

Redefining the role of the ARO in the 1st Staffing Plan Validation

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1. Introduction

KHNP (Korea Hydro & Nuclear Power) aims to construct the first unit of the i-SMR (innovative Small Modular Reactor) in the 2030s. Currently, the standard design (2024–2025) is being finalized, and the submission of documents to regulatory authorities, including the preparation of the SSAR (Standard Safety Analysis Report) to obtain SDA (Standard Design Approval), has been completed. To establish the technical basis for the human factors engineering aspects of the staffing plan in SSAR Chapter 18, the 1st SPV was conducted using the i-SMR simulator. Validation was performed based on the operation strategy of the i-SMR ICR(Integrated Control Room) by forming two types of operating staffing (3+1 and 6-person staffs). The operating staffing consist of SS (Shift Supervisor), RO (Reactor Operator), and ARO(Assistant Reactor Operator), and this paper aims to describe the role of the ARO among them.

2. SPV(Staffing Plan Validation)

The i-SMR adopted a new operating method where three operators control four modular reactors from a single ICR. Accordingly, human factors analysis and suitability validation for the new operating staff configuration are essential. For SPV, a simulator and a computerized procedure system(iCPS) were developed, and validation scenarios were created. Considering the lack of domestic precedents and regulations, validation was conducted by configuring the following two cases of operating staffs:

Table. 1. Staffing Case

case	Staffing
case1(6 persons)	RO1, RO2, RO3, RO4, SS, ARO
case2(3+1persons)	RO1, RO2, SS, ARO

2.1. Development of Simulator and Computerized Procedure System

A simulator model (core/thermal-hydraulics) reflecting the i-SMR standard design and approximately 300 operational HMI required for validation were developed. The computerized procedure system for the i-SMR was designed and developed based on the APR1400 CPS design, tailored to i-SMR operational concepts,

requirements, and automation needs. Specifically, it was optimized for i-SMR operation by applying multi-module features, strengthening automated operation functions, and enhancing operation support information. Additionally, 23 operational procedures (normal, abnormal, emergency, etc.) for scenario execution were developed and implemented as computerized procedures.

2.2. Development of SPV Scenarios

The operational conditions for the 1st SPV scenarios were selected based on i-SMR initiating events and NUREG-0711 selection criteria. These conditions are derived from safety analysis performed during the basic design stage, including LOCA, Non-LOCA, and multi-failure accident. The selection primarily focused on operational conditions related Anticipated Operational Occurrences (AOO) and Postulated Accidents (PA). A total of 9 scenarios were developed by combining these conditions to cover single-module failure, two-module failure, and shared facility failure (3 scenarios each).

2.3. 1st SPV and the Role of ARO

The purpose of the validation is to evaluate whether the assumed operating staffing for the i-SMR can safely and reliably operate four modular reactors under high-workload accident scenarios, based on initial functional requirement analysis, functional allocation, and job analysis The ARO's role in the ICR operational strategy is as follows.

Table. 2. ARO's role

CASE	ARO's role
ARO in 6 persons case	The ARO resides within the ICR. During normal operation, ARO independently perform 'plant crew oversight'. In emergencies, ARO is responsible for essential safety function status checks, And informs the relevant agencies of the emergency
ARO in 3+1 persons case	The ARO resides within the plant. When an abnormal situation occurs in one or more modules, ARO moves to the ICR upon being called by the SS(Shift Supervisor) and perform module monitoring roles under the SS's direction.

3. Operators' Opinions on ARO

The HFE issues through the 1st SPV regarding the ARO are as follows:

Table. 3. Identified issue

	Identified Issue	Review Opinion
1	Since the ARO enters the ICR irregularly, prior plant situational awareness is necessary. General plant status can be identified if the ARO resides in the field office.	Scheduled for further validation in the 2nd SPV
2	Need for flexibility in calling ARO's and formalizing call procedures in the manuals.	Since the timing of the ARO call is a decision made by the SS, it is difficult to specify strictly in the procedures
3	Need for a strategy in case of ARO call failure or delay.	Scheduled for re-validation in 2nd SPV
4	Need to review the plan to grant ARO's role of operating shared facilities.	Scheduled for further validation in the 2nd SPV
5	Assign tasks to field shift supervisors and grant them operational control over shared facilities.	Scheduled for further validation in the 2nd SPV

The ARO of the 6-persons case mainly performed simple monitoring or emergency notice tasks. However, the ARO of the 3-person case expressed that there were difficulties in performing tasks because they had to be deployed by the SS's call during emergencies and simultaneously grasp the plant status while executing their roles. Operators suggested that if the ARO resides in the field office, systems to identify plant status should be installed. And if they reside in the ICR as a shared facility operator, they could immediately grasp plant status and be deployed. These opinions will need to be confirmed in the 2nd SPV.

4. Conclusions

The new operation form applied to the i-SMR affects human performance in terms of workload, situational awareness, and crew collaboration, which differ from existing large-scale nuclear power plants. To confirm the possibility of 3-person operation (one of the TTRs of i-SMR), the 1st SPV was conducted. Considering the lack of domestic precedents and regulations, validation

was performed by configuring two types of staffing: 3+1 and 6-person. The results showed some differences in situational awareness and workload, but no significant overall differences were found. Major tasks of the ARO, such as essential safety function checks and emergency situation notice, are expected to be handled through LDP, HMI design and functional automation. Ultimately, whether 3-person operation is possible without the ARO's role will be re-confirmed through the 2nd SPV. The results of this validation are expected to contribute to obtaining SDA by being included in the i-SMR SDA application documents.

REFERENCES

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