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Empirical Approach for Evaluating or Upgrading EOP Strategies Using the Decision theory and Simulator

Sok-Chul Kim and Duck-Hun Lee
Korea Institute of Nucleare Safety
Hyun-Jang Kim
Nuclear Training Center,KEPCO

ABSTRACT

This paper presents preliminary findings regarding a modeling framework under development for use in a multi-attribute decision model for advanced emergency operating procedures(EOPs). This model provides a means for optimal decision making strategy for advanced emergency operating procedures conceptualizing the dynamic coordination of responsibilities and information in the human system interactions with advanced reactor systems. For the purpose of evaluation of the applicability of this modeling framework, an empirical case study for a post-cooldown strategy during an steam generator tube rupture (SGTR) accident was carried out. As a result, it was found empirically that the multi-attribute decision model is a useful tool for establishing advanced EOPs that reduce the operator's cognitive and decision making burden during the accident mitigation process.

I. INTRODUCTION

With the introduction of advanced digital technology, the role of the main control room crew related to human-system interaction of an advanced reactor might have a paradigm shift. The shift from conventional to advance human system interaction includes changes in functional allocation from active motor to passive monitor in the cybernetics loop and changes in performance requirement that lead to : crews adaptation to shifts in mental workload, increased importance of the crew's situation awareness, importance of navigation and search strategies associated with the advanced interface system. Therefore, the cognitive activity of the operator may take a significant role in the accident mitigation process because of the dynamic coordination of responsibilities and information that occurred as a natural part of the human system interactions in an advanced reactor systems. [1,2,3,4] Cognitive error leads the operators to incorrect diagnosis and poor decision making. Incorrect diagnosis means that the operator will be unable to choose the correct response for mitigation actions. Therefore, correct diagnostics are related to correct selection of response strategies. However, the understanding of the process and the ability to maximize diagnostic performance via the operator support system and ergonomics is limited.[5]

A more effective way of reducing diagnostic errors during the accident mitigation process is to establish an advanced EOP which can minimize the chance of diagnostic error and to consider coordination of the task interface between the operator and operator aid systems.[6]

This paper presents preliminary findings regarding a modeling framework under development to establish an advanced EOP which can minimize cognitive and decision making errors during the accident mitigation process using a multi-attribute decision model and simulation. For an evaluation of the applicability of this modeling framework , an empirical case study was carried out for the post-cooldown method during the mitigation process of the SGTR accident.

II. MULTI-ATTRIBUTE DECISION ANALYSIS APPROACH

The decision analysis approach to identifying an optimal strategy for accident mitigation consists of three steps: identification of mitigation options and decision factors; assessment; decision of strategy.

A.Identification of Mitigation Options and Decision Factors

The first step consists of a comprehensive identification of the mitigation options and the decision factors[7] that affect which options are preferred. The EOP developer, at first, should identify a set of decision factors and determine their hierarchy considering the following:

- Radiological and environmental impact due to predicted consequences
- System availability and available resources for functional restoration
- Performance reliability of operator and hardware
- Cost benefit analysis

Tradeoffs among the detailed decision factors are determined through the expert judgment or success criteria of probabilistic safety assessment results with consideration of the predicted consequences and system availability. As such, these tradeoffs should consider all aspects of each decision factor such as operator's work load and cognitive load. Tradeoffs are represented in terms of released amounts of radionuclides to the environment, allowable time for accomplishing the tasks and the complexity of tasks to be done.

B. Assessment

After the decision factors and tradeoffs are determined, alternatives for the strategies of accident mitigation against predicted consequences are identified and evaluated. The second step is to assess the feasibility of the strategies with respect to the important decision factors considering the uncertainty in such predictions. The applicability of the alternatives can be evaluated either empirically or subjectively by means of the plant simulator or expert judgment . However, the operator cognitive model such as the operator's strategy usage model should be taken into account. The set-up in the experimental approach is outlined in Figure 1. This shows how the predicted scenarios are rated using the decision factors. The outcome is used to predict the expected performance, and the predictions are verified via a comparison with observed operator performance in the simulator test. In this experimental approach , a difficult issue is the determination of the dependent variables. In order to assess alternatives for mitigation strategies, however, it is necessary to set up crisp decision criteria. The quality of a diagnosis is not just whether the operator makes correct diagnosis or not, but how efficiently it is done.

C. Decision of Strategy

The third step is to rationally determine the most preferable strategy among the options based on the predicted consequences, considering constraints and tradeoffs of the consequences.

III. APPLICATION OF MULTI-ATTRIBUTE DECISION MODEL TO ENHANCEMENT OF EXISTING EOP FOR SGTR MITIGATION

For evaluation applicability of this modeling framework, an empirical case study for post-cooldown strategy during SGTR was carried out. Current symptom based EOPs contain "key utility decision points" for determination of optimal mitigation strategies considering plant status and equipment availability at that time. In reality, however, most of the EOPs related to " key utility decision points" simply provide several strategies for accident mitigation parallel without a hierarchy. It is not easy for the operators to select an optimal strategies under a high stressed situation such as LOCAs or SGTRs which requires frequent operator intervention within a limited time period. The current SGTR procedure for the Westinghouse PWR provides three post-cooldown methods with equal priority : cooldown by back-fill; cooldown by steam generator blowdown; cooldown by steam dump.

Current EOPs for a SGTR mitigation without implementation hierarchy may increase the operator's decision load and lead to cognitive errors. This case study was carried out to show how to implement a multi-attribute decision model into advanced EOP development and to enhance the applicability of current SGTR EOPs by minimizing the decision load.

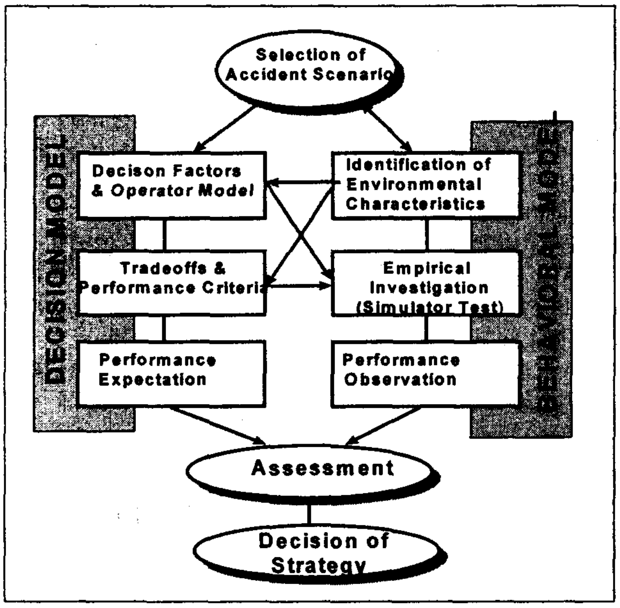

Figure. 1 Empirical Approach for selection of optimal strategy for accident mitigation

A. Decision Model For Case Study

1. Identification of Decision Factor

For this case study, three decision factors were selected as follows:
Release of radioactive materials
a) Whether radioactive materials have already been
released or mitigation strategy not in process ? Is the radioactive material release management a
major plant safety objective?
Impact of system functionality
Sea water contamination in the feedwater system can cause a limited strategy selection.
Availability of resources
The availability of the CVCS letdown system, AFWS, main condenser, inventory of condensed water and S/G blowdown system .

2. Determination of Tradeoffs

Tradeoffs among the detailed decision factors were determined through meeting with the scenario developer and the instructor of the simulator test. As the quantitative tradeoff values, 92 % pressurizer level, 78% steam generator level and 1.3m AFW inventory which are required as contingency items in the current EOPs [8,9] were selected and the availability of the AFWS, the main condenser system, the inventory of condensed water and the S/G blowdown system were identified as the qualitative tradeoff value.

3.*Decision* Support Chart

Based on the decision factors and tradeoff values, the development of a decision support chart which provides the hierarchy selection of the post-cooldown methodology during the SGTR . The decision support chart , as shown in Figure 2, provides the preferred option and secondary option considering the change of consequences and the status of system availability. The secondary option can be implemented if either the preferred option is not available due to status change or time is not available to perform the
preferred options.

B. Empirical Evaluation of Decision Support Chart

In order to evaluate the applicability of the decision support chart, empirical investigation was carried out against on-the-job MCR crews of the Westinghouse 950MW PWR plant using the full scope plant simulator.

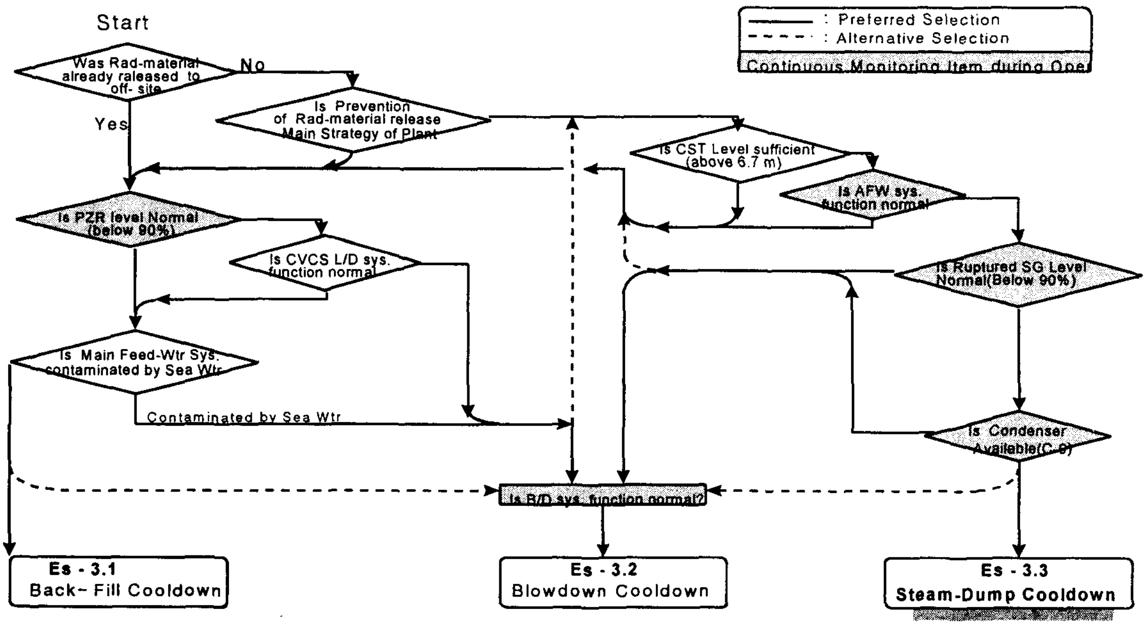

Figure. 2 Decision Support Chart for Post-ooldown during the SGTR mitigation

1. Subjective and Test Facility

For this empirical investigation, nine on-the-job crew teams from Kori unit 3&4 and Youngkwang unit 1&2, sixty seven individuals including simulator instructors took part in the simulator test. Each team consisted of five operators at minimum: shift supervisor, shift technical advisor, reactor operator, turbine operator and electrical operator. According to Korean legal enforcement, each team has a minimum one licensed SRO (Senior Reactor Operator) and one licensed RO. They have service duration 3 to 11 years as an MCR crew.For this empirical investigation, a KEPCO full scale simulator at Kori Nuclear Training Center was used, referred to as YGN 1&2, which is 950 MW Westinghouse PWR.

2. Accident Scenario

A post cooldown phase of a steam generator tube rupture accident was selected as the test scenario with the following initial condition:

Because the secondary feedwater side was contaminated by sea water due to condenser tube leak, the plant was in the process of power reduction from full power to 30% reactor power before the initiation of the SGTR.

In the process of accident mitigation with the implementing E-0 and E-3 procedure, the plant should enter into the post cooldown process with steam generator water level approaching solid state because of RCS depressurization delays. Under the above accident conditions, the most preferable option is the steam generator blowdown method because the back-fill and the steam dump methods would not be applicable due to the deteriorated situation of the primary and secondary. Therefore, the point of this accident scenario is to investigate whether each crew should select the S/G blowdown method as the post cooldown method .

3. Results and Discussion

Two types of simulator tests were performed, one with and one without the decision support chart . Four of nine crews were evaluated using the decision support chart. As the performance measure, whether operators selected the S/G blowdown method correctly or not, four time dependent plant parameters were used, pressurizer pressure, steam generator pressure, pressurizer level and steam generator narrow range level.

As a result, all crews with the decision support chart selected the steam generator blowdown method successfully. However, only two teams out of five, without the decision support chart, selected the correct options. In terms of time-dependent plant parameters, as shown in Figure 3-8, the case with the decision support chart shows a better performance than without the support chart.

Two teams without the decision support chart shows indeciveness which resulted in parameter which are represented in Figure 7 and 8.

The two successful crews without the decision support chart was representative of crews with shift supervisors with outstanding qualities in terms of experience and expertise, and excellent intra-organizational and inter-organizational communication. Before the simulator test, questionnaires on their experiences , service duration and the source of stress was provided to identify their organizational characteristics. [10,11] All operator behaviors during the accident mitigation process was videotaped. After the simulator test, performance evaluations were conducted based on videotape analysis and test records with simulator instructors.

Major findings from this empirical investigation can be summarized as follows:

The decision support chart which provides hierarchy for strategies can relieve the diagnosis and decision making loads during an emergency situation such as an SGTR.

Organizational factors such as crew composition in terms of experience level or leadership of the shift supervisor during the accident mitigation process affects the accident process and consequences.

IV CONCLUSIONS

The empirical approach incorporating a multi-attribute decision model to develop advanced EOPs which can relieve cognitive and decision burden from the crew during accident mitigation was suggested in this study. To evaluate the applicability of this multi-attribute decision model, an empirical investigation was carried out using the plant simulator with a decision support chart developed based on multi-attributes decision model and an SGTR accident scenario.

This empirical investigation provided valuable insights into how operating crews actually cope with emergency situations and what should be taken into account for development of advanced EOPs that can reduce cognitive and decision making errors during the accident mitigation process. Ideally more data and empirical investigation for various cases should be completed. As a matter of fact, this empirical approach may have limitations on the selection of decision factors, tradeoffs and performance measures.

Despite these limitations, certain conclusion can be drawn based on the empirical investigation of this study:

Advance EOP should be revised to reduce cognitive and decision making burden during the accident mitigation process considering operator behavior model and decision model.

The decision support chart based on multiple-attribute decision model was represented as a useful approach for developing advanced EOPs.

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