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Analysis of Phenix End-of-Life asymmetry test with multi-dimensional pool modeling of MARS-LMR code

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ABSTRACT

The understanding of complicated pool behaviors and its modeling is essential for the design and safety analysis of a pool-type Sodium-cooled Fast Reactor. One of the remarkable recent efforts on the study of pool thermal–hydraulic behaviors is the asymmetrical test performed as a part of Phenix End-of-Life tests by the CEA. To evaluate the performance of MARS-LMR code, which is a key system analysis tool for the design of an SFR in Korea, in the prediction of thermal hydraulic behaviors during an asymmetrical condition, the Phenix asymmetry test is analyzed with MARS-LMR in the present study. Pool regions are modeled with two different approaches, one-dimensional modeling and multi-dimensional one, and the prediction results are analyzed to identify the appropriateness of each modeling method. The prediction with one-dimensional pool modeling shows a large deviation from the measured data at the early stage of the test, which suggests limitations to describe the complicated thermal–hydraulic phenomena. When the pool regions are modeled multi-dimensionally, the prediction gives improved results quite a bit. This improvement is explained by the enhanced modeling of pool mixing with the multi-dimensional modeling. On the basis of the results from the present study, it is concluded that an accurate modeling of pool thermal–hydraulics is a prerequisite for the evaluation of design performance and safety margin quantification in the future SFR developments.

1. Introduction

In the twenty-first century, many countries are concentrating their efforts on the development of Generation-IV (Gen-IV) nuclear energy systems satisfying the goals of improved sustainability, superior economics, enhanced safety and reliability, increased proliferation resistance and physical protection (GIF, 2002). They have joined to form a framework of the Generation IV International Forum (GIF) to activate international cooperation on the development of future nuclear systems, and the six most promising Gen-IV nuclear systems were selected by the GIF. The selected nuclear systems are Sodium-cooled Fast Reactors (SFR), Gas-cooled Fast Reactors (GFR), Lead-cooled Fast Reactors (LFR), Molten Salt Reactors (MSR), Very High Temperature Reactors (VHTR), and Super Critical Water-cooled Reactors (SCWR). It is expected that the Gen-IV nuclear energy systems are to be deployed about the year 2030.

Among the six Gen-IV reactor systems the SFR is evaluated technically matured enough and it has lower technical and regulatory barriers than other types of systems, thus, it is anticipated to be deployed in the nearest-term. Actually, the SFR has a long developmental history since 1950's, and several experimental reactors and prototypes has been constructed and operated to achieve a 400 reactor-year of accumulated operational experiences. An SFR is usually arranged in a pool layout or a loop layout. A loop-type design is advantageous in maintenance and repair. On the contrary, a pool-type SFR is featured by a large thermal inertia and minimized risk of radioactive sodium release.

Recognizing the potential importance of Gen-IV SFR deployment in the long-term energy strategy in Korea, the Korean government has increased the investments on research and development for SFR technologies since 1990's. These efforts resulted in the development of design concept of KALIMER, which has been selected as a reference Gen-IV design of pool-configuration SFR by the GIF (2007), followed by the development of prototype Gen-IV SFR (PGSFR) since the year 2012. One of the most challenging parts in the SFR technology developments in Korea is to prepare a well-validated accurate system code applicable to

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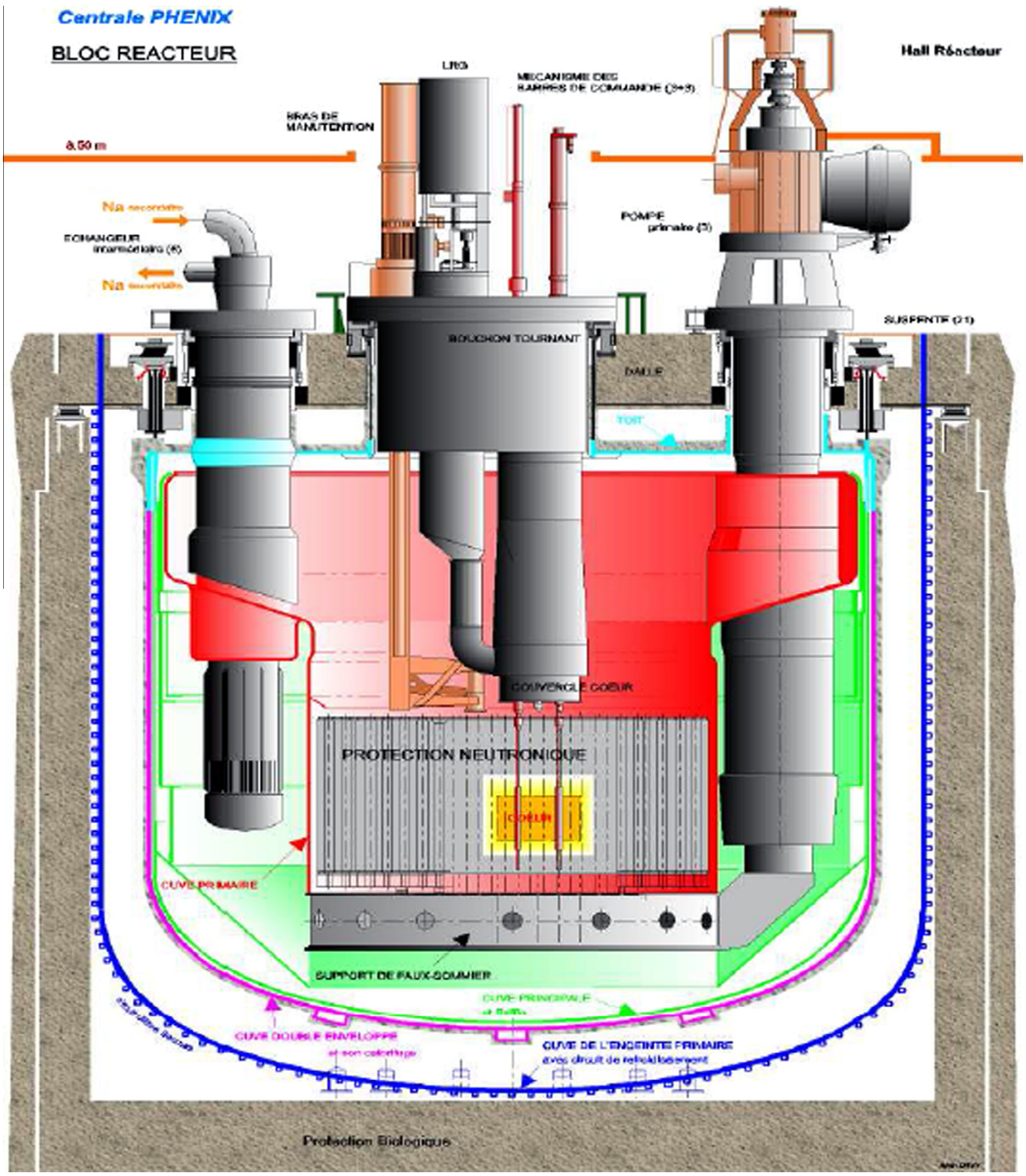

Fig. 1. Schematic of Phenix reactor.

the analysis of pool-type SFR systems, which is a prerequisite to guarantee an enhanced safety of Gen-IV SFRs.

In a pool-type SFR, all the main components are located in the hot pool and the cold pool. Therefore, the primary pumps, intermediate heat exchangers (IHXs), lower internal structures, reactor core, and upper internal structure (UIS) give rise to very complicated thermal–hydraulic phenomena in the pool regions. This means that a system code developed for the application to a pool-type SFR has to be validated for various thermal and hydraulic

Table 1
The sequence of Phenix asymmetry test.

Time (sec)	Test sequence
100	Secondary pump PS1 is tripped
105.5	Fast control rod insertion is started
105.5	Speed of secondary pump PS3 is decreased
114.5	Speed of PS1 is maintained at 100 rpm
147.5	Reactor SCRAM
154.5	Speed of PS3 is maintained 110 rpm

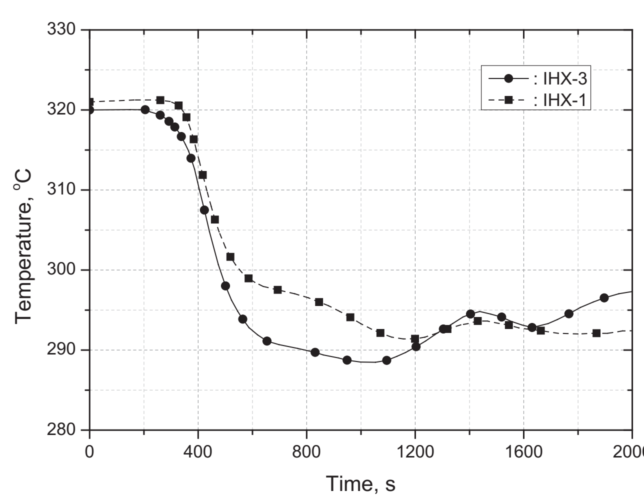

Fig. 2. IHX secondary temperatures during the asymmetry test.