Human System Interface Design Considerations for Adding an Operator Support System to the Digital Control Room of Nuclear Power Plants

Hyun-Chul Lee*
Korea Atomic Energy Research Institute, Advanced I&C Research Division, 111 daedeok-daero 989 beon-gil, Yuseong-gu, Daejon, South Korea 34057
**Corresponding author: leehc@kaeri.re.kr*

Keywords : operator support system, human system interface, interaction compatibility, human factors, control room operator, digital control room

1. Introduction

It is common to modify and supplement systems in nuclear facilities during operation. This is mainly due to reasons such as solving problems that arise during operation, the emergence of new technologies with improved safety or efficiency compared to those applied, complaints from users, and the dissemination of incidents and improvement cases from similar systems. Recently, AI and big data processing technologies have been frequently discussed, and there is a growing trend to actively introduce them into operating nuclear facilities to enhance the performance of nuclear power plant personnel and improve facility safety. These technologies are expected to show excellent performance in tasks such as situational awareness and automatic control of nuclear processes, and research and development in this area is active. Ultimately, such technologies will lead to operational automation or autonomous operation, but in the current transitional stage, they are being introduced to control room operators in the form of operator support systems (OSS). Specifically, this refers to the Human-System Interface (HSI) of the operator support system. The HSI of the operator support system must be added or integrated into the HSI of the operating control room. It is important to achieve the benefits of the operator support system without degrading the performance of the existing HSI, and systematic application of human factors engineering is indispensable for this purpose. This study aims to present design considerations for operator support system HSIs that can be applied when adding new functions or subsystems to operating systems. This constitutes part of the systematic application of human factors engineering to integrate a new operator support system..

2. Design Consideration

The integration of a new HSI into the HSI in use aims to improve the operator's performance. However, erroneous/insufficient integration can lead to operator error or poor performance. In order to prevent such negative effects, the following HSI design considerations are proposed.

2.1 Support Function Definition

The support functions of the OSS must be clearly defined. Defining what the OSS supports must be accompanied by specifying the operational situations in which the support functions must operate. Conversely, this also defines the limitations of the support functions or the OSS. For example, if the OSS provides diagnostic results, the range of events it can diagnose must be clearly defined, and this range must be specified according to the nuclear process conditions/specifications. Based on these specifications, the presentation and operating conditions of the support system HSI must be determined. For instance, a support system that provides diagnostic results for emergency events will differ in scope and support range from one that provides diagnostic results for abnormal events. Emergency event diagnosis typically begins after the reactor trip, with the operator support system producing diagnostic results thereafter. Therefore, the HSI of such a support system must be designed to present diagnostic results to the operator after the trip, ensuring accessibility and reliability. Identifying available HSIs within the existing system in the situation can be helpful.

2.2 Definition of HSI Interactions

The interactions between the operator and the support system HSI must be defined. This involves determining when, to whom, what, and in what format the support functions are provided, thereby defining the operator's interactions. In some cases, operator interaction may be minimal or nonexistent, but most support system HSIs require operator interaction due to their hierarchical information display structures. Understanding the interactions between operators and the existing system HSI is essential. The interactions between operators and the support system HSI must be consistent with existing interactions. If new types of interactions are required, understanding the principles of existing interactions and designing new ones accordingly can accelerate operator adaptation and acceptance while reducing the likelihood of errors. A useful tool for expressing interactions is the SysML Sequence Diagram (SD)[2]. SDs diagrammatically represent signals (interactions)

exchanged between the operator, the support system HSI, and the support system itself. When using SDs, it is recommended to divide operator–support system HSI interactions into small interaction types and define them as "combined fragments." Since operator actions in nuclear main control rooms are generally standardized, interactions between operators and machine systems can be expressed as sequential connections of small interaction types. Defining small interactions as combined fragments allows them to be applied universally across multiple operational scenarios. Even complex interactions can be expressed concisely, making analysis and design more effective. Designers of support system HSIs should strive to explore and derive interaction models that define typical interactions. If typical interactions can be defined for the scope of support provided by the system, operators will find it easier to become familiar with them, ultimately reducing the training burden.

2.3 Format from Function

The characteristics of the support functions must determine the format in which they are provided to operators. For operational situations where diagnostic speed is critical, it is undesirable for the support system to provide diagnostic results only after the operator has completed diagnosis independently and then queries the results via the HSI. If diagnostic results must be provided before the operator completes diagnosis, the HSI must be designed to attract the operator's attention. Such requirements are frequently encountered in support system HSI design. To provide support functions efficiently, the following factors should be considered:

- Urgency: If results must be provided immediately, the HSI should automatically present them (e.g., imminent severe accident).
- Safety: Support functions critical to safety must be designed for immediate recognition (e.g., procedure violations).
- Accuracy: If operators need to compare or evaluate options, the HSI must provide sufficient objective facts (e.g., identifying a failed channel).

When multiple support functions are provided, their relative importance must be established and reflected in the HSI design.

3. Conclusions

Integration of new support systems into operating environments requires HSIs that are compatible with existing interfaces[1]. Identical interactions should employ consistent HSIs, while new interactions should preserve established design concepts wherever possible. Defining interactions in accordance with the scope and conditions of support functions is essential, and the format of HSIs must reflect the characteristics of these functions. Such considerations represent a critical component of systematic human factors engineering in nuclear facility operations.

REFERENCES

[1] NUREG-0700 Rev.4, Human-System Interface Design Review Guidelines, USNRC, 2026.
[2] ISO/IEC 19514:2017, Information technology - Object Management Group Systems Modeling Language (OMG SysML), 2017.

ACKNOWLEDGEMENT

This study was supported by the Korean Institute of Energy Technology Evaluation and Planning (KETEP) and Ministry of Trade, Industry, and Energy (MOTIE) of Republic of Korea (No.20224B10100130)