Transactions of the Korean Nuclear Society Autumn Meeting
Goyang, Korea, October 24-25, 2019

Human-System Interface Design for Severe Accident Management Support System

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1. Introduction

The severe accident management guideline (SAMG) was developed for handling, management, and mitigation of severe accident (SA) in nuclear power plants (NPPs). There are two major purposes of SAMG: 1) preventing and mitigating of core damage, and 2) maintaining the integrity of the containment in the NPPs.

When the core exit temperature exceeds 649 degrees of Celsius in Korean NPPs, the operators close procedure(s) being performed and enter the SAMG [1]. Once the technical support center (TSC) is established, the decision making regarding the SAMG is performed by the TSC and corresponding actions are mostly performed by MCR operators.

However, there are several issues in applying the SAMG. First, it is impossible that the SAMG can cover all the potential SA scenarios and phenomena in the scenario [2]. The second is that the plant behavior under the SA is highly uncertain [3]. Third, the SAMG does not provide specific actions, but mitigative strategies, while emergency operating procedures (EOPs) include specific actions [4]. Thus, operator's actions following a mitigative strategy need to be selected by operators or TSC.

For these reasons, severe accident management support systems (SAMSSs) have been developed so far. The severe accident management expert system (SAMEX) was developed by Korea Atomic Energy Research Institute (KAERI) that has functions to predict major safety function behavior of NPPs. The accident diagnostic, analysis and management (ADAM) has been developed in Energy Research Institute (ERI). It applies the information generated by on-line as well as SA code simulation to use for accident management and training. The severe accident management system online network (SAMSON) developed in ARD corporation has the function of predicting occurrence time of major events such as loss of coolant accident (LOCA), steam generator tube rupture (SGTR). The severe accident management operator support (SAMOS) developed by US-NRC has the function of major NPPs event variable behavior predictions and major event distinction [4].

This study aims at suggest a human-system interface (HSI) of SAMSS based on human factors engineering program. First, operating experience review (OER), functional requirement analysis (FRA), and task analysis (TA) have been carried out, following NUREG-0711 [5]. Then, an HSI of SAMSS has been suggested to support the application of SAMG in the mitigation of SA.

2. Analysis for Developing a SAMSS HSI

Following the human factors engineering program recommended by NUREG-0711, this study carried out OER, FRA, and TA.

2.1 Operational Experience Review (OER)

The purpose of OER is to encompass lessons learned from another complex human-machine system, especially predecessor designs and those involving similar HSI technology to identify HFE-related safety issues [5].

For OER, major SAs and developed SAMSSs were reviewed. As a result, a total of sixteen (16) design requirements were identified, and their four examples are as shown in Table I.

Table I: Example of design requirements

No.	Design requirements	Ref. No
1	Functions are required that support the accident management strategies of response organizations.	[6,7,8]
2	Functions are required to inform the operator of the possibility of core damage in advance.	[6,7,8,9]
3	Functions are required to monitor the major safety functions in the NPPs.	[7,8,10,11]
4	Functions are required to inform that the plant has reached a controlled, stable state.	[6,7,12]

2.2 Functional Requirement Analysis (FRA)

FRA is the identification of functions that must be performed to satisfy the safety goal. For the FRA, this study identified safety functions for the mitigation of SA based on the SAMG developed by KAERI [13]. Then, the safety function has been analyzed by using multilevel flow modeling (MFM). The MFM model of safety function can show causal relation among safety functions, systems and components. Fig. 1 shows an example of the MFM model for steam generator coolant injection in the SAMG.

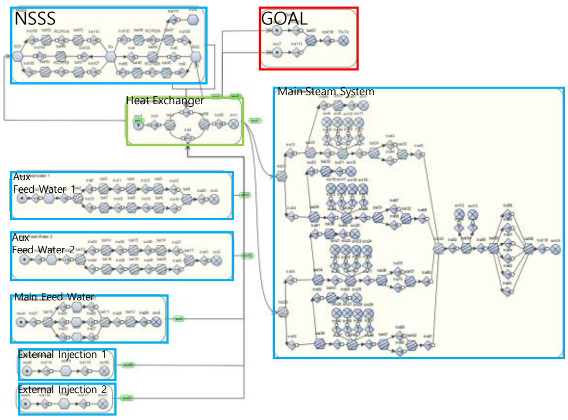

Fig. 1. Example of MFM model for safety function of steam generator coolant injection

2.3 Task Analysis (TA)

TA identifies the specific tasks personnel perform to accomplish functions. It also identifies alarm, information, controls, and tasks support needed to perform tasks. For TA, this study applies hierarchical tasks analysis and task decomposition methods. Table II shows an example of a simplified result in TA for "Check the available means for high-pressure coolant injection" step in the mitigation-01 guideline.

Table Ⅱ: Example of task decomposition method for "Check the available means for high-pressure coolant injection" in the mitigation-01 guideline

step	Task	information	
		sys	com
3.2.1. C.1	Check the available means for high-pressure coolant injection (turbine-driven aux feed-water pump)	Auxiliary Feed-water System	AF-PP01A, AF-PP01B
3.2.1. C.2	Check the available means for high-pressure coolant injection (motor-driven aux feed-water pump)	Auxiliary Feed-water System	AF-PP02A, AF-PP02B

3. HSI Design for Severe Accident Management Support System

Fig. 2 shows the structure of HSI design for the SAMSS. It consists of four areas, i.e., 1) information display area (red color), 2) guideline display area (yellow color), 3) function-based display area (blue color), and 4) task-based display area (purple color).

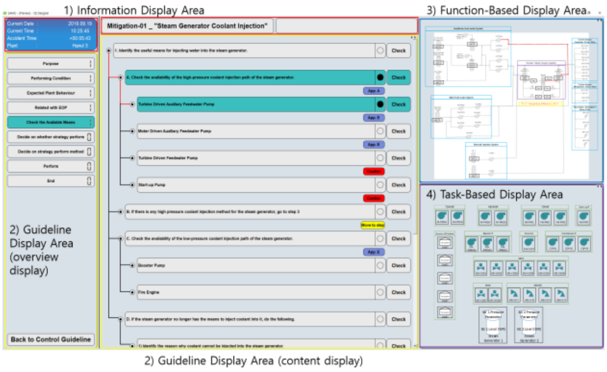

Fig. 2. Overall of human-system interface for severe accident management support system

3.1 Information Display Area

The information display area provides the basic information for the mitigation personnel. This includes the current date and time, the elapsed time after the entry of a SAMG, the corresponding unit, and the titles of the guideline and step currently applied. Fig. 3, shows the information display area.

Fig. 3. Information display area

3.2 Guideline Display Area

The main purpose of the guideline display area is to show the contents of SAMG and help the personnel perform the SAMG. It is divided into the overview display and the content display. The overview display shows the overview of SAMG steps in the selected guideline. The personnel can select and perform steps, and transfer between steps and guidelines, as shown in Fig. 4.

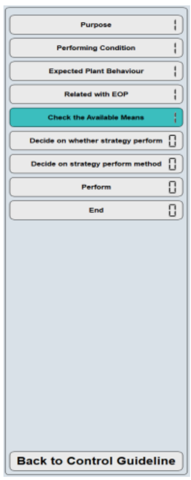

Fig. 4. An example of overview display

The content display provides the details of instruction for the selected step in the overview display as shown in Fig. 5. The personnel can also mark the performed instruction by clicking the symbol of "○".

Fig. 5. An example of content display

3.3 Function-Based Display Area

The function-based display area presents the goal of guidelines and the causal relation between the goal and systems. This area displays the systems and components to achieve the goal of selected guideline.

Fig. 6 shows the systems, components and their causal relation for the strategy of steam generator coolant injection. The diagram is organized based on the result of FRA that applies the MFM.

First, the yellow boxed area represents the goal of this guideline, which indicates difference of temperatures between hot-leg and cold-leg. Users can identify the nuclear steam supply system heat is being removed through this area.

Second, the purple boxed area means the simplified nuclear steam supply system and shows the heat exchange between the reactor core in nuclear steam supply system and success paths using the steam generator. The path of success paths and the path of the generate heat are marked with red arrows.

Third, the blue boxed area shows the components and systems required to achieve the objective of the guideline. The left boxes are auxiliary feed-water system (AFWS), main feed-water system (MFWS), and external injection system (EIS), respectively, while the right boxes indicate turbine bypass condenser dump valves (TBCDVs), turbine bypass atmospheric dump valves (TBADVs), and main steam atmospheric dump valves (MSADVs)

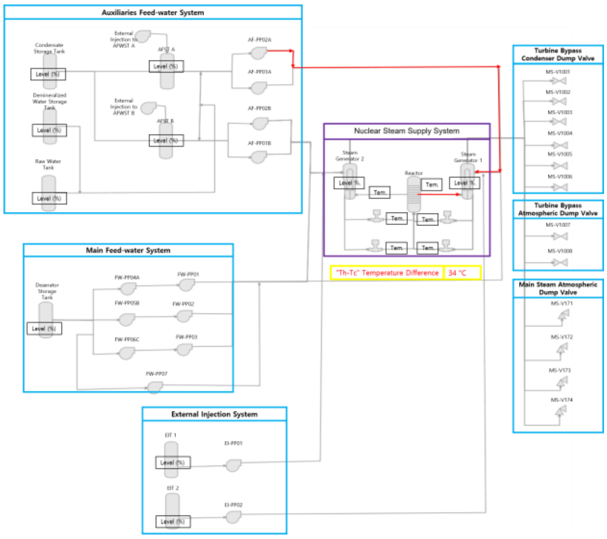

Fig. 6. Function-based display area for the guideline of steam generator coolant injection

3.4 Task-Based Display Area

The task-based display area collectively presents the information required to carry out the selected step. The necessary information was identified by the activity of TA. Fig. 7 shows an example of task-based display for the strategy of steam generator coolant injection. The symbols and icons are also grouped according to proximity of information.

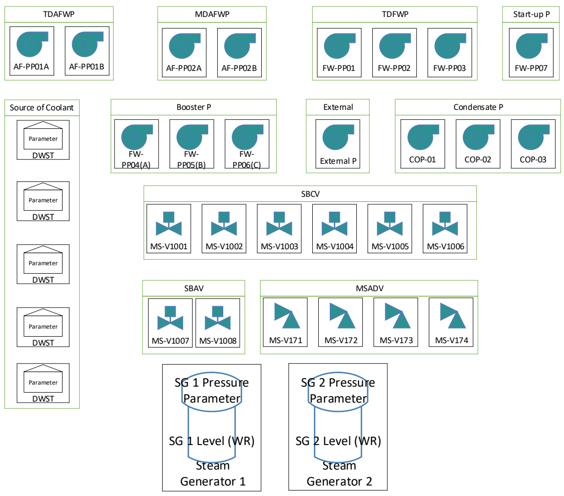

Fig. 7. Task-based display area for the guideline of steam generator coolant injection

4. Conclusion

This study suggested an HSI of SAMSS for management of SA. The OER, FRA, and TA have been carried out following NUREG-0711. Their results were used as an input of HSI design. The HSI has features of task- and function-based displays to support the mitigation personnel.

Acknowledgment

This research was supported by Nuclear R&D Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (Grant No. 2017M2A8A4017947)

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