Thermal Hydraulics in Liquid Metal Fast Reactors

Summary / Objectives:

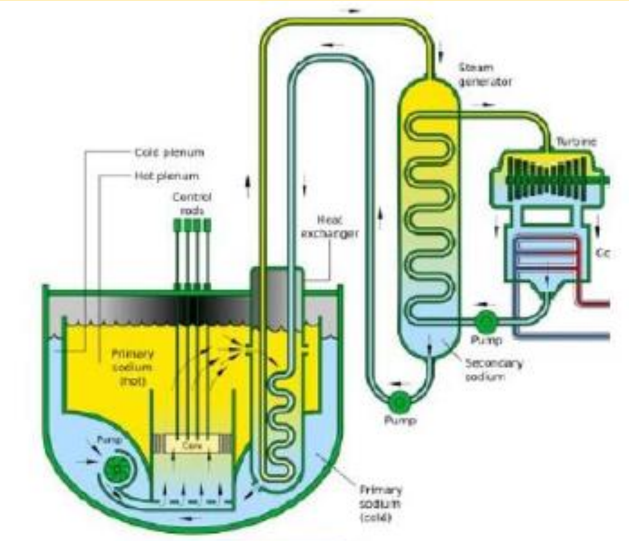
Thermal-hydraulics play a determining role in the design, operation and safety of liquid-metal reactors (LMRs) cooled by sodium, lead or lead-bismuth eutectic. The strong heat transfer performance and high boiling point of liquid metal enable the use of high working temperatures without pressurization. Because no pressure vessel is needed, most reactor designs then adopt a "pool-type" primary circuit, which minimizes the potential consequences of a primary leak and provides a large reserve of thermal inertia in accidental scenarios. While these common design characteristics of LMRs have direct advantages, they are also the source of complex thermal-hydraulic phenomena with potential high impact: strong temperature gradients must be controlled to avoid thermal fatigue on reactor structures, decay heat removal in pool-type designs depends on complex natural convection patterns. In this way, many key aspects of the justification of LMRs depend on understanding and simulating complex thermal-hydraulic phenomena. This webinar provides an overview of these phenomena and the current state-of-the-art for simulating them.

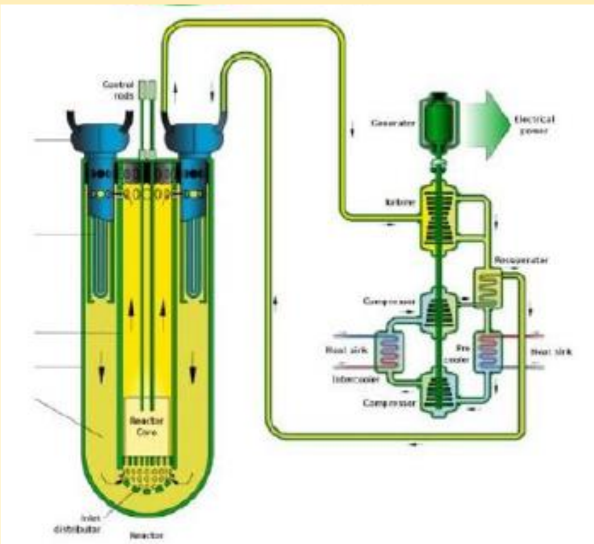
Meet the Presenter:

Dr. Antoine Gerschenfeld obtained his PhD from Ecole Normale Supérieure, France, in 2012, and has been coordinating R&D on the thermal-hydraulics of Sodium Fast Reactors at the Commissariat a l Energie Atomique et aus Energies Alternatives (CEA)'s Thermal-Hydraulics and Fluid Mechanics Section (STMF) since 2013. In that capacity, he has led the development of a subchannel thermal-hydraulics code (TrioMC) as well as the development of a tool for coupling coarse and fine models in a single reactor-scale simulation (MATHYS). He has also been involved in a number of collaborations : bilateral exchanges with DOE, JAEA and IPPE, as well as EURATOM projects.

Introduction on Thermal Hydraulics of LMFR:

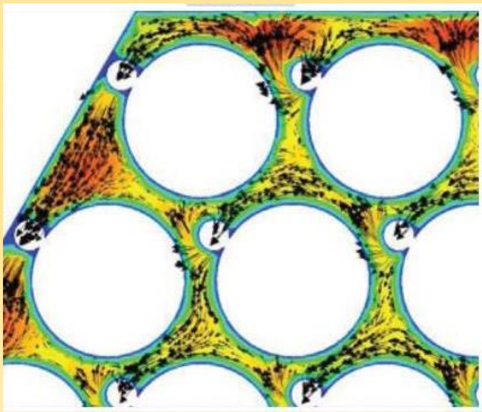
Liquid metal coolants have advantages such as little neutron moderation, large working temperature at ambient pressure and good to excellent thermal conductivity. However, they are also the source of complex thermal-hydraulic phenomena with potential high impact.

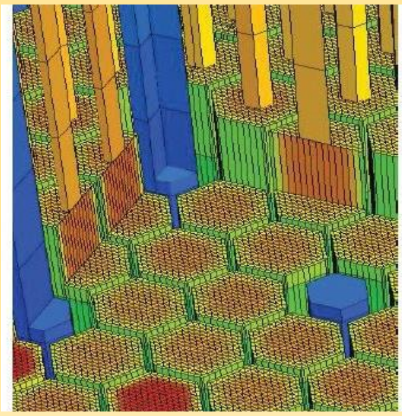


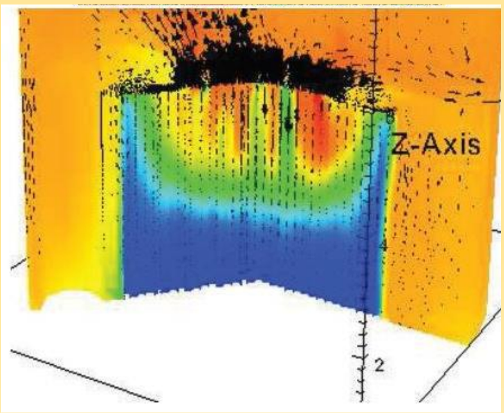


Issues / Core:

Subassemblies (S/As) have quite complex structures such as pins and wires (or grids). Issues of interests inside S/As are to know cladding temperatures both in nominal states (≤ 620^{o}C) and in accidents (≤ 1200^{o}C). There are issues from the point of overall behavior of core both in normal operations and accidental scenarios, which includes the coupling problem with neutronics and fuel thermal mechanics.

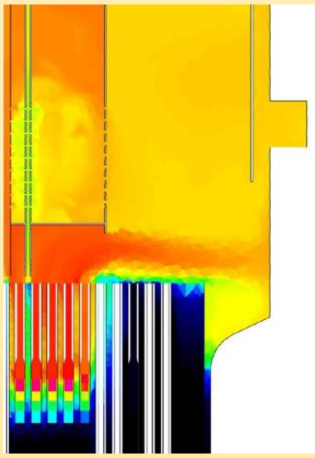


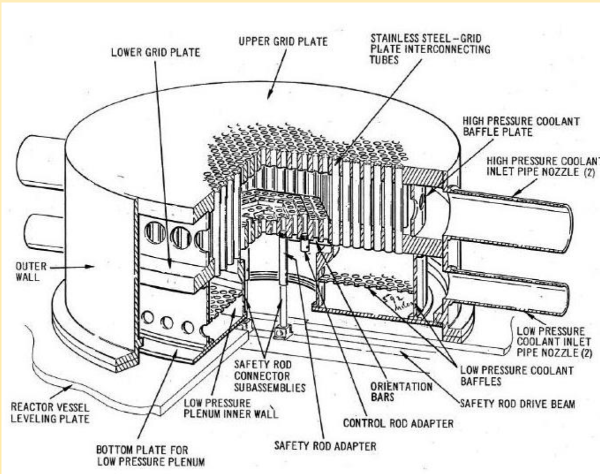


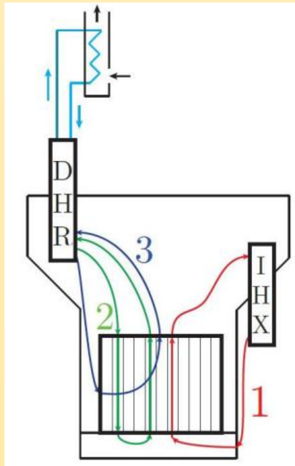


Issues / Pool, Component and Global:

In hot or cold pools, main issues on thermal hydraulics are on thermal load such as thermal fluctuation due to jet mixing, thermal stratification and hot/cold shocks in accidents. Issues on components are about its performance in normal or steady states and accidental aspects such as the pump trip situation. Gas transport in the primary circuit and decay heat removal system are issues involving the complete reactor.

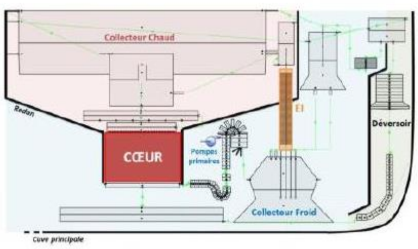
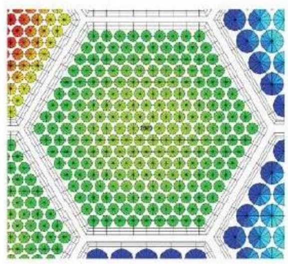
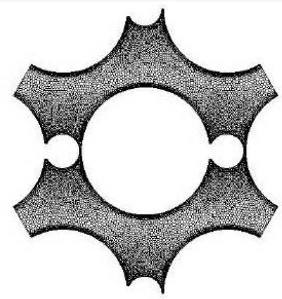






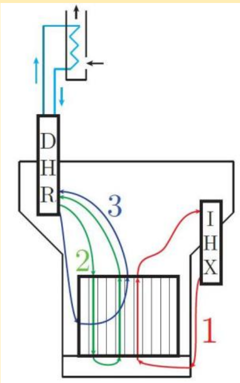
Modeling thermal hydraulics:

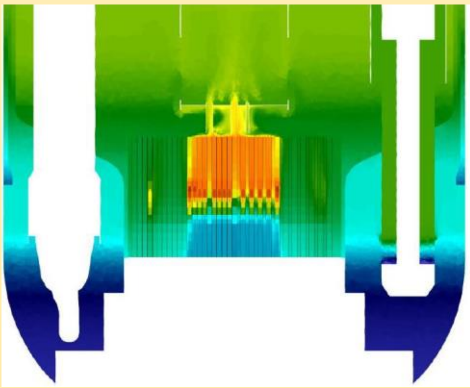
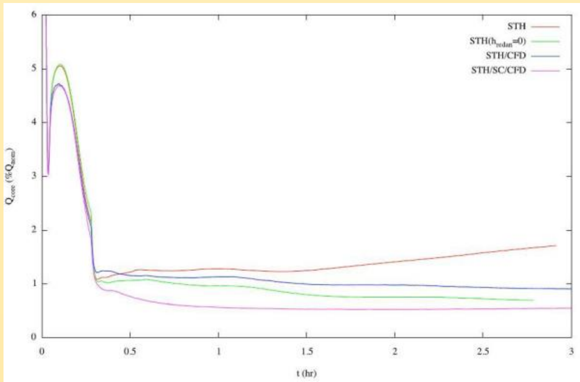
Thermal hydraulics has highly non-linear behavior and problem of scales. Ab initio modelling is very difficult and a cut-off scale is needed. There are various thermal-hydraulics codes according to the choice of cut-off. Those codes will be used according to the issues to be evaluated.

Scale	System (STH)	Subchannel (SC)	CFD
			
Simulation scale	channel (1D) volume (0D, 3D)	subchannel (between pins)	microscopic (DNS) fine (LES, RANS)
Physical models	every phenomenon (heat transfer, pressure drop)	fine geometry (wires, grids...)	nothing (DNS) turbulence (LES/RANS)
Code used at CEA	CATHARE	TrioMC	TrioCFD

Application / Natural convection in LMRs:

Natural convection is a global phenomenon in a reactor. Modelling based on STH is a natural choice. However, there are problems how to evaluate local issues which give feedbacks to the global behavior. On the other hand, modelling everything in CFD is not a reasonable approached because of the problem of extra computational cost. Combinations of STH and CFD (or SC) based on code coupling are prospected approaches.



Application/ Validation(Natural convection):

All physical models introduced must be established experimentally. Then, validation of the physical models are important. Because of the non-linearities, combined effects resulting from the interactions of separate phenomena must also be validated. Therefore, validation experiments will be performed with a hierarchy. There are some examples on combined effects tests and integral scale tests using actual reactors.