# Experimental investigations on rod bundle cooling by a water spray in spent fuel pool accident conditions

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Abstract

Increased attention has been paid in the last decade to the Spent Fuel Pools (SFP) accident phenomenology. The DENOPI project is part of this approach with the aim to gain knowledge in the SFP under loss of cooling or loss of coolant accident conditions and to better evaluate the safety margins. Questions are still pending regarding the physical phenomena involved during the uncovery phase of the accident. Besides, the capabilities of a spray system to cool down a partially or totally uncovered assembly must be assessed. To address these issues, the ASPIC facility has been set up at the scale of one full height 17x17 rod bundle which is electrically heated. In this study, the results of a reference test are presented and discussed. For instance, the rod and wall section temperatures are analyzed and a comparison is undertaken for the time evolution of these temperatures with and without the activation of the spray during the test. Besides, the impact of the spray on the outlet steam characteristics is examined.

Spent Fuel Pools (SFP) generally contain a large number of Fuel Assemblies (FAs) that could be several times larger than the FAs in the reactor vessel (e.g. 2.5 times for the French 900 MWe reactor). Even if the residual power of each FA is smaller than what is encountered in reactor conditions, the total amount of fission products stored in a SFP is tremendous. Hence, SFP accident phenomenology has to be precisely understood in order to avoid any risk of fission product release from SFP. In loss-of-cooling or loss-of-coolant accident in a SFP, one mitigation measure consists in activating a water spray system at the top of the pool. Such a mitigation measure has led to several recent studies (Kaji et al. 2019; Nagatake et al. 2019; Cao et al. 2018; Gao et al. 2018) in order to determine the physical mechanisms involved in such conditions and the overall efficiency of this measure.

The DENOPI project, conducted by the IRSN (the French Technical Safety Organization), aims at improving the knowledge of the phenomena involved in SFP accident prior to the severe accident phase (clad failure), evaluating the mitigation by a water spray, and developing/validating thermal-hydraulic models. The DENOPI project is organized around three axes that investigate three consecutive phases of the accident at three different scales of interest (Migot et al. 2022; Martin et al. 2017). The first axis is devoted to study the convective loops and boiling process at pool-scale before uncovering of the fuel assemblies. In the third axis, the oxidation of the cladding under air/steam mixture is analyzed. In the second axis are studied the phenomena involved at the assembly scale during the uncovering of the fuel but before any subsequent clad oxidation or degradation. To achieve the second axis objectives, a progressive multi-steps approach was chosen. In the first step, experiments have been carried out on a one-meter height assembly in the MEDEA mock-up (Brillant and Fourré 2019; Brillant and Martin 2021). The second step has been reached in the ASPIC facility with a full scale electrically heated rod bundle.

An overview of the ASPIC facility is drawn on Fig. 1. The central test section of ASPIC is a square stainless-steel tube with an internal dimension of 225 mm. The pressure in the test section is measured by means of 8 differential pressure transducers located in between two adjacent grids of the assembly and are almost equally spaced all along the height of the test section. In a similar way, the temperature is measured by means of several 1 mm K-type thermocouples distributed on the faces of the test section. These thermocouples aim at measuring either the fluid temperature or the wall temperature. Above the test section, the upper head is connected to the water injection. Water is sprayed through a spray nozzle down to the rod bundle which is inside the test section. Besides, the upper head collects, on one side, the water that would be carried up by flooding (and drives it to the flooding line), and, on another side, the air/steam that comes from the central section (and drives it to the exhaust line). A 17x17 rod bundle is inserted inside the test section. This assembly is a four-

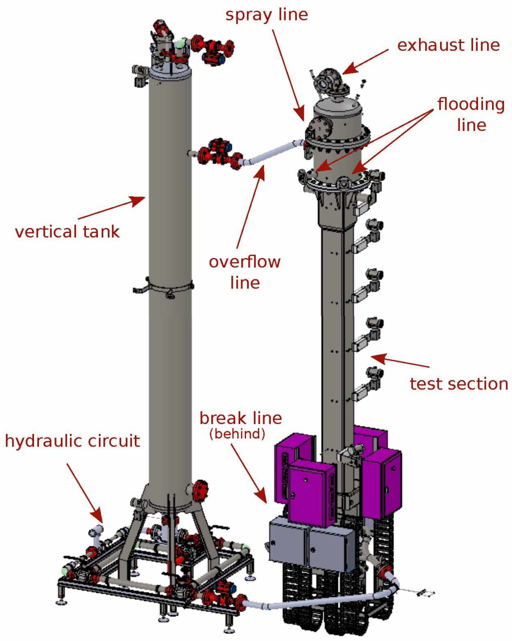


Figure 1: Overview of the ASPIC facility.

meter height electrically heated rod bundle. This assembly has the full geometrical characteristics of a standard French PWR900 assembly with prototypical top nozzle, spacer grids, and mixing grids. The total power of the assembly can be set up to 80 kW. The rod temperature measurements are obtained over the full height of the assembly by means of 320 thermocouples located at sixteen levels.

For the reference test of the first ASPIC test series, the assembly was dewatered by about one-meter. The test starts with a stabilized temperature of walls and fluid at saturation. Then, the assembly power is switched on at 20 kW and the rod temperature on the dry part raises rapidly (see Fig. 2). The spray system is activated with a flowrate of $5\,\mathrm{g\,s^{-1}}$ as soon as a rod temperature is measured above 110 °C. The highest temperatures are noticed at the upper part of the assembly. The impact of the spray on the temperature rise kinetics is rather small at the first period of the test but increases as temperature raises in the rod bundle. In the test conditions, no top-down quenching is observed. Besides, the activation of the spray leads to lower rod temperatures and thus let the rods move away from the critical domain of temperature as far as rod degradation and fission products release are concerned. These are major outcomes of this experimental test series in typical spent fuel pool accident conditions. In the final paper, the impact of the spray on the temperature evolution of the rods, the fluid, and the walls will be deeply discussed. Furthermore, the outlet steam flowrate and temperature will be analyzed.

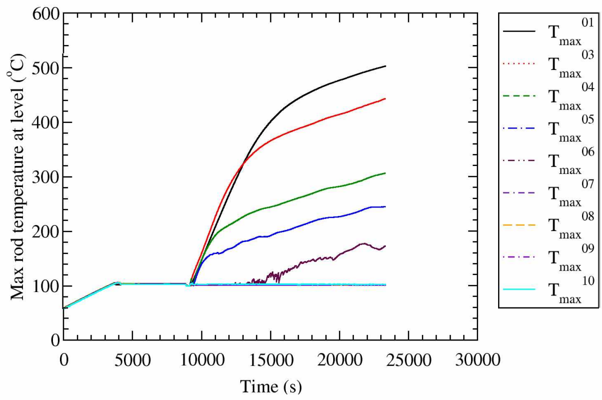


Figure 2: Maximum rod temperature at several elevations for the reference test with the water spray.

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