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Thermal-hydraulic conditions at and downstream of a quench front during a Loss-of-Coolant Accident in a Pressurized Water Reactor

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Ensuring the integrity of the reactor core is essential in the operation of a nuclear plant, as any failure can result in the release of irradiated fuel or fission products. A loss-of-coolant accident (LOCA) is a hypothetical situation resulting from breaches in the primary circuit pipes of a pressurized water reactor (PWR). That breach leads to a core pressure drop, followed by the evaporation of the coolant water. As a result, the system's cooling capacity is reduced, raising the fuel rod temperature, which may ultimately lead to the failure of the fuel cladding — the primary barrier containing radioactive materials. To maintain the rod temperature within a safe range and prevent it from melting, the reactor core possesses a water-injection system responsible for reflooding the core assembly and cooling it down. As the reflooding process occurs, a quenching front is produced due to the high temperature of the fuel cladding (~1000 °C): the intense boiling phenomenon, combined with the hydrodynamic instabilities at the liquid-vapor interface, gives rise to a droplet-vapor flow downstream of the quenching front. This two-phase flow of droplets and vapor, also known as dispersed flow film boiling (DFFB), has been previously studied in industrial contexts, particularly by agencies such as the French Authority for Nuclear Safety and Radiation Protection (ASNR) and the U.S. Nuclear Regulatory Commission (USNRC). Even though it was shown that those droplets can enhance the heat dissipation in the DFFB, their characteristics, in terms of size and velocity distribution, are poorly known. Considering that context, this study aims to characterize and model those droplets generated downstream of a quench front. A new experimental apparatus will be mounted, allowing the tests to be performed under LOCA-like conditions. Reflooding will occur inside a heated tube whose hydraulic diameter corresponds to the area between four fuel rods. Moreover, implementing optical techniques will allow the characterization of the droplet population, using the phase doppler anemometry (PDA), and the wall's temperature profile, utilizing infrared thermography (IRT). By solving a two-dimensional heat equation, the heat flux at the inner surface can be estimated, enabling the application of conservation equations to the internal flow. These data will support the development of physical models for predicting droplet characteristics, which will be compared to the DRACCAR code for validation and potential improvement of its droplet distribution models during a LOCA.

Keywords: LOCA; Heat transfer; Boiling; DFFB.

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