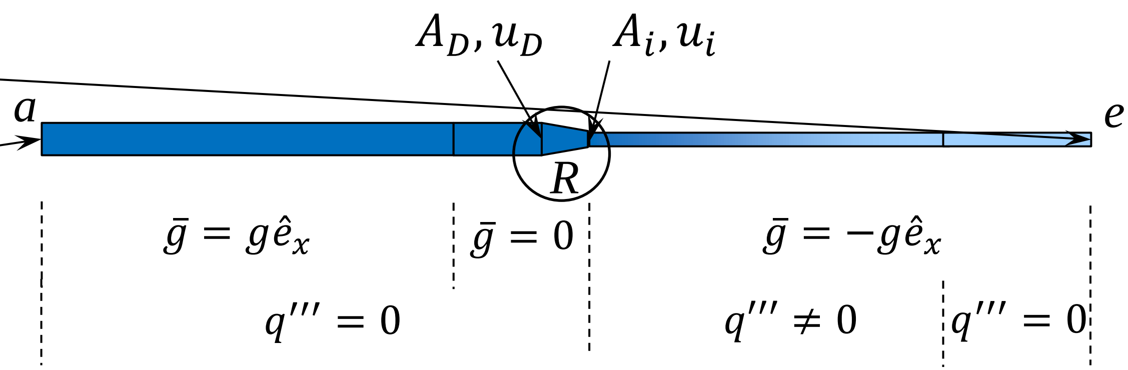
$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} = -\frac{\partial p}{\partial x} - \frac{\partial p_{fr.}}{\partial x} + \rho \bar{g} \cdot \hat{e}_x$$

$$\frac{\partial\left(\rho\left(e + \frac{u^2}{2}\right)\right)}{\partial t} + \frac{\partial\left(\rho u\left(h + \frac{u^2}{2}\right)\right)}{\partial x} = q''' + \rho \bar{g} \cdot \bar{u}$$

$$\begin{cases} \rho = f_\rho(h,p) \\ \dfrac{\partial p_{fr.}}{\partial x} = \dfrac{f(Re_h)}{D}\dfrac{\rho u^2}{2} sign(u) \\ Re_h = \dfrac{\rho u D}{\mu_h} \\ f(Re) = 0{,}316\, Re^{-1/4} \end{cases}$$

First approach: The systems was modeled in **COMSOL**, with some additionnal assumptions…





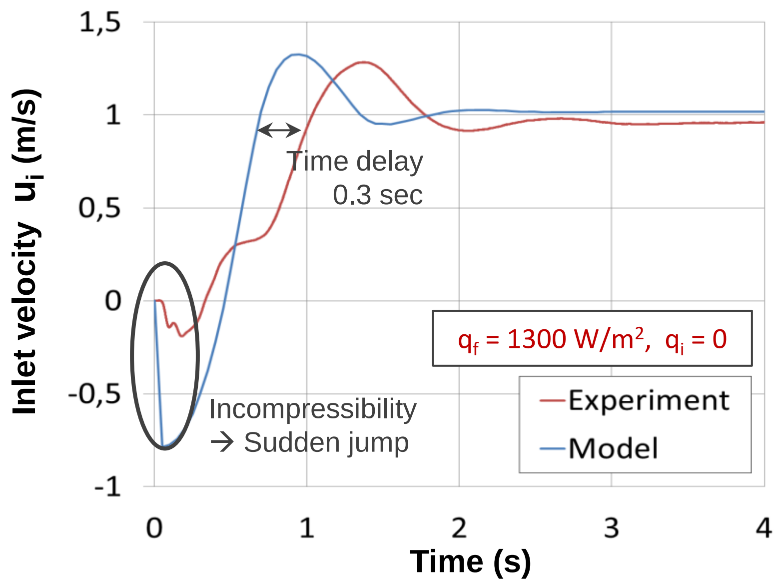
Energy Conservation $\quad \dfrac{\partial(\rho h)}{\partial t} + \dfrac{\partial(\rho u h)}{\partial x} = q''' - \rho \bar{g} \cdot \bar{u}$

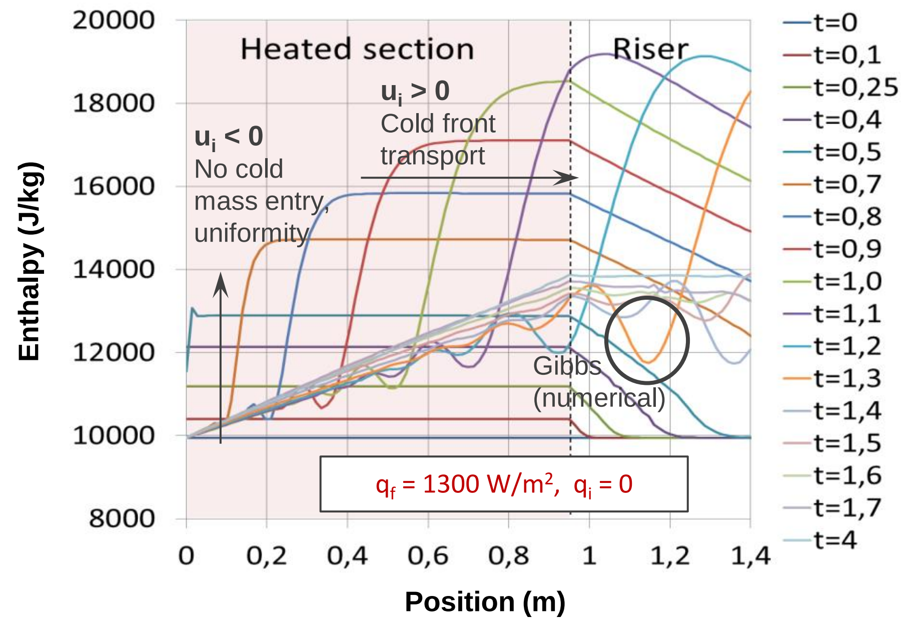
Clossure Equation $\quad \rho = f_\rho(h) = \left(\dfrac{h - h_f}{h_{fg}\rho_g} + \dfrac{h_g - h}{h_{fg}\rho_f}\right)^{-1}$

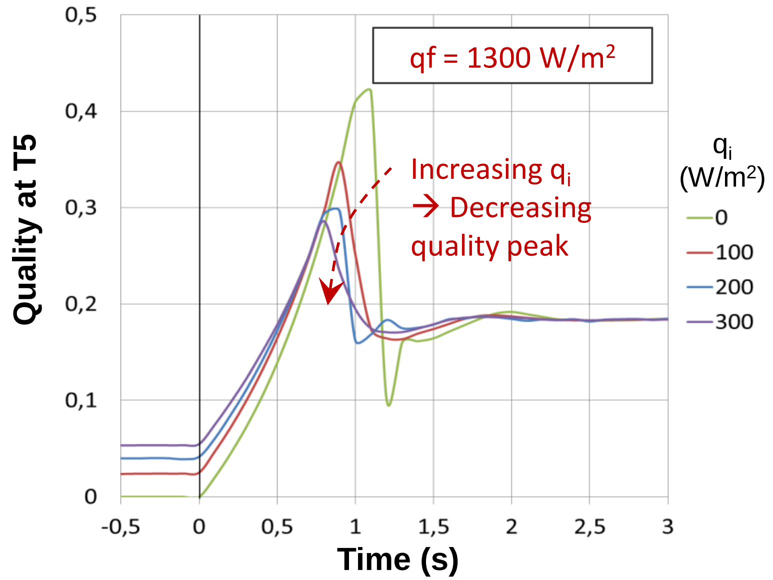
Momentum Cons. (Integral form) $\quad \dfrac{\partial G}{\partial t} = P_a - P_e + (\rho u^2)_a - (\rho u^2)_e - \Delta p_{fr.} + \int_a^e \rho \bar{g} \cdot \hat{e}_x\, dx + \Delta\left(\dfrac{\rho u^2}{2}\right)_R$

Mass Conservation $\quad \dfrac{\partial u}{\partial x} = \dfrac{q''' v_{fg}}{h_{fg}} \qquad u_D = \dfrac{A_i}{A_D} u_i \qquad G = \int_a^e \rho u\, dx$

MODELING– SOME RESULTS







Essential overall behaviour captured.
It lets us estimate the local variations of mass quality.

Local values of quality can exhibit an overshoot, whose amplitude is higher as the initial power is closer to 0, due to finite transit time from the entrance of the test section

This could explain *transient* crisis at the downstream positions of the test section, and not upstream.

Refinement of simulations shall be done by including pressure effects and improving numerical aspects.

CONCLUSION

Findings of this work

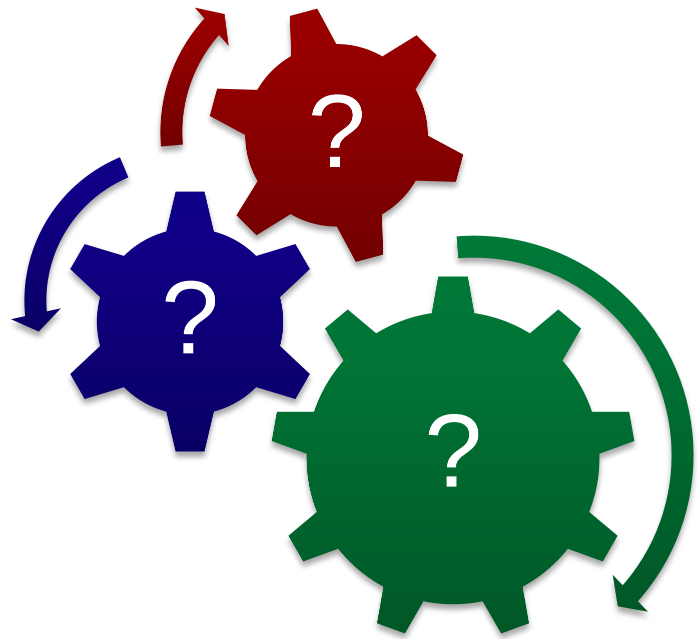
- Transient behavior of a boiling helium thermosiphon with a vertical heated section has been studied experimentally.
- **Power-premature boiling crisis** has been observed after power step pulses.
- Boiling crisis is more likely to happen **at higher positions** (higher void and transit time from entrance).
- **Initially established flow can inhibit** this transient feature, which gives us hints of how to protect devices from this effect.
- A first **simple model** predicts quite precisely the mass flow rate measurements, which would allow to **evaluate correctly bulk vapor concentration** evolutions.

Other work-lines

- **Horizontal heated section** (experiments finished, data being processed)
- **Thinner vertical heated section** (experiments finished, data being processed)
- **Modeling of the hydraulics:** consider pressure effects (coming soon)
- Evaluation of macroscopic conditions that may lead to crisis during transients in horizontal and vertical sections.

FROM RESEARCH TO INDUSTRY

Thank you for your attention!



COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES
DSM/IRFU/SACM
CENTRE DE SACLAY | 91191 GIF-SUR-YVETTE CEDEX