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The K-HRA, Rev.1 Method for Post-Initiator Human Actions at Internal Event Scenarios

Jaewhan Kim[1]*, Yochan Kim[1], Jinkyun Park[1], Wondea Jung[1], Hojun Jeon[2], Hyun-gyo Lee[2], Kyemin Oh[2]
[1]*KAERI, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea*
[2] *KHNP-CRI, 70, Yuseong-daero 1312beon-gil, Yuseong-gu, Daejeon, 34101, Republic of Korea*
**Corresponding author: jhkim4@kaeri.re.kr*

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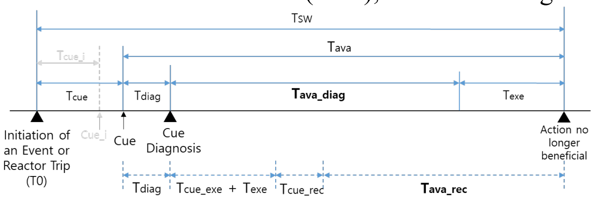
1. Introduction

Human reliability analysis (HRA) in probabilistic safety assessment (PSA) is necessary to identify important human actions that affect plant safety, and to assess their probability of success or failure in a given performance condition. An HRA technique requires a systematic process, method, and data with a sound technical basis for quantifying both diagnosis error probability (DEP) and execution error probability (EEP). This paper summarizes the main features of the revised K-HRA method, K-HRA, Rev.1, for evaluating post-initiator human actions, which are requested for event scenarios induced by internal events.

2. K-HRA, Rev.1 with Its Technical Basis

2.1 Task Analysis and Timeline Analysis

Task analysis is conducted to understand overall flow of task performance and work context, prior to detailed assessment of HEPs. Timeline analysis is essential for gathering time-related information for HRA of post-initiator human failure event (HFE), as shown in Fig. 1.



- T_{SW} = Total system time window
- T_{cue_i} = Time at which an actual physical condition appears for a critical task to be required
- T_{cue} = Time for operator's initial recognition of the cue, or time for arriving at a procedural step associated with a required task
- T_{diag} = Time required for cognition of a required task (cognition includes diagnosis and planning)
- T_{ava} = Total time available for a required task
- T_{cue_exe} =Time for an additional specific condition for a required task to be initiated (i.e., cue for execution)
- T_{exe} = Time required for actual execution of a required task, including transportation and manipulation
- T_{ava_diag} = Time available for diagnosis of a required task
- T_{cue_rec} = Time at which cue for error detection is recognized by an operator
- T_{ava_rec} = Time available for error detection and recovery

Fig. 1. Timeline Analysis for HRA of post-initiator HFEs

2.2 Diagnosis Error Analysis

The diagnosis error analysis is performed using the THERP time reliability curve (TRC) for a nominal DEP and the PSF multiplier decision tree for adjusting a base DEP, which are shown in Fig. 2 and 3, respectively. The nominal DEP is obtained in a median value from the THERP TRC. The base DEP is the transposed value of a median DEP value to a mean DEP. The base DEP is multiplied by the DEP PSF multiplier using the decision tree from Fig. 3, to obtain the final DEP. The DEP PSF multipliers were derived via an expert elicitation process, considering multiple PSF states.

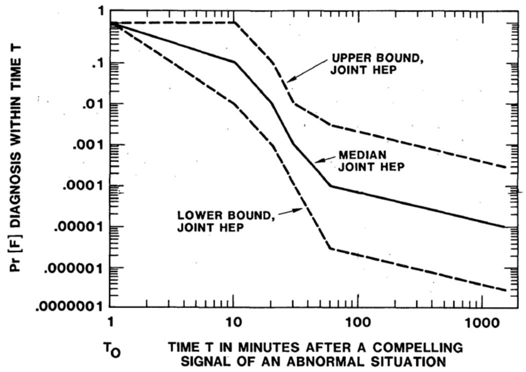


Fig. 2. THERP Nominal Diagnosis Error Probability Curve (from NUREG-1278 [1])

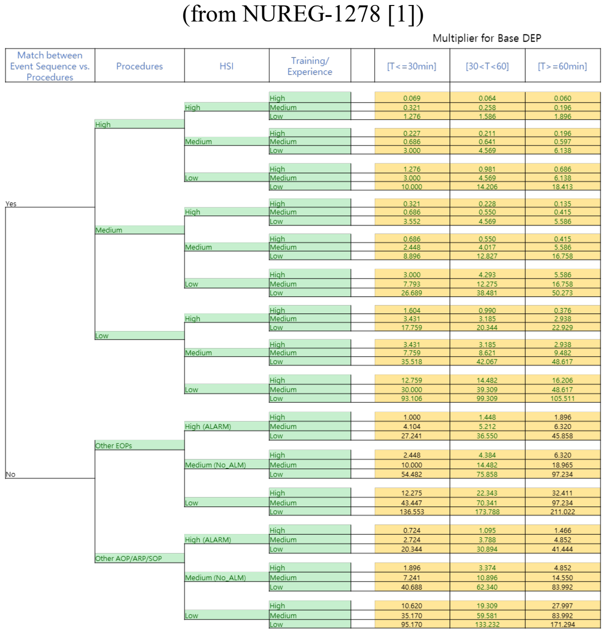


Fig. 3. The DEP PSF Multiplier Decision Tree for Adjusting a Base DEP

2.3 Execution Error Analysis

The estimation of EEP starts from identification of critical action steps to be performed by the operators. For individual critical actions, base HEPs of potential errors of omission and commission considering task type and stress level are estimated. K-HRA, Rev.1 provides Bayesian updated HEP tables for omission and commission errors, which resulted from Bayesian update of the THERP nominal HEPs with HuREX operator error data [2]. The base HEP for an individual critical action is adjusted by the levels of procedure and experience, and then multiplied by recovery failure probability (RFP). Final EEP for an HFE is obtained by summation of all individual non-recovered EEPs.

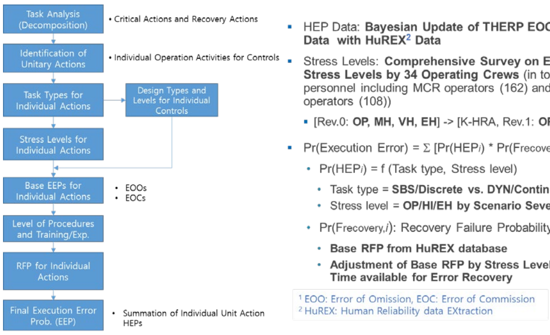


Fig. 4. The Process and Major Characteristics of the Execution Error Analysis of K-HRA, Rev.1

A comprehensive survey on expected stress levels for anticipated scenario conditions from emergency operations was conducted via operator questionnaires. In total 68 items of scenario conditions, including 45 for the at-power state and 23 for the LPSD state, have been identified and prepared for questionnaire survey through a comprehensive review of HRA methods and PSA scenario conditions. In total 34 operating crews from the utility participated in the questionnaire survey. The actual number of operators participated in the questionnaire survey is in total 270 operators including 162 from MCR operators and 108 from local operators. As a result of the questionnaire survey, the stress levels were determined to be optimum (OP), high (HI), or extremely high (EH). Most of the emergency operating scenario conditions belong to a HI stress level. In particular, the following scenario conditions were identified to be in an EH stress level: (1) SAMG actions, and field actions such as using portable equipment under beyond design basis external events (BDBEEs), (2) actions in wearing of SCBA (self-contained breathing apparatus) in a fire situation, or actions in wearing of radioactive protective clothing or items in a low-level leakage of radiation dose, (3) actions requested by the functional recovery procedure (FRP), and (4) last resorting actions for preventing core damage. For the low-power and shutdown (LPSD) scenarios, the accident conditions that belong to an EH stress level include (1) loss of two or more safety functions in addition to an initiating event, (2) failed condition of leakage isolation or RCS makeup in the loss of coolant accident (LOCA), and (3) failed condition of RCS makeup in the low-level or over-drained incident during mid-loop operation.

The base RFP value was extracted from the HuREX database [2], and that is adjusted for use in a specific accident condition by the level of stress and the time available for error recovery, as shown in Table 1.

Table 1. The RFPs in consideration of time available for error recovery and level of stress

Time Available for Error Recovery	Dependency Level	RFP for HI Stress	RFP for EH Stress
$0 < T_{ava\_rec} <= 15$ min	HD	5.10E-1	5.25E-1
$15 < T_{ava\_rec} <= 30$ min	MD	1.60E-1	1.86E-1
$30 < T_{ava\_rec} <= 60$ min	LD	6.90E-2	9.75E-2
$T_{ava\_rec} > 60$ min	ZD	2.00E-2	5.00E-2

2.4 Dependency Assessment

Dependency assessment between HFEs is one of the areas that most relies on analyst's judgement and expertise. The EPRI's dependency assessment tree is adopted for use in K-HRA, Rev.1 because it provides various dependency-influencing factors and reasonable level of dependency in a practical way, based on the accumulated experiences over many PSAs [3]. The dependency assessment tree is represented in Fig. 5. Basically, EPRI's guideline is used for dependency assessment between HFEs, but for determining time difference between two HFEs for the heading of 'sequential timing', the time between two operator cues as well as the time between two time limits determined by system time window, represented in Fig. 6.

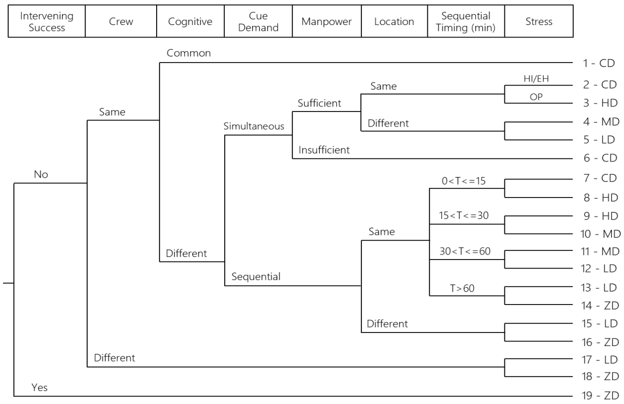


Fig. 5. The Dependency Assessment Tree adopted in K-HRA, Rev.1

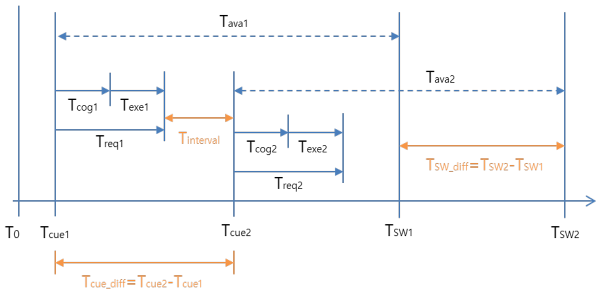


Fig. 6. Representation of Time Difference between Two Sequential HFEs

3. Conclusion

K-HRA, Rev.1 is characterized by the DEP PSF multiplier decision tree based on expert elicitation, stress levels resulted from a comprehensive survey by a multitude of the operating crews, Bayesian update of THERP HEPs with HuREX operator error events from full-scope simulators, and the base RFP extracted from HuREX database. The K-HRA, Rev.1 method is to be used for human reliability analysis of post-initiator operator actions to be modelled in accident scenarios initiated by internal events.

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