Operator Workload Results in Integrated Control Room for i-SMR

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1. Introduction

The standard design of i-SMR is in progress from 2024. Unlike conventional large nuclear power plants, i-SMR's main control room is being designed to monitor and control four reactor modules in a single integrated control room. In addition, analysis and validation are underway to configure the number of optimized operators so that three to four operators can reside in this integrated control room to enable normal, abnormal, and emergency operation, and to ensure power plant safety.

In the case of overseas N company, SMR was designed so that 12 reactor modules could be operated by three people in one control room, and NRC's design certification (2023) was obtained. On the other hand, in Korea, the design of the main control room for SMR with multiple reactor modules and the configuration of the number of operators are being attempted for the first time. And the first SPV (Staffing Plan Validation) for operator staffing optimization was performed based on NUREG-1791 [1] process.

This paper intends to deal with the results of the operator's workload measured through the first SPV.

2. The 1st Staffing Plan Validation

According to NUREG-1791, SPV is the final step in the process of determining the initial number of operator's staffing. In other words, it is the step of validating the established staffing plan after establishing an operation concept, reviewing operating experiences, analyzing FRA/FA, TA, and job definition, and establishing a Staffing Plan.

The number and qualifications of the initial operators are determined through SPV by optimizing the assumed operator configuration.

In the 1st SPV, HFE analysis for i-SMR design were performed based on the standard design up to June 2025 and reflected in the implementation of the i-SMR dynamic simulator [2] while standard design in other areas of i-SMR is in progress. Therefore, although the 1st SPV was not carried out when the standard design of i-SMR was 100% completed, the information and insights needed to determine the initial operator configuration were nevertheless obtained. The next SPV is scheduled to be carried out when the standard design is completed. Table.1 shows an overview of the first SPV.

Table I: The 1st SPV Overview

ITEM	DESCRIPTION	Note
Test bed	i-SMR Simulator	
Evaluation Tools	SACRI, SART, NASA-TLX, MCH, BARS	
Experts for Evaluation	HFE Expert : 4 people	
	Operation Expert : 2 people	
Scenarios for Evaluation	Operational conditions from NUREG-0711 (including Multi-Module Event)	9 cases
Operators for Evaluation	APR1400 Operator's licensee (8 people) OPR Operator's licensee (2 people)	
Operator Training for i-SMR	i-SMR Systems Theory	1 week
	Simulator Practice	1 week
Validation	**Team A** : 4 people (RO:2, SS:1, ARO:1) *ARO is on call outside the ICR	1 week
	Team B : 6 people (RO:4, SS:1, ARO:1)	1 week

3. Operator's Workload

This paper deals with workload among human performance such as situation awareness, workload, and collaboration evaluated in the 1st SPV. Most of the operators who participated in the validation are APR1400 license holders and have more than 10 to 20 years of experience working in the main control room of the power plant. The human performance results derived through these were expected to be more reasonable as it was judged that relative comparison with APR1400 would be possible.

NASA-TLX and MCH were used as evaluation tools for workload in the 1st SPV. MCH (Modified Cooper–Harper) was used to supplement the existing NASA-TLX. MCH is a subjective evaluation tool that has been modified to measure the cognitive and cognitive workload of the operator more directly based on the Cooper–Harper scale originally used to evaluate aircraft operation characteristics.

Table II shows the average and standard deviation of six NASA-TLX items that the operator responded to while performing the SPV. The evaluation items were evaluated on a 10-point scale. Overall, Team A's workload was relatively high. However, this is not a significant level, as the gap with Team B is minimal. For both teams, it is a significant result that all items were below the 4-point scale.

Table II: Average and Standard deviation by NASA-TLX [3]

Title	Total (μ / σ)	Team A (μ / σ)	Team B (μ / σ)
1. Mental Demand	2.73 / 2.536	3.03 / 2.728	2.54 / 2.410
2. Physical Demand	2.06 / 1.761	2.54 / 1.942	1.75 / 1.574
3. Temporal Demand	2.54 / 2.380	2.99 / 2.516	2.25 / 2.265
4. Performance	1.98 / 2.276	1.43 / 1.441	2.33 / 2.635
5. Effort	3.39 / 2.520	3.60 / 2.440	3.26 / 2.584
6. Frustration Level	2.42 / 2.139	2.94 / 2.313	2.08 / 1.966

Table III compares the difference from the average by presenting the average of MCH scores and variance analysis results for each team's position. As a result of the analysis, it was found that there was no statistically significant difference in the MCH score according to team composition for SS and RO. On the other hand, in the case of ARO, it was analyzed that Team B's MCH score was statistically significantly higher than Team A. This means that the subjective workload of Team B's ARO is relatively greater than that of Team A. However, the average MCH score of Team B's ARO was 2.44, which was evaluated as having no problem in job performance.

Table III: Results by MCH [3]

Position	Average		p-value
	Team A	Team B	
SS (shift supervisor)	3.00	3.56	0.160
RO (reactor operator)	3.11	2.89	0.551
ARO (assistant RO)	1.75	2.44	0.012

Figure 1 shows the workload between Team A, Team B, and APR1400 as a result of NASA-TLX. Since the same scenario was not applied, it is difficult to directly compare with APR1400, but the comparison results are meaningful. The operators who participated in the first SPV said that the emergency operation was simpler than that of the existing nuclear power plant (APR1400) by operating the passive safety system in an emergency situation, and these passive systems were very helpful in reducing the mental and physical burden. In this validation, it was found that the workload was relatively low compared to the existing nuclear power plant even though the four reactor modules were operated with a small number of operators.

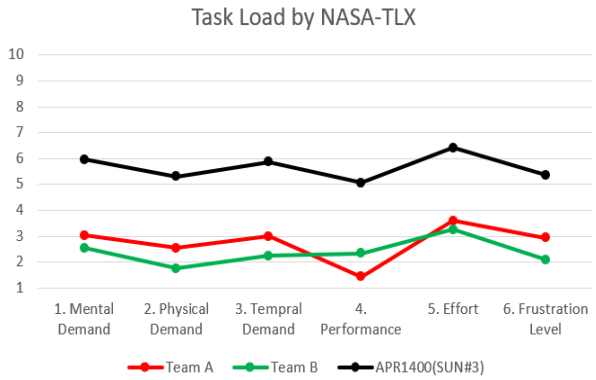

Fig. 1. Workload Results between Team A, B and APR1400

4. Conclusions

The 1st SPV was performed with reference to NUREG-1791. As a result of the SPV, it was found that the operator's workload was much less than that of the existing nuclear power plant. This is considered to be the influence of the application of the passive safety systems, the simplification of the systems, and the automated operation. Among the issues to be supplemented through this SPV, in particular, improvement of the operation strategy of the integrated control room is required. In order to consider the optimal composition of the operator staffing and various operation modes (including O/H), it is necessary to supplement the operation strategy.

REFERENCES

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