Open post-doc position - Aix-Marseille Université

Numerical simulation of an oxide-metal model system

Contact
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Starting : before end of 2015
Net salary : 2000 €
Location : MADIREL (madirel.univ-amu.fr)
Duration : 2 years

Introduction

Nuclear power production regularly returns to the headlines in particular when News put focus on the ageing of nuclear power stations and on the risk of severe nuclear accidents. The nuclear safety is clearly a priority in the nuclear field and is nowadays the major concern at all stages of industrial development: design, construction, operations and dismantling. This includes the consideration of potential accidents and protection of the populations. Important efforts are therefore concentrated on containment technologies of highly radioactive materials and in particular on the interaction between corium and concrete containment pits. The goal of this Post-Doc is to contribute to this activity with CFD numerical simulations of the hydrodynamics and energy transfer in a model corium bath in order to provide new insights in the understanding of the thermal boundary conditions at corium/concrete walls.

Conducting tests in prototypical materials (uranium dioxyde UO_2 and molten steel), has demonstrated the existence of metal phase segregation phenomena in macroscopic proportions and the absence of gravitational stratification. This is reflected in particular by the appearance of configurations in which the metal phase is preferably close to the concrete walls of the containment pits. This anisotropy in the distribution of chemical species leads to a significant change in heat transfer between walls and molten metals. It may in particular lead to a strongly inhomogeneous alteration of the pits and would thus introduce to additional constraints, not yet taken into account in the models.

Objectives and elements of the Post-Doc work program

This research project will be conducted along several steps corresponding each to an increasing level of complexity. The system in question will consist of a model mixture of three phases, two condensed and a gaseous one, in a two dimensional geometry with a Model Corium Bath (MCB). An in house Volume of Fluid program will be used. The initial condition will consist in 50 droplets (metal) and bubbles (air) in a continuous phase with specific temperature and boundary conditions. Inductive heating and concrete alteration will not considered.

- The VOF program available at MADIREL should be adapted to three phase systems and the treatment of free interfaces improved. Specific techniques for the treatment of parasitic currents should be implemented.
- The Navier-Stokes equation modified by capillary contributions should then be used for the calculation of the hydrodynamics in the MCB in isothermal conditions.
- The formation of oxides at the metallic droplet interfaces should be described with the aim to account for thermo-solutal effects and changes in interfacial tension at metal/oxide interfaces.
- The final phase of this project should focus on thermal aspects. The temperature field in the MCB and heat transfer at the boundary walls should be described by the integration of the heat equation.

Required expertise

The candidate should have a solid expertise in fortran development and in Volume of Fluid Techniques. An experience in numerical modeling of multiphase systems and capillary phenomena would be appreciated. The candidate should be able to actively contribute to the understanding of model limitations, algorithms validation and critical analysis of numerical outputs. An experience in program parallelization would also be appreciated.

Fast overview of the experimental framework of this post-doc.

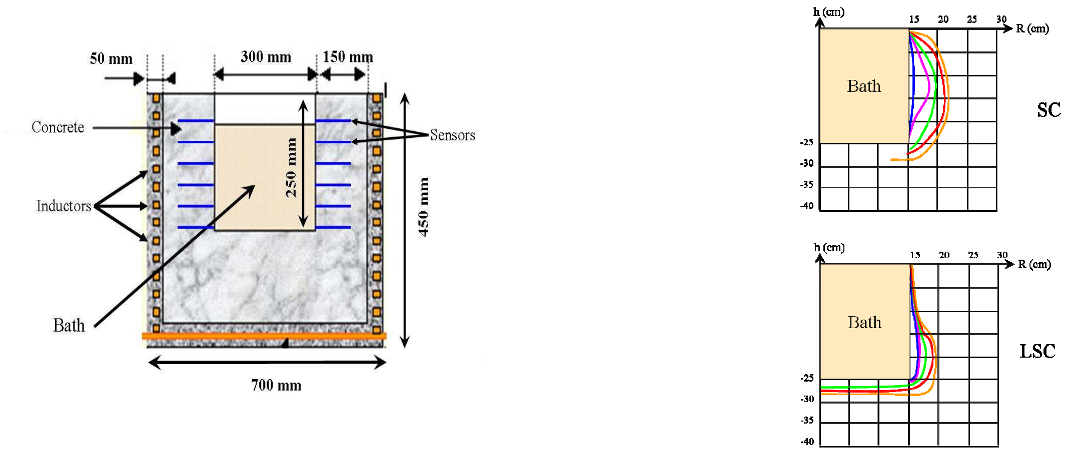
Nuclear accidents above INES Level 7 imply severe damage of reactor cores. One of the consequences is the partial (or total) meltdown of the reactors vessels due to the loss of the main cooling system. The molten mixture under consideration here, the corium, consists of reactor structural materials and chemical products. A fraction of these latter is generated by the interaction of corium with the concrete containment pit, last containment barrier before soil and ground water contamination. This high temperature mixture will modify the thermo-mechanical properties of concrete. Despite good performances at room temperature, concrete can show critical behaviors at high temperature. In such situations, it is essential to rapidly cool down the corium and to simultaneously prevent steam explosion due to excessive mechanical loading of the containment. Molten Core Concrete Interaction (MCCI) involve complex processes characterized by generation of gaseous phases, thermal and solutal convection in a bubble-agitated melt, physico-chemical evolution of the corium bath with a wide solidification temperature range (of the order of 1000 K) and last but not least concrete ablation.

The understanding of the concrete ablation profile in the VULCANO-ICB tests of DTN/STMA/LPMA is the main scientific goal of this project. Due to the specific properties of uranium dioxide, experiments with prototypic materials are absolutely necessary. The Corium Concrete Interaction (ICB) program has been elaborated to this end in the frame of national and international collaborations (EC, EDF, SUEZ, IRSN, CEA). Twelve experiments have been carried out in the CEA-VULCANO facility with prototypic corium and sustained heating. Although reduced in size, the CEA VULCANO facility allows the simulation of corium-concrete interactions representative of reactor case situations. These experiments started in 2007 and still raise important fundamental questions. As an example, post-test analysis evidenced unexpected concrete ablation profiles and phase separation effects where the metallic fraction appears to be concentrated in specific locations of the container. Both phenomena are still not yet fully understood.

Two types of concretes, representative of reactor pits, have been used: “siliceous” concretes (SC with 63% w/w SiO2, 16% w/w CaO) and “lime-siliceous” concrete (LSC, 26% w/w SiO2, 42% w/w CaO). VULCANO-ICB test section consist in half cylinders of height (resp. diameter) 25 cm (resp. 15 cm) equipped with temperature sensors providing measures of ablation kinetics (see figure 1). An inert zirconia wall closes the half cylinder to mimic cylindrical symmetry. A plasma arc furnace is used for the melting and synthesis of the oxide mixtures (ZrO_2, SiO_2 and Fe_2O_3) that are further transferred into the concrete container. Overall, VULCANO-ICB experiments demonstrate the existence of :

1 – An important radial ablation kinetics for SC and a less pronounced one for LSC. Experimental ablation profiles for SC and LSC are plotted in the figure.

2 - A phase separation for both SC and LSC with metal dominant wetting structures along the ablated concrete walls instead of a metal-oxide stratified distribution.



Left: Schematic front view of the VULCANO-ICB test section. The maximal melt load is 60 kg. Right : time evolution of ablation profiles for SC and LSC concretes.

From the numerical point of view, the simulation of multiphase systems in nuclear facilities is for long the object of important algorithmic developments. The main problem in this context is the precise description of free stiff interfaces and capillary forces. The simulations planned in this Post-Doc project will focus on the hydrodynamics in the oxide bath with the aim to give access to relevant temperature and heat flow profiles at the bath/concrete boundaries.