TWO-PHASE FLOW CFD IN NUCLEAR REACTORS (I)

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1 INTRODUCTION

Multiphase flows are working processes for a variety of industrial applications as conventional and nuclear power plants, combustion engines, propulsion systems, flow inside human body, oil and gas production and transport, chemical industry, biological industry, process technology in metallurgical industry or in food production etc. These conditions become especially complex in nuclear power plants, where the parameters required testing and analysis are extensive and challenging. Some countries like Japan, declared the multiphase flow field to be strategic importance for the future technological development.

There are about 438 nuclear power reactors in operation in 31 countries around the world, generating electricity for nearly 1 billion people. They account for approximately 17 percent of worldwide installed base load capacity for electricity generation and provide half or more of the electricity in a number of countries.

Complex systems such nuclear reactors with their several types involve a large number of components and phenomena. The simultaneous behavior and interactions among the reactor components as well as the study of each component and its multitude phenomena, one at a time, are important for the system operation, performance and safety. In nuclear applications the complex behavior of all the system beside the basic two-phase behavior is needed. Consequently, the understanding of two-phase flow problems in nuclear systems requires extensive testing and *computational* studies.

There are various types of nuclear reactors which have arisen from the various combinations of fuel, coolant and moderator types. These can be classified as follows:

- Conventional and advanced pressurized water reactors (PWR) which is a water-cooled reactor under sufficient pressure to limit steam generation at the core exit and where the large quantity of heat produced is transferred to a secondary system via heat exchangers as is illustrated in Figure 1. There are two types of the steam generator; namely, U-tube steam generator and once-through steam generator (OTSG). During the operation of this component during normal and transient conditions, two-phase flow phenomena are encountered.
- Conventional and advanced boiling water reactors (BWR) which differ from the PWR in that it generate steam directly within the core and do not have a separate steam generator (Figure 2).

- Gas cooled reactors (GCR)
- Liquid metal cooled reactors

Recently, it is identified six most promising nuclear energy systems for the new generation of nuclear power plants. Two employ a thermal neutron spectrum with coolants and temperatures that enable hydrogen or electricity production with high efficiency (the Supercritical Water-Cooled Reactor [SCWR] and the Very High Temperature Reactor [VHTR] shown in Figure 3. Three employ a fast neutron spectrum to enable more effective management of actinides through recycling of most components in the discharged fuel (the Gas cooled Fast Reactor [GFR], the Lead-cooled Fast Reactor [LFR], and the Sodium-cooled Fast Reactor [SFR]). The Molten Salt Reactor (MSR) employs a circulating liquid fuel mixture that offers considerable flexibility for recycling actinides and may provide an alternative to accelerator-driven systems for actinide destruction.

The safety and performance of these reactors depend on the heat removal from the reactor core. The flow characteristic and behavior of fluid flows are important during normal and transient operations. They set the safety limits and major efforts are devoted to study the thermal hydraulic aspects of normal and off-normal behavior. It is clear that a variety of liquids and gases have been used to cool nuclear reactors. Two-phase flows are experienced with its transport processes (boiling, condensation) in various types of reactors with various multiphase flow patterns. Variety of flow regimes in multiphase flow are observed such as bubbly flow, slug flow, churn flow and annular flow. Multiphase flow is characterized by the existence of the interface between different phases. The interface between the phases can be described as irregular, transient, and stochastic. The interaction between phases can be extremely complicated.

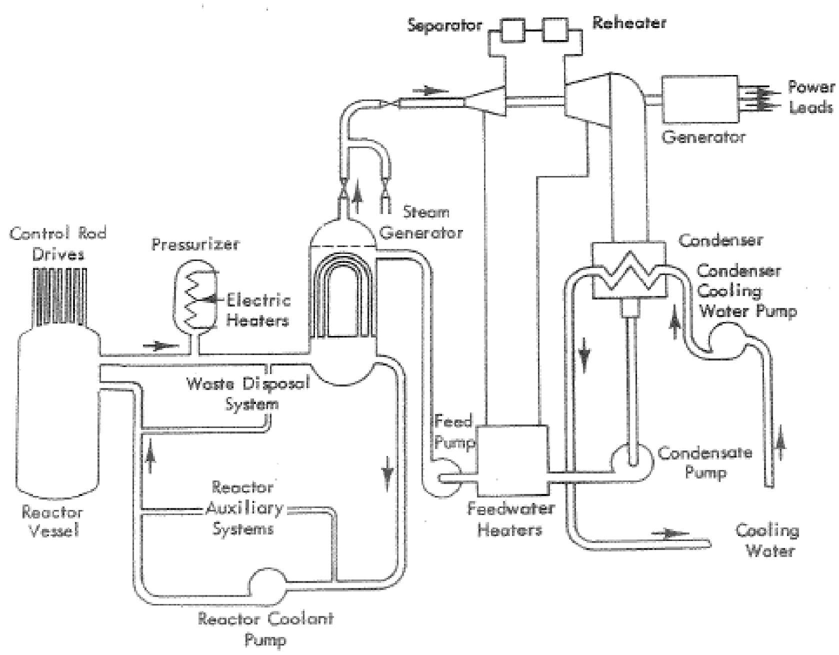

Figure 1 Typical PWR system