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General description and influencing factors of unexpected plant conditions

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1. Introduction

Human errors have been involved in a large portion of incidents and accidents of NPPs. There have been lots of efforts to reduce human errors in systematic and managerial ways by establishing human factor regulations and guidelines and by applying all predictable accident scenarios in the design and the management strategies of NPPs. Despite all these efforts, a human operator still encounters unexpected plant conditions in NPPs. Since unexpected plant conditions require a human operator to do very different information processing with anticipated plant conditions, provoke wide range of error mechanisms and error types, and cause generation of impaired cognitive abilities, so it is necessary to understand cognitive process itself for appropriate situation assessment. Second generation human reliability analysis methods, cognitive models, and quantitative models for situation assessment have been developed for a human operator to understand cognition process and to estimate situation assessment, but they do not include the effects of unexpected plant conditions with an explicit set of influencing factors. Thus, this paper examines the general characteristics of unexpected plant conditions and suggests influencing factors on situation assessment of an individual human operator in unexpected plant conditions.

2. General description of unexpected plant conditions

2.1 Definition and characteristics of unexpected plant conditions

According to NUREG-1624 [1], an unexpected plant condition describes a deviation situation from the base case scenarios of plants. In the given context of the specific event, human operators do behave in rational and logical ways but undesired operator responses occur in unexpected plant conditions, such as the complications of hardware and instrumentation failures, deficiencies of procedure, or natural disasters [2]. In other words, the unexpected plant conditions coupled with relevant performance shaping factors (PSFs) can have significant impact on human information processing and provoke a wide range of error types [1]. Also, impaired cognitive abilities of human operators can occur when plant conditions proceed beyond cognitive limitations of human operators. It leads to inappropriate operator diagnosis and actions, and then worsens plant conditions.

The four characteristics of unexpected plant conditions by analyzing serious accidents and significant incidents are suggested in NUREG/CR-6350 [2]: a) the plant behavior is outside the expected range, b) the plant behavior is not understood, c) evidence of the actual state and behavior is not recognized, and d) prepared plans are not applicable or helpful. These are closely related to difficulties of human operators on information processing in unexpected plant conditions. According to these characteristics, it is obvious that relevancy of experience and training, degree of situational complexity, suitability of procedure, available time, and adequacy of human-machine interface highly influence occurrences of unexpected plant conditions.

2.2 Situation assessment and error type

In NUREG/CR-6350 [2], situation assessment defines “operators’ construction of an explanation to account for observed plant behavior”. It means that operators can understand the current plant state and how the plant behaves as a result of the situation assessment process. Furthermore, operators update their situation model based on new information, and the situation model guides operators’ response planning.

There are three main causes of situation assessment failure: a) incomplete mental model through memory loss and lack of training, b) inaccurate information through instrumentation failure and misreading indicators, c) heuristic and recency bias [1,2]. These factors provoke human errors both in anticipated and in unexpected situations, but human error rates may increase when operators encounter unexpected plant conditions.

In unexpected plant conditions, human operators have difficulty in finding a prepacked solution at the rule-based level. When operators fail to find a satisfactory solution in rule-based route, knowledge-based processing occurs for situation assessment. In other words, error mechanisms associated with knowledge-based processing must be considered for the evaluation of situation assessment in unexpected plant conditions [2].

Early version of the HRA methods attempted to distinguish between errors of omission and errors of commission. It was revealed that this distinction was not suitable in making more accurate prediction error, so the discussion for describing error has slowly moved toward such terms as slips, lapses, and mistakes [3]. This is due to intuitively appealing evidence, and consistent the human information processing.

Wickens [4] developed the four types of human errors: slips, lapses, mistakes, and mode errors, and represented how error types are consistent with the information processing context. The representative human error types are connected to each step of the information processing context in Figure 1: knowledge-based mistakes for Situation Assessment, rule-based mistakes, lapses, and mode errors for Intention of Action, and slips for Action Execution.

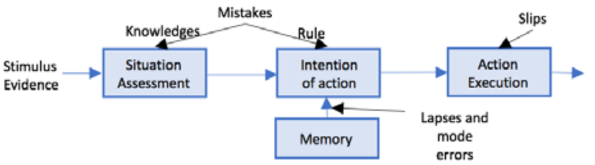

Fig. 1. Information processing context for representing human errors

The knowledge-based mistakes at Situation Assessment may result from the influences of biases and cognitive limits especially when human operators have insufficient knowledge or expertise to interpret complex information [4]. For example, human operators fail to consider all the alternatives, experience their working memory overload, succumb to a confirmation bias, misinterpret communications, and so on.

3. Analysis of influencing factors

3.1 Material

In order to collect cognitive factors which can influence situation assessment of a human operator, a rigorous review of existing HRA methods and cognitive models was conducted. Since the second generation HRA methods have been developed based on the consideration of cognition, cognitive factors in second generation HRA methods, which are Cognitive reliability and error analysis (CREAM), A technique for human event analysis (ATHEANA), Standardized plant analysis risk-human reliability analysis (SPAR-H) and Méthode d'Evaluation de la Réalisation des Missions Opérateur pour la Sûreté (MERMOS), are included into analysis at the initial stage. They provide a few number of cognitive factors because they determined influencing factors on the basis of information processing framework and theoretical psychology model.

Although the first generation HRA methods have focused on quantitative approach and identified human as a mechanical component so failed to explain logical causes and consequences of human errors, massive PSFs especially in the Technique for Human Error Rate Prediction (THERP) were suggested. Thus, PSFs in the first generation HRA methods, which are THERP, Accident Sequence Evaluation Program (ASEP), Human Error Assessment & Reduction Technique (HEART), Systematic Human Action Reliability Procedure (SHARP), and Success Likelihood Index Method (SLIM), were included in the analysis

Lastly, cognitive models, such as Information, diagnosis/decision, action (IDA) model and Information, decision, and action in crew context (IDAC) model, were reviewed. These cognitive models were developed to predict the operator responses in nuclear power plants during cognitive, psychological, and physical activities [5], and provided a large number of performance influencing factors (PIF).

3.2 Method

An inductive approach was used to identify PSFs on situation assessment of an individual human operator in unexpected plant conditions. Inductive approach aims to identify relationships and patterns from data sets collected, so it is useful to find meanings from massive information. There are a large number of factors from the HRA methods and the cognitive model. These factors were considered as sub-factors and categorized to preliminary PSFs which were selected in terms of human information processing models and theoretical psychology models. If a sub-factor was not related to any preliminary PSFs in consideration of cognitive basis, new PSF was created to include the sub-factor.

The process of the inductive approach consists of four steps: (I) selecting HRA methods and cognitive models for analysis, and collecting sub-factors from the selected ones, (II) determining preliminary PSFs for grouping the sub-factors, (III) grouping and filtering the sub-factors suitable for research purpose using a flow chart, and (IV) formulating sub-groups in each PSF if necessary and revising, refining, and checking the relationship between PSFs and sub-factors.

A flow chart, which is used at step III, was developed to group and filter sub-factors suitable for research purpose. Since the goal of this paper is to identify PSFs which cause cognitive impacts on situation assessment when an individual human operator encounters unexpected plant conditions, assumptions are made as follows: (1) managerial and organization factors, which are controllable in unexpected plant conditions, are assumed to be well-developed, and (2) team-related factors are excluded to focus on impacts on situation assessment for an individual human operator.

3.3 Results

At the step I, nine HRA methods and two cognitive models were reviewed to collect influencing factors on human performance. After eliminating methods which have duplicate PSFs or no specific PSFs, four HRA methods and one cognitive model in Table I were selected to collect sub-factors.

Table I: HRA methods and cognitive models for PSFs

Method	**Date**	**Authors**	**Remarks**
THERP	1983	A.D Swain / H.E. Guttmann	Sixty-five External/ Internal/Stressor PSFs
HEART	1988	J. Williams	Forty Error Producing Conditions
CREAM	1998	E. Hollnagel	Nine common performance conditions
SPAR-H	2005	D. Gertman / H. Blackman	Thirty-nine sub-factors
IDAC Model	2007	Y.H.J. Chang / A. Mosleh	Fifty-three PIFs

At the step II, preliminary PSFs, which are available time, stress, complexity, experience/training, procedures, ergonomics/HMI, fitness for duty, and work processes, were determined for grouping sub-factors. All PSFs do not directly affect human cognition because classical PSFs, which were usually introduced in the first generation HRA methods, were not considered to be causal in a certain mechanism. Due to the nature of cognition, there is a certain mechanism for the relationship between PSFs and human behavior. Thus, it is necessary to distinguish PSFs which influence human performance in terms of cognition science and information processing approach. A rigorous review of existing HRA methods and cognitive models was conducted to select preliminary PSFs, which may affect human cognition during human information processing, for grouping sub-factors. The PSFs in SPAR-H were used as the preliminary PSFs due to the following reasons [3]: a) Eight PSFs are identified based on an explicit information processing model of human performance derived from the behavior sciences literature that was then interpreted in aspects of activities at NPPs, b) The SPAR-H method makes a distinction between diagnosis and action during the evaluation of PSFs.

At the step III, sub-factors were grouped to preliminary PSFs. If there were no preliminary PSFs to assign sub-factors, the sub-factors were assigned to "others". According to the assumptions of the research, the managerial and organizational factors and team-related factors were excluded. The factors related to situation assessment of a human operator were selected, and these were divided to personal and situational factors pertinent to unexpected plant conditions. After checking whether there are same or similar factors among previously identified influencing factors, the factors were included as the identified influencing factors. For instance, the sub-factor "architectural feature" in THERP is grouped to Ergonomics/HMI. It may influence to the PSF "stress" but it was not assigned to "stress" because THERP distinguishes its stressors through their classification "External PSFs", "Internal PSFs", and "Stressors". The factor is considered a controllable factor in unexpected plant conditions through a managerial approach. Another example is "number of simultaneous goals" in CREAM. It is grouped to the preliminary PSFs "complexity" and "stress". The factor is not a controllable factor in unexpected plant conditions through managerial and organizational ways and a team-related factor. It affects situation assessment of a human operator, increases workload in unexpected plant situations, and causes stress to a human operator, so the factor is included as an identified influencing factor. Two examples of the process are represented in Figure 2.

(a)

Sub-factor	Architectural features (Control room design, control display relationships)
Origination	THERP – External PSFs – Situational characteristics
I. Preliminary PSF	Ergonomics/HMI
II. M/O factor?	Yes (Done)
Result	OUT

(b)

Sub-factor	Number of simultaneous goals
Origination	CREAM
I. Preliminary PSF	Complexity, Stress
II. M/O factor?	No, No
II. Team-related factor?	No, No
III. SA-related factor?	Yes, Yes
IV. Personal or Situational factor?	Yes (Situational), Yes (Situational->Personal)
V. Same or Similar one?	No, No
Result	IN • Situational factor – Complexity - Number of simultaneous goals • Personal factor – Stress - Number of simultaneous goals

Fig. 2. The process for grouping and filtering sub-factors: (a) THERP, (b) CREAM

At the step IV, five (5) situational factors "procedure", "complexity", "available time", experience/training", "others" and two (2) personal factors "stress", "fitness for duty" were identified as influencing factors on situation assessment of an individual human operator in unexpected plant conditions as the result of the step III. The term "others" was changed to a representative term "threat" under the consideration of the characteristic of its sub-factors "threats of failure", "loss of job", "severity of consequence", and "criticality of situation". The term "fitness for duty" was changed to "personality (individual characteristics)" because there are no physical factors among sub-factors "emotional state", "cognitive modes and tendencies", and "short-term memory ability". During the analysis of sub-factors in each PSF, it was found that the sub-factors in stress have quite different properties in terms of human cognition so they were divided to sub-groups "workload" and "threat" in the PSF "stress". The identified PSFs are presented in Table II.

Table II: Influencing factors on situation assessment of an individual human operator in unexpected plant conditions

Type	**PSFs**
Situational Factors	Procedure
	Complexity (Information load)
	Available Time
	Experience/Training
	Threat

<table>
<tr><td rowspan="3">Personal Factors</td><td rowspan="2">Stress</td><td>Workload</td></tr>
<tr><td>Threat</td></tr>
<tr><td colspan="2">Personality
(Individual characteristics)</td></tr>
</table>

4. Conclusions

Literatures were reviewed to examine definition and general characteristics of unexpected plant conditions and situation assessment and error types in unexpected plant conditions. In order to collect cognitive factors which can influence situation assessment of a human operator in NPPs, PSFs in the existing HRA methods and cognitive models were analyzed using a flow chart developed based on the research purpose and characteristics of unexpected plant conditions. As a result, five (5) situational factors “procedure”, “complexity”, “available time”, experience/training”, “threat” and two (2) personal factors “stress”, “personality (individual characteristics)” are identified as influencing factors on situation assessment of an individual human operator in unexpected plant conditions. This influencing factors will be useful to study information processing mechanism of an individual human operator in unexpected plant conditions.

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