Numerical study on the influence of simplified spray boundary conditions for the characterisation of large industrial safety spray systems used in nuclear reactors

J. Malet[1], A. Foissac[1,2], C. Vayaboury[1], T. Gélain[1], S. Mimouni[2]
[1] IRSN, PSN-RES/SCA Saclay, France
[2] EDF, MF2E, Chatou, France
jeanne.malet@irsn.fr; celine.vayaboury@irsn.fr, thomas.gelain@irsn.fr;
stephane.mimouni@edf.fr; arnaud.foissac@irsn.fr

Abstract

During the course of a severe accident in a Pressurized Water Reactor (PWR), hydrogen can be produced due to reactor core oxidation, leading to potential combustion and deflagration, as observed in Three Mile Island and Fukushima accidents. In some reactors, spray systems (over 500 nozzles) are placed at the top of the containment to prevent overpressure. Spray modelling is thus part of thermal-hydraulic containment codes. The two major phenomena involved in spray behaviour under such accidental conditions are the thermodynamical effect of a spray (steam condensation on droplets, leading to a local increase of hydrogen concentration) and the dynamical effect (mixing of gases, leading to a decrease of hydrogen concentration). The competition of these two coupled phenomena is an important issue for nuclear safety and can be assessed using CFD codes.

For nuclear reactor (containment vessel of around 60 000 m^3), simplifications have to be done to simulate a nuclear accident in the containment where gas mixture (steam, hydrogen and air) is mixed by the spray systems. Up to now, no CFD calculations are available in the open literature on spray systems in a real-scale nuclear containment, using detailed spray initial conditions, accurate droplet modelling and droplet-gas momentum interaction. Many choices can be performed to reduce the computational time of such sprays in a very large containement: atomization zone is neglected, some calculations consider only one droplet size and velocity at one single injection point, other calculations consider a dynamical equilibrium between gas and droplet, etc. The objective of this paper is to evaluate the influence of several choices, performed on spray boundary conditions, on some selected 'output' parameters that can influence the overall gas mixing in nuclear reactors.

This evaluation is performed on a real-scale PWR spray nozzle (hollow cone) having an outlet diameter of 1 cm and a maximal diameter of its envelope of about 2 m. CFD calculations are performed using the ANSYS/CFX-FLUENT code (lagrangian approach) and the EDF NEPTUNE_CFD code (eulerian approach).

Experimental results are obtained on the CALIST (Characterisation and Application of Large Industrial Spray Transfer, 160 m^3) facility at the IRSN. The droplet measurements are performed using Phase-Doppler Interferometry (PDI, ARTIUM) and fog sprays are used to have an estimation of the characteristics of the gas entrainment. Measurements performed at the very first zone where droplets are formed and spherical, i.e. 20 cm from the nozzle outlet, are used as 'boundary conditions' in the CFD calculations. Other measurements are recorded down to around 1 m from the nozzle outlet.

Sensitivity studies are performed using these 'boundary conditions' post-processed in different ways: for example, a radial profile of a variable (droplet size or velocity) can be reduced into a single mean value of this variable. Furthermore, 'boundary conditions' on droplet characteristics are not sufficient, since the gas is already entrained at this location. Sensitivity calculations to the choice of the gas 'boundary conditions' are also performed, as well as sensitivity studies to several parameters like mesh density, number of particles in the lagrangian approach, turbulence model, etc. Example of code-experiment comparisons is presented in Figure 1. Influence of different injection conditions on the entrained gas velocities is presented in Figure 2.

The final paper will present the experiments, the CFD codes, the code-experiment comparison and the sensitivity studies used to evaluate the importance of different parameters regarding to nuclear safety analysis.

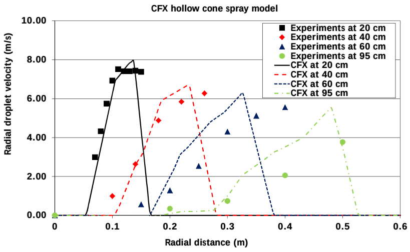

Figure 1: Code-experiment comparison of radial velocity profiles

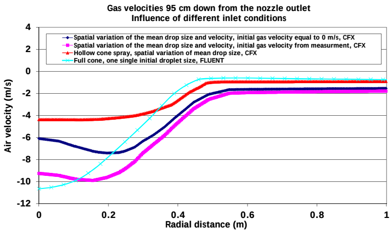

Figure 2: Influence of various initial conditions of the entrained gas velocities