

Study on the I-SMR Simulator Development and HFE Validation

Kyeong-Min KIM*, Chan-Ho Sung, Joo-Youl Lee
KHNP Central Research Institute, Daejeon, 34101, Republic of Korea
*Corresponding author: kyungmin@khnpp.co.kr

1. Introduction

After the development of APR1400, the latest nuclear power plant in Korea, KHNP is promoting the development of SMR(Small Modular Reactor) that can be used in various fields other than power generation projects at the level of new growth engines. I-SMR(Innovative-SMR) being developed in KHNP is a reactor that can improve not only safety but also economic feasibility. One of the important operating concepts for the economic feasibility of I-SMR is the concept of operating multi-unit module with three persons. A simulator is essentially used to verify the suitability of multi-unit three-person operator.

The simulator in Nuclear Power Plant is a facility designed and manufactured to simulate the physical behavior of nuclear power plants and is an essential facility used not only for nuclear power plant reactor operator license tests but also for license refresher training of operators.[2]

The purpose of this paper is to describe the development plan for the I-SMR simulator development and the implementation plan for three-person operation verification.

2. Method and results

KHNP is carrying out SMR technology development to use it as a new growth engine for the company after APR1400 plant.

In the IAEA and WNA, SMR is defined as a small nuclear power plant with an output of less than 300 MW. The I-SMR under development by KHNP has the following operating concepts.[3]

- A high level of automation.
- Monitoring and control of multiple units in one MCR
- Integrated Human-System Interface(HSI)
- Three-person operating in one MCR

According to the above concepts, I-SMR determines as an operation concept that three operators control and monitor four 170MW reactor modules in one MCR(Main Control Room) to increase economic feasibility. Compared to the APR reactor type, innovatively simplified and advanced technology will directly intervene in the operation of the plant and reduce the number of elements to operate rapidly.

It is necessary to verify through the development of SMR simulator that it is possible to operate multiple modules with three operators by securing automation design technology. In addition, HFE(Human Factors

Engineering) validation shall be performed for the suitability of three-person operation.

2.1. I-SMR developing status

Currently, there are about 50 SMR developments identified by the IAEA and WNA. In particular, the U.S. DOE has supported SMR development since 2000, and Nuscale Power's Nuscale SMR, which was developed based on this support, applied for design approval of the U.S. NRC in 2017 and secured standard design approval in the second half of 2020. In addition, along with a plan to build 12 modules near INL, development is underway with the aim of commercial operation in 2029.

KHNP is currently working on the basic design of SMR with the aim of applying for licensing in 2025 and commercial operation in 2033. The main concepts of I-SMR's design compared to Nuscale are shown in the table below.

Table. 1. Main concepts of I-SMR and Nuscale

Design Concepts	I-SMR	NuScale
Core Output	170 MWe	60 MWe
Reactor module configuration	4 Units	12 Units
Modularization of Reactor Building	Apply SC module	Modularization not applied
Target Construction process	24Months	36Months

The composition plan of the three-person operation group of the I-SMR is as follows.

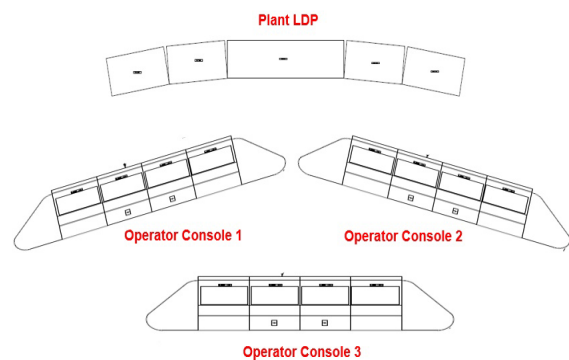


Figure. 1. I-SMR Simulator configuration concept

As there is uncertainty in licensing by regulatory agencies due to the adoption of the innovative design concept, I-SMR simulator is an essential facility for safety verification. Three-person operation validation shall also be performed on the simulator.

2.2. I-SMR Simulator Developing strategy

For the timely supply of I-SMR, it is necessary to make the most of the existing APR1400 technology as well as domestic and international development experience. Until now, KHNP is operating four APR1400 simulators (SKN3&4/5&6, SHN1&2, OSSA) developed with domestic technology using WSC's 3keymaster development environment tools. Based on this, two UAE BNPP simulators were successfully exported, and one simulator was also supplied to KINS, a regulatory agency. In particular, areas with insufficient experience will be able to shorten the development period and reduce R&D risks through expert advice.

The I-SMR development process is underway with the aim of applying for a license in 2026 and commercial operation in 2033. To meet these goals, I-SMR's simulator development will be carried out in a two-step promotion strategy. In the first stage, the dynamic mock-up development will be carried out with the aim of validating the operation suitability of three people in the main control room based on the basic I-SMR design by 2025, and the suitability of the three-person operation will be validated through this facility. In the second stage, we intend to promote a strategy to develop a full scope simulator that reflects detailed I-SMR designs by 2028.



Figure. 2. Nuscale SMR Simulator

2.3. Validation of 3-person operation using I-SMR Simulator

The I-SMR's three-person operation validation can be implemented at the end of the first step of simulator development. The I-SMR's three-person operation suitability validation will be implemented by applying the HFE program (NUREG-0711)[1], especially based

on task analysis, staffing and qualification, and important human action.

Validation is carried out through a series of processes such as establishing a validation plan, developing a validation procedure, and performing validation.

The actual three-person operating verification will be performed by RO and SRO operators trained in I-SMR operating according to the operating scenario consisting of normal, emergency, and abnormal, and operating experts and HFE experts will participate in the validation as evaluators.

If HED(Human Engineering Descripency) matters are derived during the validation, HED will be terminated through solutions such as design improvement, task improvement, and automation level through cause analysis.

3. Conclusions

I-SMR Simulator development is essential for the verification of I-SMR's three-person operation design. Currently partial-scope Simulator development is underway for three-person operating suitability validation, and a plan of the validation is being established.

Compared to the existing APR1400 nuclear power plant simulator development period, the I-SMR simulator has a shorter process period. Nevertheless, since the nuclear industry has sufficient design experience for OPR and APR nuclear power plants, we expect to be able to complete sufficiently safe and economical SMR development.

REFERENCES

- [1] NUREG 0711, NRC, Human Factor Engineering Program review Model, 2012.
- [2] U.S. Nuclear Regulatory Commission, "Nuclear Power Plant Simulation Facilities for Use in Operator Training and License Examination, and Applicant Experience Requirements", Regulatory Guide 1.149 Revision 4, May 2010
- [3] KHNP, Plant Design Description for i-SMR, 2023