KNOO
Keeping the Nuclear Option Open

Heat Transfer and Fluid Dynamic Processes in PWR Reflood

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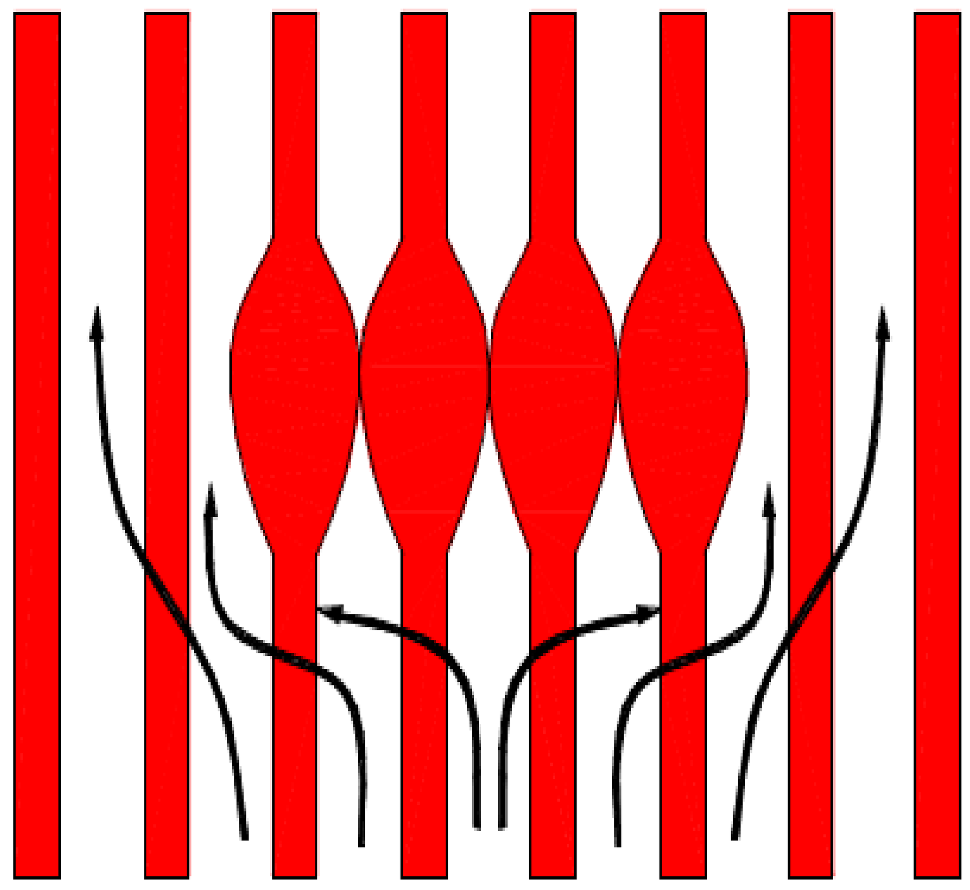


In a Pressurised Water Reactor, under normal operating conditions, the fuel pins are internally pressurised due to the helium gas that was put into the rods during manufacture and the fission gas products generated during operation. However, this internal pressure is exceeded by the higher pressure inside the reactor core.

Following a postulated large-break Loss of Coolant Accident (LOCA) the reactor core becomes uncovered and subsequently the fuel elements start to overheat. The water inside the reactor is under great pressure and flows out of the broken pipe and flashes to steam. The system pressure falls rapidly to below the pressure inside the fuel rods. Because of this, the rather ductile Zircaloy clad of the fuel rods become liable to expand radially when overheated. When happens, the rods distort into a somewhat carrot-like shape, or otherwise known as "balloon", and this would further reduce the availability of the core coolant flow area for the rewetting process to take place.

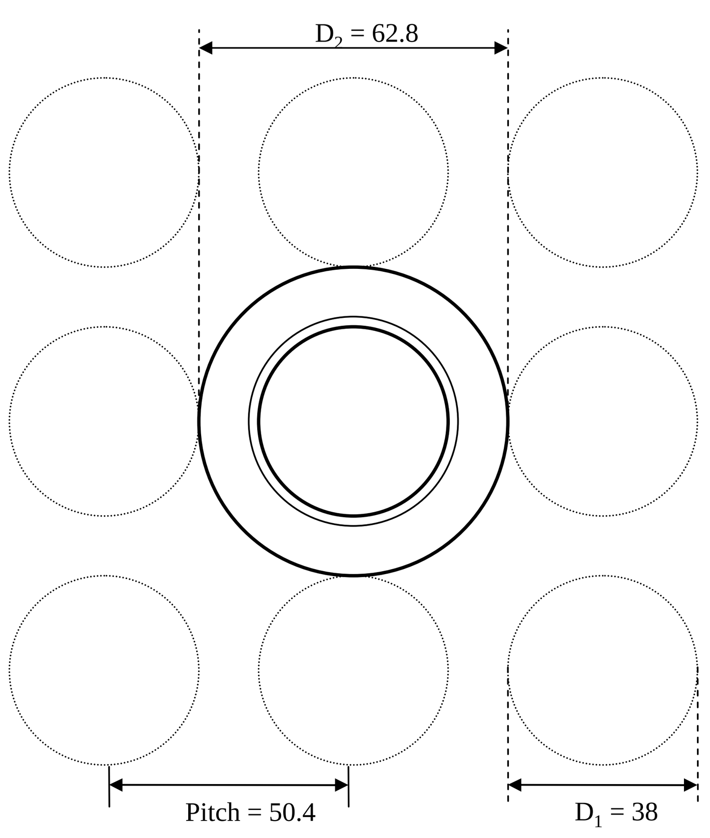
In the reflood phase of a LOCA, water droplets are entrained in the vapour flow and contribute greatly to fuel cooling before it is quenched. The ballooned fuel rod claddings are likely to divert the two-phase flow. The vapour flow will necessarily be diverted by the balloons, but it is yet unknown if the droplets would follow, or if their greater density would cause them to carry on and wet the balloons.

These projects comprise experiments and computational modelling addressing these questions. The results collected experimentally and computationally will be coupled in order to validate the data obtained.
The studies of the cooling of the fuel rods by means of droplets-wall heat transfer will be following these investigations.

Experimental work (Yiyun Jessy Zeng)

Two main experiments involved in the current experimental research project:

1) Flow diversion studies. This comprises fundamental work supporting the core KNOO project. The flow in a bundle of 3×3 tubes with the centre one being distorted (ballooned) would be simulated. The main objectives for this experiment are: (i) to offer a better quantification of vapour flow diversion in ballooned tube bundles; and (ii) to gain a greater understanding of the diversion of droplet flows by the diverted vapour, as a significant fraction of the cooling is provided by the sub-cooled droplets.



It should be noted that a scaling factor of 4 is used to increase the operability and accuracy of the experiment.

To ensure the replication of the "Reflood" being valid, density ratio between the two phases, Reynolds number (Re) and the size and pitch of bundle would be mapped to the real-case as closely as possible.

Conditions

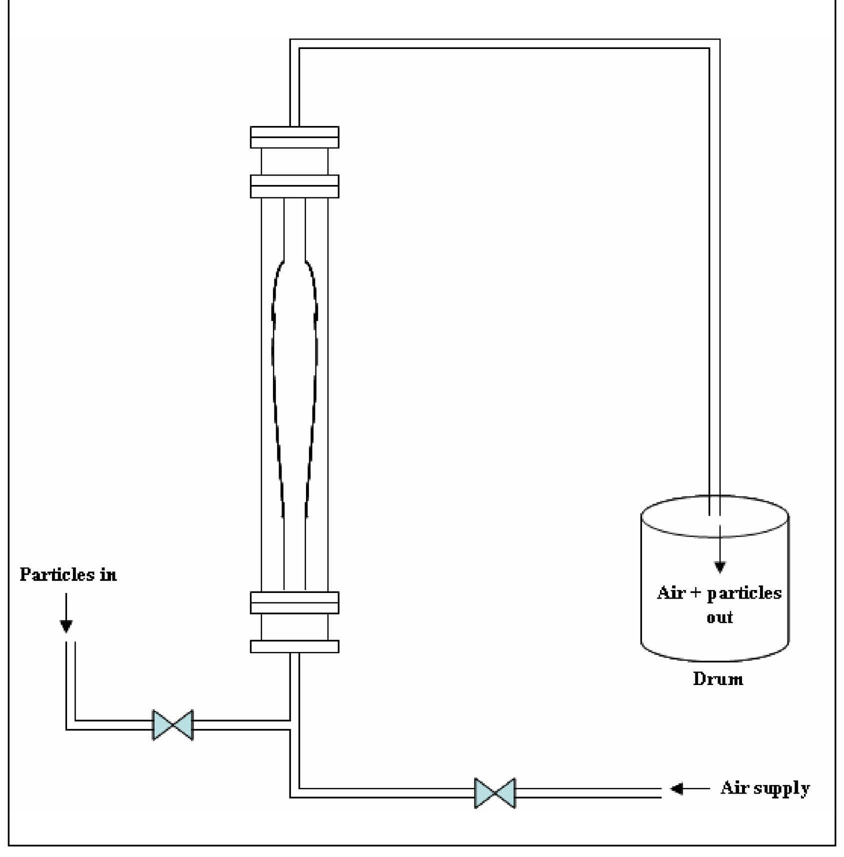
Temperature (°C) : 25

Pressure: atmospheric

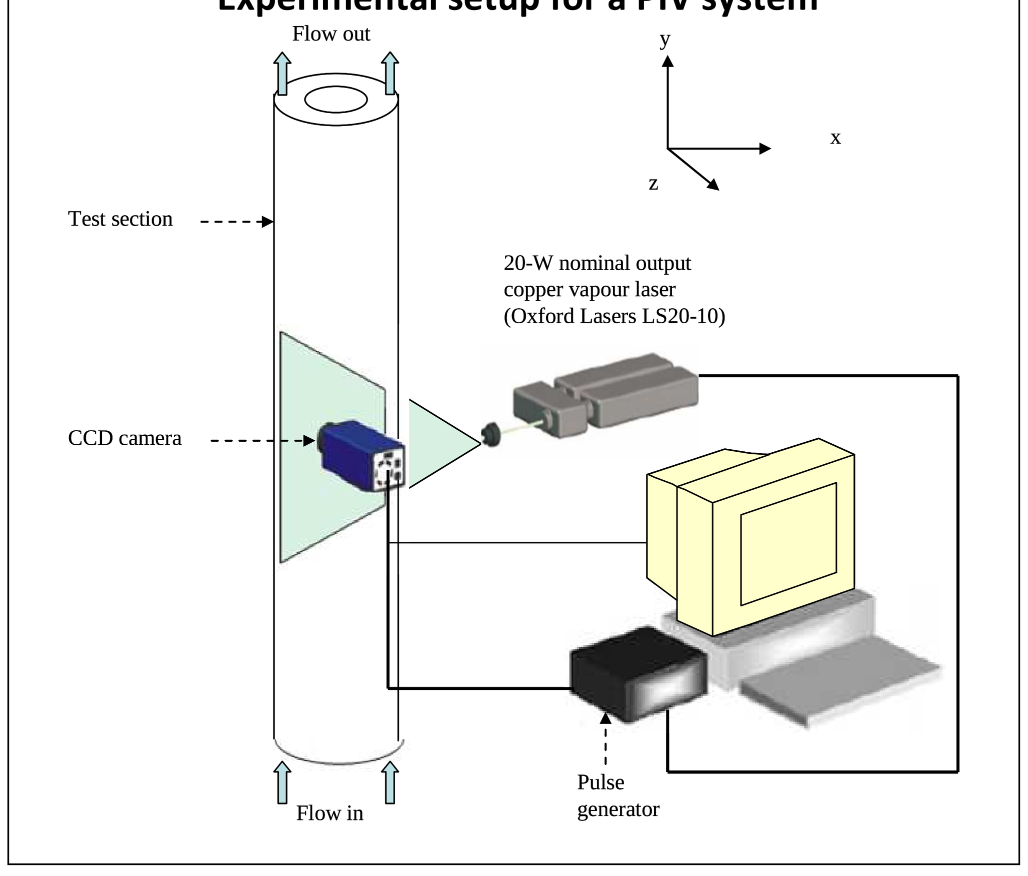
Vapour velocity, u_v (m s^{-1}): ~2-10

Volumetric flowrate, Q (l.min^{-1}): 250-1250

Schematic



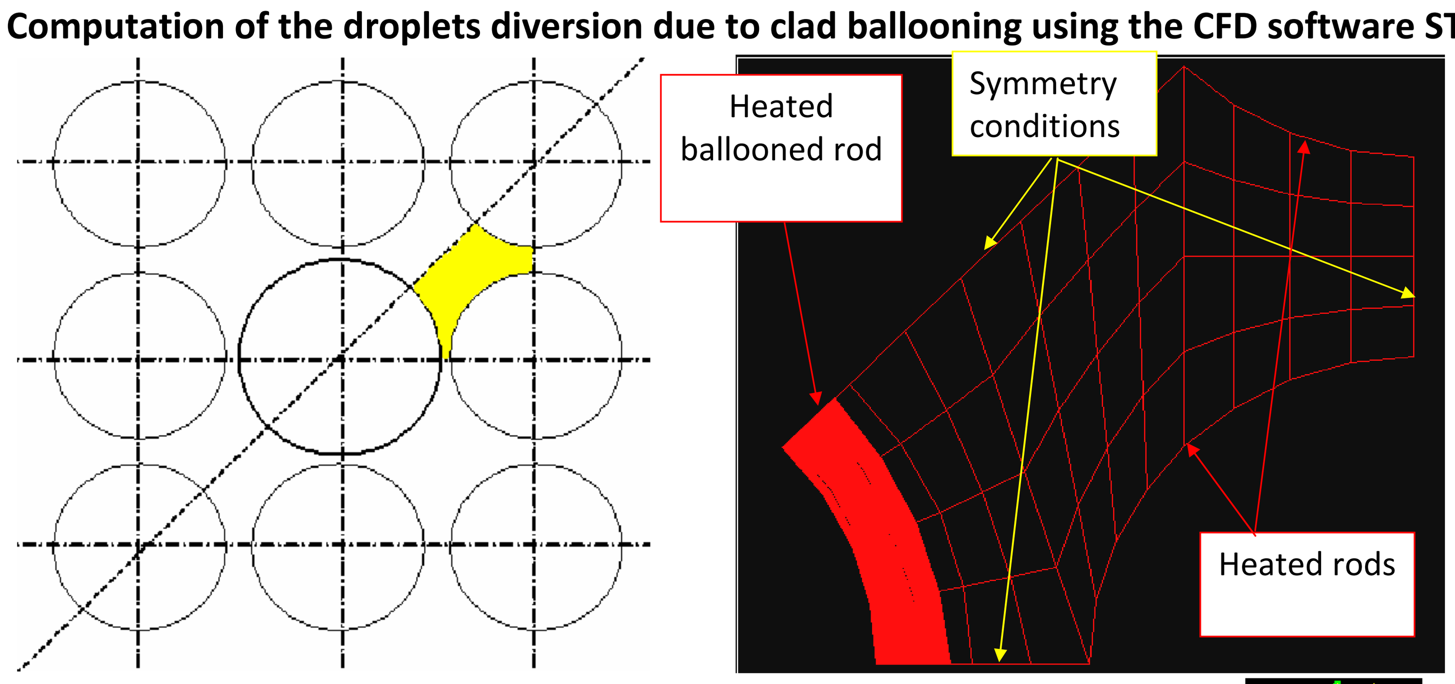
Experimental setup for a PIV system



2) A single-tube reflood experiment. This involves fundamental studies of the rewetting process itself and is aimed to enhance understanding and to inform and feed into the 'macroscopic' reactor studies carried out within the work package. Axial viewing technique will be applied to view droplet production.

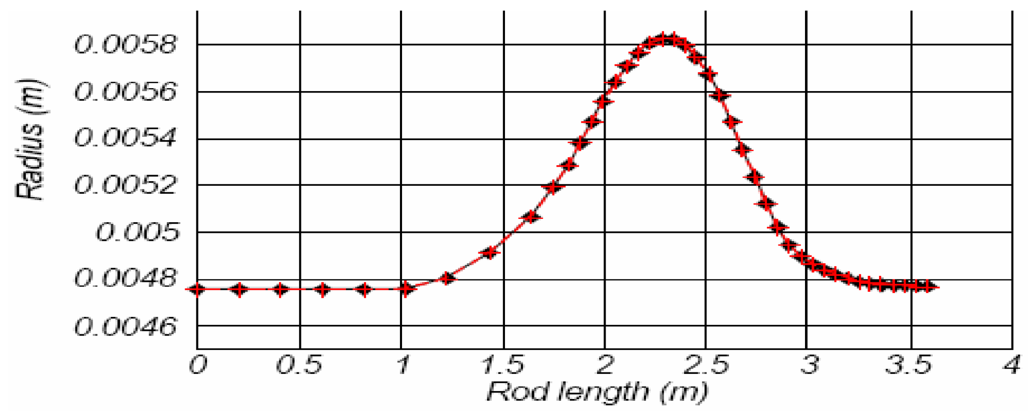
Computational work (Caroline M. D. Masson)

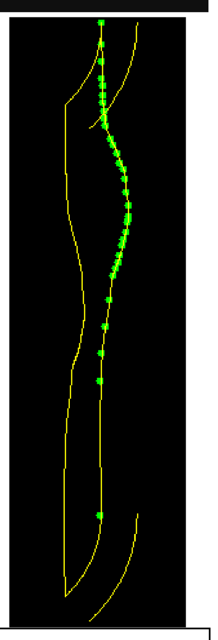
Computation of the droplets diversion due to clad ballooning using the CFD software STAR-CD.



To concentrate on the clad ballooning effect, it has been decided to have a first set of simulations of the "yellow" section of a 3x3 bundle with the central rod ballooned. No spacer grids are present.

The shape of the ballooned rod had been taken from results from Ammirable (2003)





Elevation of ballooned rod

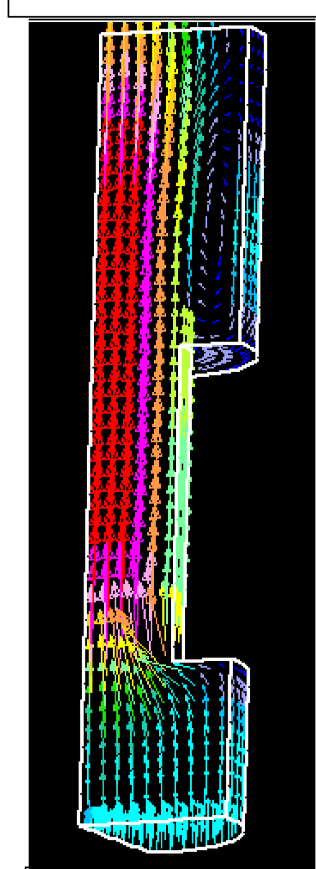
- The two-phase calculations are carried out as transient simulations, taking account of the compressibility of the continuous phase (i.e. vapour).
- The k-ε (high Reynolds number) turbulence model is used.
- In order to observe the diversion of the droplets by the vapour flow, droplets are in this first instance considered as particles with a constant mass and no heat transfer effects.

The results obtained show that water droplets diversion is negligible at the beginning of the reflood and that the diversion effect may only be significant after the droplets loose some mass due to evaporation and wall impact.

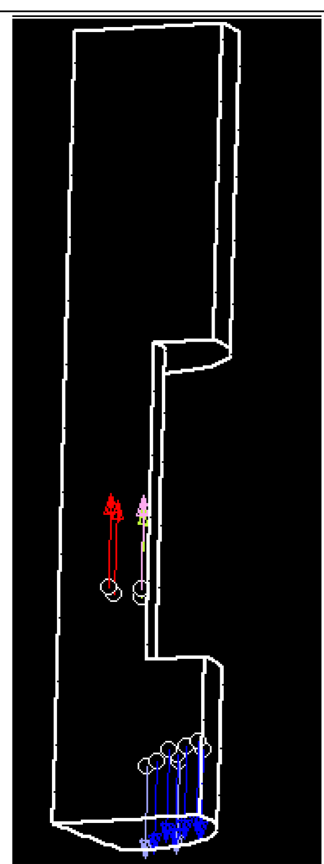
Therefore, the study of the heat and mass transfer between the droplets and the surrounding vapour and between the droplets and the walls (heated rods and later, spacer grids) will be of crucial importance.

Droplets tracking:

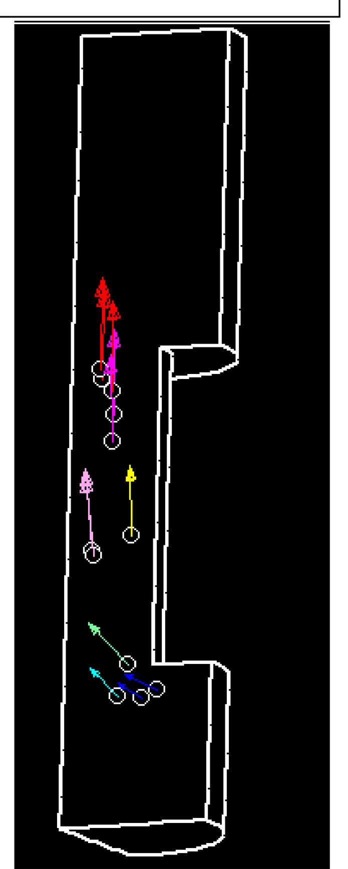
- Use of a simple geometry/mesh
- Injection from the inlet surface
- Droplets of constant diameter
- No heat transfer, focus on the momentum transfer.



Velocity vectors of the continuous phase (vapour)



Droplets path
Particles of constant high density (water)



Droplets path
Particles of constant small density (1.2 kg/m³)

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