Analysis of Diagnosis Errors for the APR1400 Main Control Rooms

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1. Introduction

The main control rooms of some new designs of nuclear power plants (NPPs) in the world are fully digitalized. Particularly, the advanced power reactor - 1400 (APR-1400) has a fully digitalized control room that vastly differs from those of previously analog or semi-digitized control rooms. The many differences between the analog and digital main control rooms (MCRs) of NPP can result in different task types and a change in the way operators carry out their functions. Some of the characteristics of these new digital MCRs provide opportunities for new types of operator errors, which may also affect operator response during time-critical tasks[1]. As such, the human reliability analysis (HRA) method for the operator actions in the new APR1400 MCRs may have to differ.

HRA usually considers the operator activities from the perspective of diagnosis and execution. Execution actions are highly dependent on diagnosis activities. If the diagnosis activities are well done, the chances of proper execution are higher, and most incidents can be mitigated without serious consequences.

This paper analyzes the diagnosis errors in the APR1400 MCR intending to develop a HRA method that can adequately analyze the operator errors. First, we define the main distinguishing features in the APR1400 MCR. Second, we identify the major diagnosis error modes based on the distinguishing features and the task types. Third, the effect of these identified error modes on HRA is discussed based on the diagnosis tasks. The nuclear regulatory and operating bodies in Korea will consider the cause-based decision tree (CBDT) method as one of the possible methods for HRA in the APR1400 NPP. Hence, this study also reviews the applicability of the CBDT method (CBDTM) as a surrogate way of analyzing diagnosis errors in the APR1400 and possible limitations.

2. The main distinguishing features of the APR1400 MCR

The advancement in technology has led to most of the changes within the digital MCRs. Particularly, as the capabilities of modern computers in processing and presenting information have increased, computer techniques have been introduced into the design of MCRs of NPPs [2]. The major distinguishing features for the APR1400 MCRs compared to analog MCRs are hereby defined.

2.1 Soft Controls

The soft controls are devices that are mediated by softwares rather than physical connections and include features such as mouse control, touch screens, and so on. The operators in the APR1400 MCR use soft control systems for operation and manipulation of equipment. Thus, using soft controls, operators can *select* (by clicking or touching) a specific screen, choose the controller, and finally manipulate the devices.

2.2 Computer-based Procedures

The APR1400 MCR uses a computerized procedure system (CPS) to provide an integrated presentation of procedural instructions and related process information required for the proper execution of applicable procedures instead of paper-based procedures.

2.3 Advanced Information Display Systems

The APR1400 MCR contains a large display panel (LDP) which is designed to allow group view, especially in the case of situations requiring frequent communication between operators. Other graphic information displays in this MCR have characteristics such as integrated displays, information support systems such as 'Aids', and procedure based displays.

2.4 Advanced Alarm Systems

The alarms in the APR1400 are distinctly different from those in conventional analog systems. These alarms systems appear in a combination of messages and lists format, and they are integrated into process displays, unlike the regular tile formats used in conventional (analog) MCRs.

2.5 Communications

Although the communication protocol has not changed (e.g., three-way communication in analog MCR), some differences in the communication pattern can be observed. Unlike the conventional MCRs, the board operators can access each other's computer interfaces in the APR1400 control room. Hence,

communication pattern is loosely coupled and the operators may communicate less verbally.

3. Identification of the diagnosis error modes

The identification of diagnosis error modes is in two phases. In the first phase, we consider only the distinguishing features of the APR1400 while in the second phase we consider the task types and related error modes.

3.1 Based on Distinguishing Features

In the first instance, error modes are assigned to all the distinguishing features based on literature reviews and observation of simulator experiments involving APR1400 plant simulator. Thereafter, the error modes are aggregated and grouped into diagnosis and execution error modes. Table I. Shows the distinguishing features and associated error modes for diagnosis. The diagnosis error modes include:

- Error in detecting alarms (includes identifying icons or messages with auditory and blinking signals to be acknowledged by pushing buttons).
- Error in Reading/ interpreting information (identifying exact values, parameters, and the deviation from the normal state on the computer display system).
- Selection errors (selecting information in reading indications, e.g., lack of differentiation between safety and non-safety components or due to interface management tasks).
- Initiating in-appropriate actions (decipher mitigation actions. For example, with the aid of alarm response procedures).

Table I: APR1400 MCR main features and diagnosis error modes

Main features of APR1400 MCR	Associated diagnosis error modes
Advanced Alarm System	Error in detecting alarms, Error in Reading/ interpreting information, and Selection errors
Soft Controls	Selection errors
Advanced Information display Systems	Error in detecting alarms, Error in Reading/ interpreting information, and Selection errors
Computer-based Procedures	Initiating in-appropriate actions

The unique communication pattern has been left out because there are rarely any error modes directly associated with it.

3.2 Consider Diagnosis Tasks

Previous research [3] has shown that MCR operators in the APR1400 NPP have three major diagnostic tasks which include 1) Recognizing the alarm of the plant, 2) Finding the cause of the situation, and 3) Selecting the proper execution strategy or procedure. Based on further analysis of the sub-tasks, the major diagnosis error modes associated with each task are matched. Figure 1 shows the top-level task types, the subtasks, and the associated error modes. The tasks were re-named based on MCR operator goals.

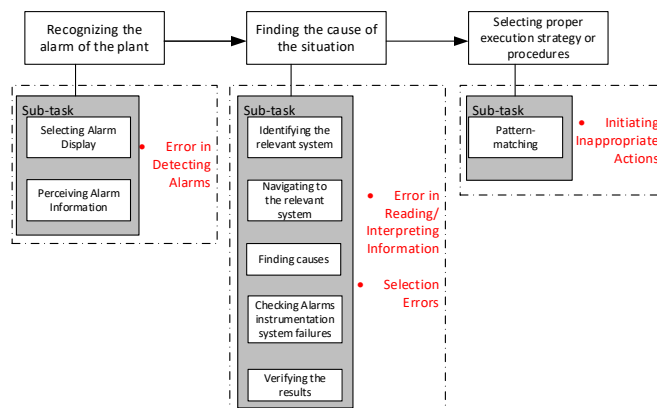### 4. Analysis of the effect of diagnosis error modes on human reliability

Fig. 1. Diagnosis tasks in APR1400 MCR with associated error modes.

4.1 Error in detecting alarms

To accurately detect alarms, the three strategies of sequencing, prioritizing and suppressing alarms are also used in the analog control rooms but they are more supported in the APR1400 MCR. For the sequencing

alarms strategy, operators have to remember the order in the analog control rooms but in APR1400 MCR, the alarms are provided in chronological order via the alarm list. For the prioritizing alarm strategy, the alarm lists also sort the alarms automatically in the order of priority, unlike in the analog control rooms where operators have to arrange the alarms by priority. The alarm list in APR1400 provides the function of suppressing the nuisance alarms. Hence, these three functions will reduce operators' mental workload in selecting alarm displays and perception.

4.2 Error in reading/interpreting information

Reading and interpretation of various information are always necessary to identify the relevant system for any situation in both analog control rooms and the APR1400 MCR. In the analog control rooms, the operators can identify the alarm systems directly because the alarm is located directly above the corresponding system's information display. However, the case of the APR1400 may be different if the alarm occurs on multiple pages. In this case, the task is more complex, as the operator has to select one among several blinking link buttons. The operator does this by based the first-out alarms (with alarm priorities in several systems) or based on system correlation. This is a potential error influencing factor since the cognitive task of the operator may be increased.

4.3 Selection errors

Selection errors are most relevant during the operators' tasks of navigation to the relevant systems and detecting the causes of an unwanted situation. This is the diagnosis error mode that involves the most interface management tasks. Interface management is the most unique attribute of the APR1400 MCR and it is not found in the analog control rooms. The operators can navigate to the relevant system through the systems directory page, the main global aid page, or the alarm list (by a right-click).

Unlike the analog control rooms where operators need to identify detailed information about alarms (by reading parameters, checking component status, or reading trends from the recorder), the alarm list in the APR1400 already shows alarm details (description, priority level, current parameter values, setpoint, and occurrence time).

4.4 Initiating inappropriate actions

To determine the proper execution method or adequate procedure to mitigate the unwanted plant condition, the operator must perform patter-matching. The process of the pattern-matching subtask, which may generate the error mode of 'Initiating Inappropriate Action' is common to both analog MCRs and the APR1400. However, the task is more supported in the APR1400 MCR via the computer-based procedures. This is because there are menus for searching keywords (such as systems, components, title, type, or registration number) within the computer-based procedures.

5. A surrogate method to analyze diagnosis errors in the APR1400 MCR

In this section, a surrogate method to analyze the diagnosis errors in the APR1400 MCR is described and current limitations are discussed. Generally, diagnosis includes identifying the causes of the abnormal event with cue recognition, interpretation, and decision-making processes.

5.1 CBDTM

The CBDTM [4] is considered here because it is an analytical approach that provides specific causes of human cognitive error and evaluates the impact of PSFs with emphasis on decision or diagnosis. Figure 2 shows the surrogate diagnosis analysis trees developed based on the CBDTM. Figures 2(A) and 2(B) have been modified to better reflect the characteristics of the APR1400 MCR. For Fig. 2(A), i.e. Alarm detection errors, the "Front vs. back panel" has been removed from the original decision tree in the CBDTM (Pcb). This is because operators in the APR1400 MCR can see all the alarms from their sitting position so the concept of front and back panel no longer applies. As for Fig. 2(B), the "Single vs. Multiple" has been added to the original CBDTM tree (Pcd) to reflect the single or multiple pages which operators may need to select in identifying relevant systems after alarms.

5.2 Limitations of the CBDTM

One of the limitations of using the CBDTM is that other performance shaping factors need to be considered to accurately analyze the error modes. For example, selection errors may include several interface management tasks. Hence, the number of interface management tasks for any particular diagnosis action should be considered in evaluating HEPs for selection errors.
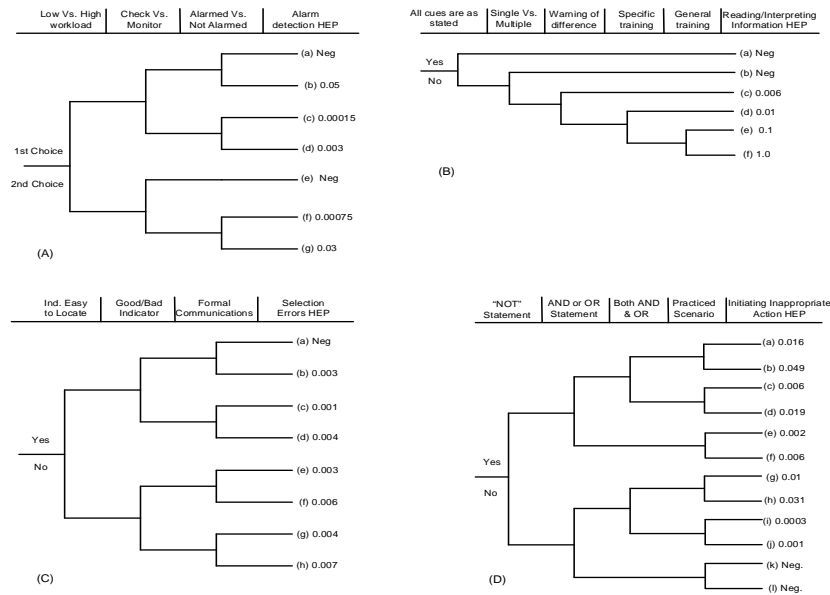
Fig. 2. The surrogate diagnosis error analysis trees.

Also, the quantification using the current trees may not be accurate because the individual values of branches in each decision tree are derived from the THERP method or generic values that are based on analog MCRs. Hence they do not reflect the system changes or diagnosis patterns involved in digital MCR.

5.3 Approach to reducing current limitations

The human reliability data extraction (HuREX) database [5] will better reflect HEPs derivable from APR1400 MCR. HuREX is a platform for HRA data collection and analysis that allows HEP estimation and PSF correlation for generic task types as well as new task types. Data for operator actions in the AR1400 MCR has also been generated on this platform. The taxonomy of the HuREX database is directly applicable to the error modes identified in this study.

Different multiplication factors may be assigned for selection errors depending on the number of interface management tasks. For example, (BHEP x 1.2) for 2-3 interface management tasks, (BHEP x 1.5) for 4-5 interface management tasks, and (BHEP x 1.8) for 6 or more interface management tasks.

6. Conclusions

This paper has identified and analyzed the major diagnosis errors that can be found in the APR1400 MCR which are; Error in detecting alarms, Error in Reading/ interpreting information, Selection errors, and Initiating in-appropriate actions. The errors were considered from the perspective of the unique systems and the major diagnosis tasks in the APR1400 MCR. This paper also showed a surrogate method to analyze the diagnosis errors both qualitatively and quantitatively

using modified decision trees adapted from the CBDTM. The limitations of the proposed method and the prospective approach to reducing these limitations have been mentioned. Future work will apply the improvement strategies and show more detailed applications of our proposed approach to analyze diagnosis errors in APR1400.

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