
Investigation of Natural Circulation Insability and Transients Important for Passively Safe Modular Reactors

PI: Mamoru Ishii – Purdue University

Collaborators: Takashi Hibiki – Purdue University

Yang Liu – Purdue University

Won Sik Yang – Purdue University

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ABSTRACT

Small Modular Reactors (SMRs) have drawn significant attention recently due to the reduced investment risk as well as electrical power option in areas without major advanced infrastructure. Many of the current water-cooled SMR designs, such as Mitsubishi's Integral Modular Reactor (IMR), Purdue University's Novel Modular Reactor (NMR), and the NuScale Power Reactor, have simplified the reactor system by removing mechanical systems and primary system penetrations (i.e. primary coolant pumps, loop piping, pressurizer). These reactors rely on natural circulation cooling for normal operation or accident management. Under natural circulation conditions, the core power and flow interact strongly, and there exist potential control problems associated with flow instabilities. Instabilities in boiling systems occur due to disturbances in various parameters affecting the heat transfer such as inlet enthalpy fluctuation, flow regime transition, steam demand change, and so on. Particularly at low or medium pressure, boiling systems are prone to static and dynamic thermal-hydraulic instabilities which can challenge the reactor safety and reliability. Static instabilities such as flow excursion (Ledinegg) instability and flow pattern transition instability, as well as dynamic instabilities such as density wave instability and flashing/condensation instability pose a significant challenge in two-phase natural circulation systems. In the reactor core, the two-phase stability is further complicated by void reactivity feedback.

The major objective of the proposed research is to perform scaled experiments to study the thermalhydraulic instabilities that can occur in SMR designs which rely on natural circulation cooling during normal operation or accident conditions. The objective will be achieved by systematically performing tests to study the general natural circulation instability characteristics and the natural circulation behavior under start-up and design basis accident conditions. Experimental data highlighting the effect of void reactivity feedback as well as the effect of power ramp-up rate and system pressure will be used to develop a comprehensive stability map. The safety analysis code, RELAP5, as well as a frequency domain code, will be used to evaluate experimental results and models. Improvements to the constitutive relations for flashing and condensation, as well as other important models, will be made in order to develop a reliable analysis tool. The proposed research focuses on two generic SMR designs, i.e. a small modular Simplified Boiling Water Reactor (SBWR) like design and a small integral Pressurized Water Reactor (PWR) like design.