An approach to reducing the adverse effect of inappropriate human actions in nuclear power plant

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1. Introduction

From end-users to regulatory bodies, it is widely recognized that human-induced events including inappropriate human actions are one of the most crucial sources degrading the overall safety of nuclear power plants (NPPs). For example, the result of probabilistic safety assessment (PSA) conducted by Exelon nuclear company in US has revealed that the contribution of human error to the core damage frequency (CDF) of NPPs is about 58% [1]. In addition, the analysis result of Nuclear Energy Agency (NEA) has emphasized that the contribution of human error to CDF could be 80% at maximum [2]. This means that a systematic framework through which inappropriate human actions can be effectively identified is necessary to enhance the safety of NPPs. For this reason, HiRITER (High Risk Inducible Task Evaluator) has been developed in this study, which is able to evaluate the effect of inappropriate human actions on risk as well as performance. In addition, a couple of real events that had occurred in domestic NPPs are simulated in order to validate the feasibility of HiRITER.

2. The overall structure of HiRITER

First of all, let us consider Fig. 1 that shows the importance of human actions from the point of view of the safety of NPPs.

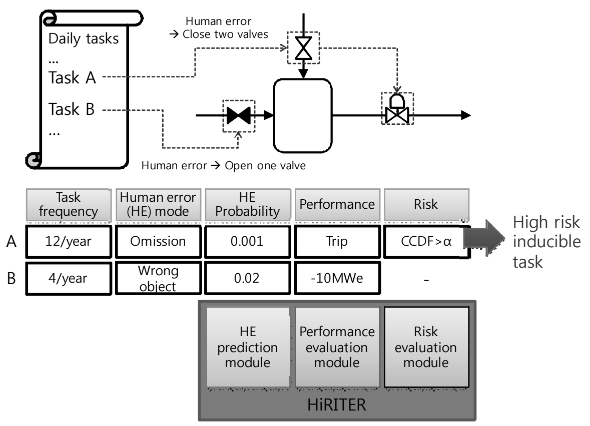

Fig. 1. The effect of human actions on the safety of NPPs

For example, there could be side effects when maintenance and/or operating personnel have to conduct two tasks (Task A and Task B). That is, if human error has occurred in the course of conducting "Task A," then two valves that are normally opened will be closed. In contrast, it is expected that the result of human error pertaining to "Task B" will cause the closing of a valve that is normally closed. In this situation, it is not easy to identify which task is more significant for the safety of NPPs. However, the relative importance of a given task can be systematically identified when we have the following information: (1) the frequency of the task, (2) the plausible mode of human error, (3) the likelihood of the associated human error, (4) the effect of the associated human error on the performance of NPPs (e.g., the variation of electrical output), and (5) the effect of the associated human error on the safety of NPPs (e.g., the variation of conditional core damage frequency; CCDF). Moreover, if the amount of CCDF variation exceeds a certain level, then it will be necessary to strictly manage the associated daily task.

For this reason, HiRITER integrates three modules that have distinctive roles: (1) human error prediction module that is able to determine the types of failure modes resulting from inappropriate human actions with the associated daily task, (2) performance evaluation module that computes the loss of electric power due to the change of component configurations caused by human error and (3) risk evaluation module that clarifies whether or not the propagation of human error can trigger an unexpected shutdown of NPPs.

First, the main function of the human error prediction module is to support practicians who have to conduct daily tasks through the prediction of the most plausible modes of human error. In other words, based on the consideration of various kinds of PSFs (performance shaping factors) for a given daily task, this module systematically identifies which type of human error is the most plausible under a given task environment.

Second, the risk evaluation module is used to estimate the change of CCDF that could be caused by human error. To this end, fault trees (FTs) have been developed based on the protection signals of NPPs. That is, since FTs facilitate feeding the updated frequency of initiating events or trip events to the results of a conventional PSA, it is possible to quantify the change of CCDF that is affected by the human error.

Third, the performance evaluation module is used to compute the loss of electrical output due to the configuration change of NPPs caused by human error. That is, if a specific human error that can be observed in the course of conducting a given task does not affect the generation of any protection signals, then the change of electrical output is calculated by the performance evaluation module. To this end, the performance evaluation module was developed using PEPSE (performance evaluations of power system efficiencies) model, which allows us to conduct a turbine cycle simulation [3]. Fig. 2 depicts a part of PEPSE model included in the performance evaluation module.

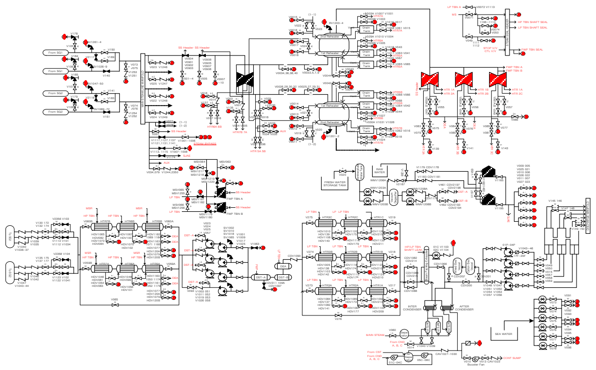

Fig. 2. A part of PEPSE model included in the performance evaluation module

3. The validity of HiRITER

As explained in the previous section, HiRITER can estimate the effect of human error that can be observed in the course of conducting a given task from two viewpoints: performance (i.e., the change of electrical output) and risk (i.e., the change of CCDF). However, in order to effectively utilize HiRITER, it is indispensable to validate the appropriateness of estimated results. In this regard, a couple of real events that have occurred in domestic NPPs are simulated in order to validate the feasibility of HiRITER. Table 1 shows the result of comparisons.

Table 1. The result of comparisons between real events and HiRITER estimations

ID	Date of occurrence	Actual result	Estimation
1	10 April, 2008	-16.0MWe	-18.0MWe
2	22 January, 2008	-23.0MWe	-22.0MWe
3	31 March, 2008	-1.3MWe	-1.2MWe

For example, an event that has occurred on 10 April, 2008 was caused by the abnormal open of a bypass valve linked to low-pressure feedwater heaters. As a result, a domestic NPP experienced the loss of electrical power, the amount of which was 16MWe (about 1.7% of the total electric output). Interestingly, when the identical malfunction was applied to HiRITER, it was estimated that the loss of electrical power is 18MWe, the relative error of which is about 12.5%. In addition, it was observed that the relative errors of other events are 4.3% and 7.6%. Therefore, it is reasonable to state that the estimation of HiRITER seems to be reliable.

4. Discussion and conclusion

As explained from the previous sections, HiRITER that consists of three modules has been developed in order to effectively manage an important task that can affect not only the performance but also risk of NPPs. In addition, the appropriateness of HiRITER was validated based on comparisons between the loss of electric output experienced from actual events and estimated outputs from HiRITER. As a result, it was observed that relative errors of these comparisons seem to be within a reasonable range.

It is evident that additional effort is decisive to enhance the applicability of HiRITER. For example, since the human error prediction module only covers four kinds of human error modes that have been frequently observed in Korea for the last 20 years, it is necessary to enlarge the capability of this module by considering other modes of human error. In addition, since the coverage of protection signals being included in the risk evaluation module is a part of the whole spectrum, more extensive effort is required to build up more concrete FTs.

However, it is also true that the framework shown in Fig. 1 is a novelty because it integrates two different aspects. Actually, the Electric Power Research Institute (EPRI) has reported the concept of GRA (generation risk assessment), which deals with the productivity and profitability of NPPs on the basis of the principles of the PSA [4].To this end, EPRI's GRA model sets up the top event in terms of functional failures of a specific system as well as the loss of electrical power divided by discrete criteria (e.g., "50% loss of electric power"). Accordingly, it is worth emphasizing that the use of HiRITER can contribute to enhance the performance and safety of NPPs.

Acknowledgment

This research was supported by Nuclear Research & Development Program of the National Research Foundation (NRF) grant funded by the Korean government (Ministry of Education, Science and Technology). (Grant code: 2011-0001902).

REFERENCES

[1] In Y., "PSA results for Exelon Nuclear," IAEA workshop on Improvement of Safety and Economics in NPPs, Taejeon, Koera, 2002.

[2] NEA, "Nuclear regulatory challenges related to human performance," No. 5334, 2004. NEI, www.nei.org, 2011

[3] Alder G.C., Blakeley B., Fleming D.R., Kettenacker W.C., Minner G.L. "Manuals for PEPSE® and PEPSE®-GT," Idaho Falls: ScienTech; 1999.

[4] Electric Power Research Institute, "Generation Risk Assessment Plant Implementation Guide," TR-1008121. Palo Alto: EPRI, 2004.