# LESSONS LEARNED from HRA RESUTLS for FP and LPSD PRAs with K-HRA Methodology

Seok-Won Hwang[1], Seong Kyu Park[2]

[1] KHNP CRI: 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, 34101, Korea, swhwang1221@khnp.co.kr
[2] ACT: #406, IT venture town, 35, Techno 9 Ro, Yuseong-Gu, Daejeon, 305-510, Korea, sparkpsa@actbest.com

*For the last 3 years from 2013 to 2015, FP(Full Power) and LPSD(Low Power/Shutdown) PRAs((Probabilistic Risk Assessments) were performed for all the operating nuclear power plants in Korea. K-HRA methodology was adopted to perform HRA (Human Reliability Analysis) for the PRAs. K-HRA methodology is a kind of HRA methodology developed by KAERI(Korea Atomic Energy Research Institute) in 2005 based on ASEP (Accident Sequence Evaluation Program) HRA procedure. During the development of the K-HRA methodology, most of the effort was put into the standardization of the HRA process and clarification of the inputs used to estimate HEP (Human Error Probability). In other words, the main purpose of the K-HRA methodology development is to minimize the variations in HRA results among different HRA analysts. The objective of this study is to evaluate the appropriateness of HRA results performed with K-HRA methodology for FP and LPSD PRA. The appropriateness of HRA results was evaluated considering the important PSFs (Performance Shaping Factors) which are known to influence human performance greatly. For example, total time available, time available for diagnosis, stress level, task type, man-machine interface, level of procedure quality, level of training and task location. HRA results or HEPs for FP PRA was well explained in the aspect of the PSFs considered with some exceptions. However, there were some additional exceptions and items which could not reflect the accident contexts sufficiently in estimating HEPs for LPSD PRA. This paper explains the exceptions which made the HRA results or HEPs for LPSD PRA inconsistent in the aspect of well-known PSFs. This paper also suggests some items to be incorporated into the K-HRA methodology for the future revision to make the K-HRA methodology more self-consistent and robust for all scopes of PRA.*

## I. INTRODUCTION

For the last 3 years from 2013 to 2015, FP and LPSD PRAs were performed for all the operating nuclear power plants in Korea. To make the PRA results more consistent, K-HRA methodology was adopted to perform HRA for the project. K-HRA methodology is a kind of HRA methodology developed by KAERI in 2005 based on ASEP (Accident Sequence Evaluation Program) HRA procedure. During the development of the K-HRA methodology, most of the effort was put into the standardization of the HRA process and clarification of the inputs used to estimate HEP (Human Error Probability). In other words, the main purpose of the K-HRA methodology development is to minimize the variations in HRA results among different HRA analysts. This paper describes the process and results for evaluating the appropriateness of HRA results performed with K-HRA methodology for FP and LPSD PRAs.

## II. ANALYSIS

### II.A. Introduction to K-HRA Methodology

So far, several HRA methodologies have been adopted to perform PRAs in Korea. HCR/ORE, ASEP HRA and THERP are the typical ones which have been used. Because PRA results are significantly influenced by HRA results, this variation in HRA methodology made the comparison of risk metric less meaningful among PRAs in Korea.

K-HRA methodology is a kind of HRA methodology developed by KAERI with the cooperation of KEPCO-E&C in 2005. The K-HRA methodology is based on ASEP (Accident Sequence Evaluation Program) HRA procedure. During the development of the K-HRA methodology, most of the effort was put into the standardization of the HRA process and clarification of the input data used to estimate HEP (Human Error Probability). In other words, the purpose of the K-HRA methodology development is to minimize the variation in HRA results among different HRA analysts.

In the K-HRA methodology, the human tasks of NPPs are classified into pre-initiating and post-initiating human failure events (HFEs). Post-initiating HFEs can be further subdivided into diagnosis errors and execution errors. Fig. 1 shows the framework of the K-HRA methodology for a detailed quantification. Detailed quantifications of pre-initiating HFEs are performed using the unavailability equation of THERP (Swain and Guttman, 1983). Detailed quantifications of the diagnosis and the execution errors for post-initiating HFEs are performed using the following equations:

$$HEP_{diag} = Basic\_HEP_{diag} \times \Pi w_i (PSF_i) \quad (1)$$

$$HEP_{exec} = \Sigma[Basic\_HEP_{exec}(i) \times HEP_{rec}(i)] \quad (2)$$

where $Basic\_HEP_{diag}$ = f(available time for diagnosis), $Basic\_HEP_{exec}(i)$ = f(task type(i), stress level(i)) and $HEP_{rec}(i)$ = f(available time(i), MMI(i), supervisor recovery(i)).

The basic HEP of a diagnosis error ($Basic\_HEP_{diag}$) is quantified according to the available time. 'w' is a weighing factor for the PSFs estimated using the decision tree. The basic HEP of an execution error ($Basic\_HEP_{exec}$) is determined by the subtask types and stress level. The recovery HEP of an execution error ($HEP_{rec}$) is estimated using the decision tree. The total HEP is a summation of the diagnosis HEP ($HEP_{diag}$) and execution HEP ($HEP_{exec}$).

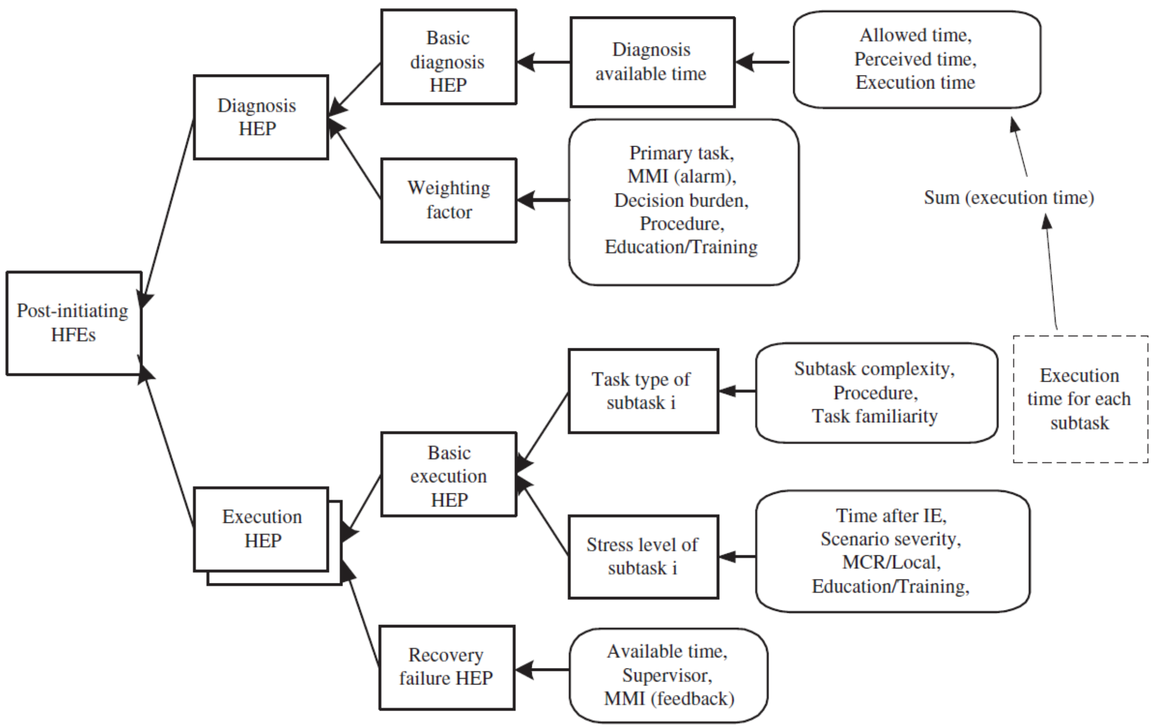


Fig. 1. The Framework of the HRA method for K-HRA Methodology

The basic HEP of a diagnosis error ($Basic\_HEP_{diag}$) is quantified according to the available time. Median joint HEP in Figure 12-4 of NUREG/CR-1278 is used for the $Basic\_HEP_{diag}$ the available time of the operator action in concern. A weighting factor applied to $Basic\_HEP_{diag}$ to reflect the PSFs posed by the accident context for the operator action is determined by decision tree illustrated in Fig 2 below. As is shown in Fig. 2, main stream task in accident context, man-machine interface, level of procedure quality and level of training quality are the main PSFs to determine the weighting factor.

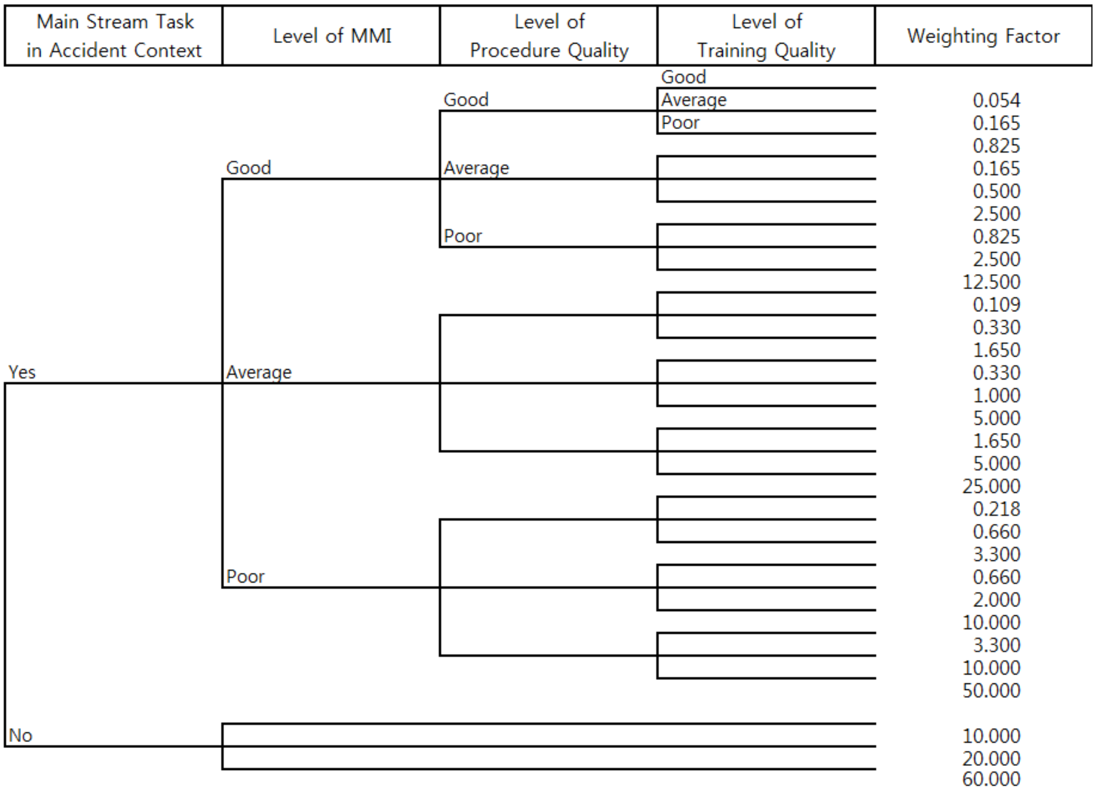


Fig. 2. The decision tree for weighting factor of diagnosis error proabability

Fig. 3 and Fig. 4 show the decision tree for task type and the decision tree for stress level which are the most important inputs to estimate $HEP_{exec}$.

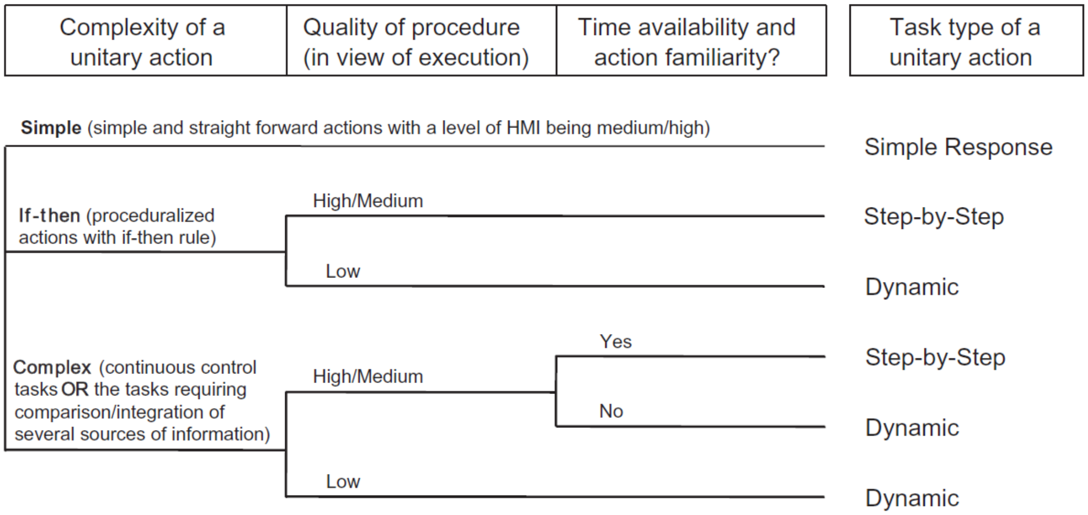


Fig. 3. The decision tree for task type

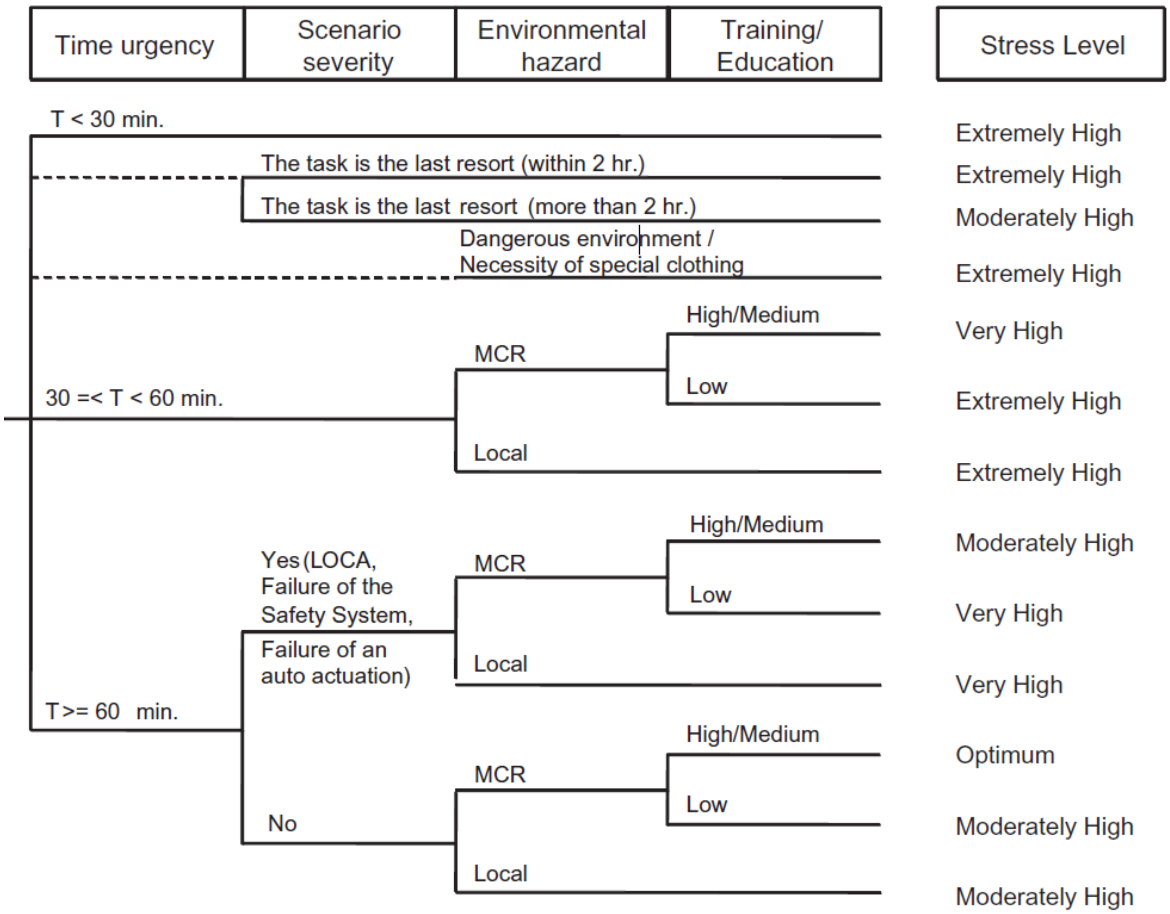


Fig. 4. The decision tree for stress level

Basic Execution Error Probability for unitary task is determined using stress level and task type. The unitary task BHEP of execution error for each stress level and task type is as follows;

| Task type | Stress level | Basic HEP (mean) | EF |
|---|---|---|---|
| Simple response | Low | 0.002 | 3 |
| | Optimum/moderately high | 0.003 | 3 |
| Step-by-step | Low | 0.01 | 3 |
| | Optimum | 0.005 | 3 |
| | Moderately high | 0.01 | 3 |
| | Very high | 0.02 | 3 |
| | Extremely high | 0.05 | 5 |
| Dynamic | Low | – | 5 |
| | Optimum | 0.01 | 5 |
| | Moderately high | 0.03 | 5 |
| | Very high | 0.08 | 5 |
| | Extremely high | 0.25 | 3 |

Fig. 5. Basic Execution Error Probability for each stress level and task type

Once the Basic_HEP$_{exec}$ is estimated for each unitary task, the possibility of recovery for each unitary task is considered. In K-HRA methodology, the decision tree for recovery factor is as follows;

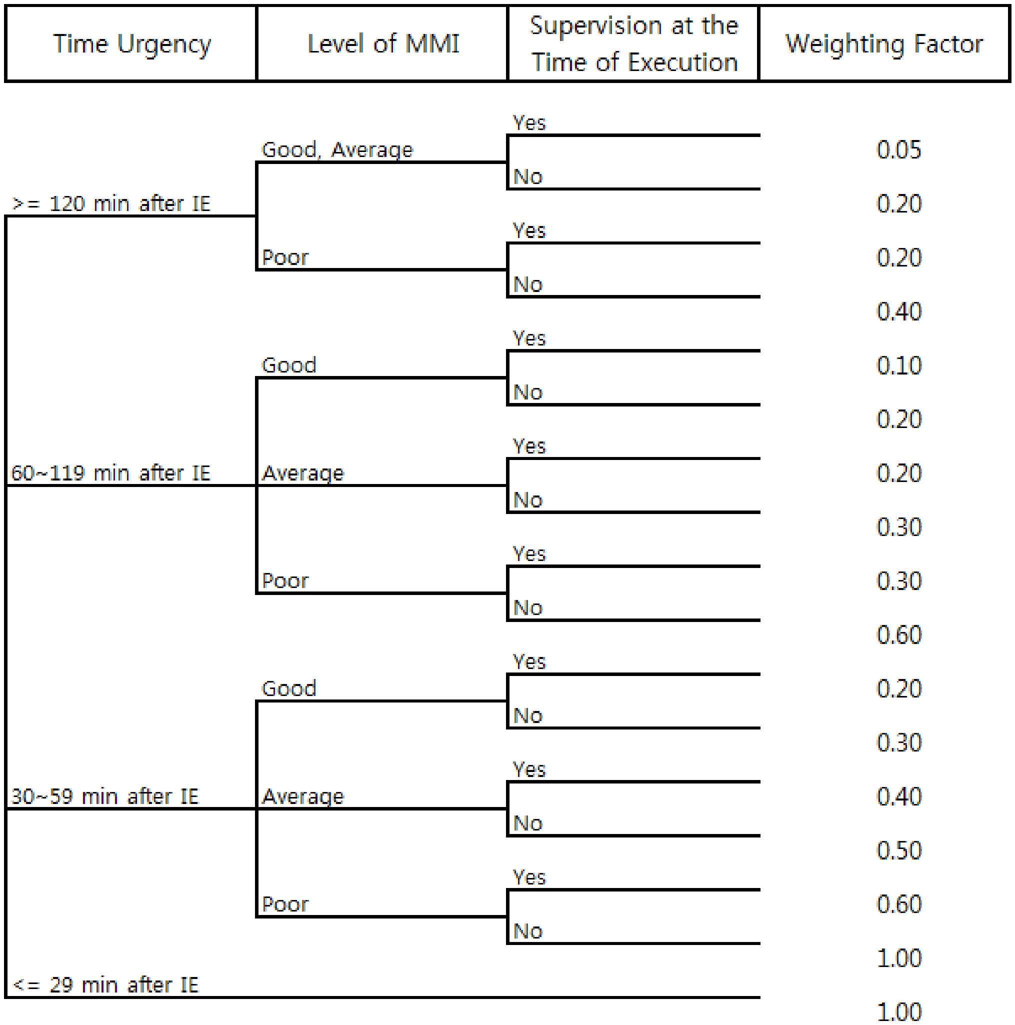


Fig. 6. Decision Tree for Execution Error Recovery

The final execution HEP is the sum of each unitary task BHEP which is the multiplication of $Basic\_HEP_{exec}$ * recovery factor. The final HEP of the HFEs concerned is the sum of HEPs for diagnosis and execution.

## II.B. PSFs for HEP Appropriateness Evaluation

The appropriateness of HRA results or HEP was evaluated considering the important PSFs (Performance Shaping Factors) which are known to influence human performance greatly in the aspect of diagnosis as well as execution in the FP and LPSD internal event PRA. Below is the quick review of the PSFs which are widely known as important for human performance and usually considered in PRA. Also is the explanation for the basis for PSF selection used to evaluate the appropriateness of HRA results or HEPs evaluated by K-HRA methodology in this study. The PSFs selected were based on the extensive review of HRA reports which were widely referenced in HRA analysis such as NUREG/CR-1278, NUREG/CR-4772, NUREG-1792, NUREG-6883, NUREG-1921, NUREG-1624 and EPRI-TR 101711 (SHARP1).

**Total Time Available for Operator Action**

Total time available is defined as time difference between the time when operator action is no longer beneficial for desired purpose and the time when operator gets a cue to perform the action. Total time available is one of the key PSFs which influence the diagnosis HEP as well as execution HEP as is mentioned in NUREG/CR-1278 and NUREG/CR-4772. For the most of HRA methods, such as THERP, ASEP HRA, HCR/ORE and CBDTM, total time available is direct input to determine diagnosis HEP and indirect input for execution error recovery. This is also true to K-HRA methodology. Total time available can be explicitly considered for recovery based on shift change. Therefore in this study, total time available is used as one of the PSFs to evaluate the appropriateness of HEPs.

**Time Available for Diagnosis**

Time available for diagnosis is defined as total time available for operator action minus time available for execution. Time available for diagnosis is one of the key PSFs which influence the diagnosis HEP as is mentioned in NUREG/CR-1278 and NUREG/CR-4772. For the most of HRA methods, such as THERP, ASEP HRA and HCR/ORE, time available for diagnosis is direct input to determine diagnosis HEP. This is also true to K-HRA methodology. Therefore in this study, time available for diagnosis is used as one of the PSFs to evaluate the appropriateness of HEPs.

**Main Stream Task in Accident Context**

This PSF is whether the task concern is the one dictated by the procedure which is used to cope with the accident scenario. If the task is required by other procedure rather than the one being performed currently, operators will be very difficult to determine to perform the task. This PSF is considered in K-HRA methodology as a direct input for diagnosis HEP estimation. Therefore in this study, main stream task in accident context is used as one of the PSFs to evaluate the appropriateness of HEPs.

**Instruments Availability for Cue**

Proper indication is essential for operators to determine to perform a certain task. Indications unavailable or misleading could prevent operators from performing proper determination. This might be a big concern for the operator actions under external events PRA for example fire event PRA which have many scenarios with instruments for cue damaged partially or totally. However, it is generally assumed that operators are sufficiently provided with proper indications for internal event PRA. Therefore, in this study the instrument available for cue is not used as one of the PSFs to evaluate the appropriateness of HEPs.

**Stress Level**

Stress is defined as bodily or mental tension and a stressor as any external or internal force that causes stress. Stress is something that is felt by a person. A stressor is something that produces stress. The stress a person experience can be psychological or physiological one. It is difficult at times to differentiate between the two. Often the stress experienced is a combination of both. The term stress is a controversial one, but it is useful in HRA work. An adverse level of stress can arise when there is some mismatch between the external and internal PSFs. For example, if the perceptual requirement of a task imposes too many demands on a worker, his performance will usually suffer because of excessive task loading, a psychological stressor. On the other hand, without sufficient task loading, the operator’s performance may be degraded because there is insufficient stress (mental or bodily tension) to keep him alert at the job. A well-designed man-machine system is one in which the task demands are consistent with the worker’s capabilities, limitations, and needs. To the extent that this consistence is not achieved, human errors and degraded motivation can be expected. The latter effect can, of course, act to crease the frequency of errors, and so on. Stress level is a PSF which is used as a multiplier for execution error probability as is provided in table 20-16 in NUREG/CR-1278. Stress is one of the important PSF that determines execution HEP in K-HRA methodology. Therefore in this study, stress is used as one of the PSFs to evaluate the appropriateness of HEPs.

**Task Type (Task Complexity)**

One way of defining task type is the degree of the complexity of the task. The degree of the complexity is also dependent on procedure quality, training and experience. In K-HRA three task-types are defined. They are simple response, step-by-step task and dynamic task whereas NUREG/CR-1278 defines two task types; step-by-step and dynamic tasks. Task Type is a PSF which is used as a multiplier for execution error probability as is provided in table 20-16 in NUREG/CR-1278. Task type is one of the important PSF that determines execution HEP in K-HRA methodology. Therefore in this study, task type is used as one of the PSFs to evaluate the appropriateness of HEPs.

**Workload (in combination with staffing and resources)**

Although workload is often associated with task complexity, the emphasis is on the amount of work that a crew or individual has to accomplish in the available time (e.g., task load), along with their overall sense of being pressured and/or threatened in some way with respect to what they are trying to accomplish. To the extent that crews or individuals expect to be under high workload it is generally thought to have a negative impact on performance particularly if the task being performed is considered complex. However, the impact of these factors should be carefully considered in the context of the accident scenario and of the other PSFs thought to be relevant. For example, in FP internal events HRA, if the scenario is familiar, its procedures and training are very good, and if the crews usually implement their procedures within the available time, then analysts might decide that relatively high expected levels of workload and stress will not have a significant impact on performance. However, if the accident scenario is unfamiliar, the procedures and training for the accident scenario are only considered adequate, and the time available to complete the action has been shortened, the analyst may decide that stress will have a significant impact on performance. In general, for internal event PRA whether it is FP or LPSD PRA, we have sufficient man-power to perform the task under concern. This might be a big concern for the operator actions under external events PRA for example fire event PRA but not for internal event PRA. Therefore, in this study the workload is not used as one of the PSFs to evaluate the appropriateness of HEPs.

**Human-Machine Interface (HMI)**

Human Machine Interfaces (HMI) impacts operator performance differently depending on the location of the action. In general, NUREG-6580, NUREG-1852 and NUREG- 1792 all agree that for control room actions, the HMI will have minimal or positive affect on the human performance. This is because problematic HMIs have either been taken care of by control room design reviews and improvements or they are easily worked around by the operating crew due to the daily familiarity of the control room boards and layout. However, any known very poor HMI should be considered as a negative influence for an applicable action even in the control room. In K-HRA methodology, HMI is used as a one of the inputs for diagnosis error modifier and for execution error recovery factor. Therefore, in this study the HMI is used as one of the PSFs to evaluate the appropriateness of HEPs.

**Execution Task Location**

According to NUREG/CR-1278, based on the task location, human failure mode varies and HEP does too. However, in K-HRA methodology, task location is considered for required execution time and input to stress level. Therefore task location does not affect HEP explicitly except for available diagnosis time. However, we have a lot of HFEs which are essentially the same in nature but performed in different locations in LPSD PRA. This is reason why execution task location is considered as key PSF to evaluate the appropriateness of HEPs in this study.

**Familiarity of the Task**

For internal events HRA, typically operators can be considered “trained at some minimum level” to perform their desired tasks so the task being performed is assumed to be familiar to operators. In K-HRA methodology, familiarity of the Task is implicitly considered when task type is evaluated so familiarity of the task is not explicitly considered in this study.

**Level of Procedure Quality**

There are three roles of plant procedures, which can aid successful operator performance. The procedures can assist the operators in correctly diagnosing the type of plant event that the event may trigger (usually in conjunction with indications), thereby permitting the operators to select the appropriate operator manual actions. The procedures direct the operators to the appropriate operator actions. The procedures attempt to minimize the potential confusion that can arise from complex accident contexts, thereby minimizing the likelihood of personnel error during the required operator actions. The level of procedure quality is one of the PSFs which affects the diagnosis and execution HEPs. Therefore, in this study the level of procedure quality is used as one of the PSFs to evaluate the appropriateness of HEPs.

**Level of Training Quality**

Training for both control room and local actions is an important factor when assessing operator performance. Training supports three functions for operator performance during an NPP event. Training establishes familiarity with the procedures and equipment needed to perform the desired actions, as well as, potential conditions in an actual event. Training provides the level of knowledge and understanding necessary for the personnel performing the operator actions to be well prepared to handle departures from the expected sequence of events. Training gives the opportunity to personnel to practice their response without exposure to adverse conditions, thereby enhancing confidence that they can reliably perform their duties in an actual event. For internal events HRA, typically operators can be considered “trained at some minimum level” to perform their desired tasks. But for external events HRA, the crew’s familiarity and level of training (e.g., types of scenarios, frequency of training or classroom discussions and/or simulations) for addressing the range of possible scenario complications and potential actions to be performed may be less than for internal events. "Less familiarity" needs to be accounted for in assessing the impact of training for fire actions and in determining their HEPs. Training on accident scenarios can often offset the effects of other negative PSFs such as poor procedures, limited time available, cues and indications, and complexity. Therefore, in this study the level of training quality is used as one of the PSFs to evaluate the appropriateness of HEPs.

**Shift Change**

As is implicated in NUREG-1624, according to the retrospective analysis of severe Nuclear Power Plant accident experiences, shift change could great influence on correcting errors performed by previous shift thus mitigating and/or terminating accidents. Therefore in this study, shift change is considered as a PSF used for HEP appropriateness. This is highly applicable to LPSD HFEs.

**Quality of Working Environment (Temperature, Humidity, Air Quality, Noise, Radiation)**

In General, if the quality of the working environment is very poor, we consider this to be a form of stressor and increase HEP. NPPs generally provide a satisfactory environment, but there are exceptions regarding the noise level and an excessive number of people in the control rooms. There are certain areas, e.g., the turbine room, where a high noise level is to be expected and ear protectors should be worn. Lighting for NPP tasks is often a problem. In some areas in a plant, the lighting may be so poor that errors in reading valve labels are likely. A special problem for certain NPP tasks is that of exposure to radioactivity and the requirement for wearing protective clothing when performing certain tasks. Operators usually have no concern about the very low levels of radiation, the clothing is uncomfortable, and a primary motivation of personnel in a rad environment is to get the job done as quickly as possible and get out of there. This motivation mitigates against human reliability. This might be a big concern for the operator actions under external events PRA for example fire event PRA but not for internal event PRA. Therefore, in this study the quality of working environment is not used as one of the PSFs to evaluate the appropriateness of HEPs.

**Accessibility**

Accessibility issues in association with operator actions is related to access to local area for operation and to special tools and equipment (protective clothes, carry-on flash light, ladder etc.) In HRA analysis, if the accessibility is not confirmed, the operator action under consideration is not credited. When accessibility is confirmed, it is considered in the execution time estimation for HEP quantification. This might be a big concern for the operator actions under external events PRA for example fire event PRA but not for internal event PRA. Therefore, in this study the accessibility is not used as one of the PSFs to evaluate the appropriateness of HEPs.

Based on the description above, for the PSFs which can be used as HEP appropriateness evaluation in this study, the attributes of the PSFs and the degree of HEP impact are can be summarized in the TABLE I. below.

TABLE I. Selected PSF attributes and the degree of HEP impact

| PSF ID | PSF | Attribute | Impact on HEP |
|---|---|---|---|
| PSF A | Total time Available for Operator Action | Minute | Varies |
| PSF B | Time Available for Diagnosis | Minute | Varies |
| PSF C | Main Stream Task in Accident Context | Yes, No | High |
| PSF D | Stress Level | Optimum, Moderately High, Very High, Extremely High | Medium |
| PSF E | Task Type | Simple Response, Step-by-Step, Dynamic | Medium |
| PSF F | Man-Machine Interface | Good, Average, Poor | Medium |
| PSF G | Execution Task Location | MCR, Field | Low |
| PSF H | Level of Procedure Quality | Good, Average, Poor | Low |
| PSF I | Level of Training Quality | Good, Average, Poor | Low |
| PSF J | Shift Change | Yes, No | High |

**II.C. HRA Results Appropriateness Evaluation for FP PRA**

In this section, the appropriateness of HRA results was evaluated for the selected HFEs (Human Failure Events) of FP internal event PRA considering the PSFs selected above. HRA results for Framatome plant which is very similar to the Westinghouse 3 loop NSSS plant were provided with the PSFs and their attributes in the TABLE II. below.

TABLE II. HRA Results Summary for FP Internal Event PRA

| HFE | PSF-A | PSF-B | PSF-C | PSF-D | PSF-E | PSF-F | PSF-G |
|---|---|---|---|---|---|---|---|
| | PSF-H | PSF-I | PSF-J | HEP(diag) | HEP(exec) | HEP(total) | |
| 0LHS-DGHS-AACDG | 59 | 56 | Yes | MH | SBS | Good | MCR |
| | Good | Good | No | 8.86E-05 | 1.00E-04 | 1.89E-04 | |
| 1ASG-OPHS-FLCTL | 39 | 37 | Yes | MH | SR | Good | MCR |
| | Good | Good | No | 3.35E-04 | 2.00E-04 | 5.35E-04 | |
| 1ASG-OPHS-WSRC | 360 | 234 | Yes | MH | SBS | Good | FIELD |
| | Good | Average | No | 2.63E-04 | 7.50E-04 | 1.01E-03 | |
| 1HFE-OPHS-ACD-SGTR | 50 | 48 | Yes | VH | Dyn | Good | MCR |
| | Good | Poor | No | 8.33E-03 | 1.60E-02 | 2.43E-02 | |
| 1HFE-OPHS-ACD-SLOCA | 35 | 33 | Yes | EH | Dyn | Good | MCR |
| | Good | Poor | No | 1.87E-02 | 1.00E-01 | 1.19E-01 | |
| 1HFE-OPHS-BLD-RCPS | 50 | 49 | Yes | VH | SBS | Good | MCR |
| | Good | Poor | No | 1.56E-02 | 2.00E-03 | 1.76E-02 | |
| 1HFE-OPHS-BLD-RCPS-SGTR | 80 | 79 | Yes | VH | SBS | Good | MCR |
| | Good | Poor | No | 5.30E-03 | 2.00E-03 | 7.30E-03 | |
| 1HFE-OPHS-FBD-LATE | 170 | 166 | Yes | VH | SBS | Good | MCR |
| | Good | Poor | No | 1.00E-03 | 2.00E-03 | 3.00E-03 | |
| 1HFE-OPHS-FBD-RCPS | 39 | 36 | Yes | EH | SBS | Good | MCR |
| | Good | Poor | No | 1.07E-02 | 2.00E-02 | 3.07E-02 | |
| 1HFE-OPHS-CLD | 50 | 48 | Yes | VH | SBS | Average | MCR |
| | Good | Poor | No | 5.49E-04 | 1.60E-02 | 1.65E-02 | |
| 1HFE-OPHS-CLD-SGTR | 99 | 94 | Yes | MH | SBS | Average | MCR |
| | Good | Average | No | 4.00E-05 | 1.50E-03 | 1.54E-03 | |
| 1HFE-OPHS-CLD-SLOCA | 40 | 36 | Yes | MH | SBS | Average | MCR |
| | Good | Good | No | 3.51E-04 | 2.00E-03 | 2.35E-03 | |
| 1HFE-OPHS-ISO-FSG | 20 | 18 | Yes | VH | SBS | Good | MCR |
| | Good | Good | No | 3.41E-03 | 8.00E-03 | 1.14E-02 | |
| 1HFE-OPHS-ISO-SGTR | 25 | 23 | Yes | VH | SBS | Good | MCR |
| | Good | Good | No | 1.96E-03 | 8.00E-03 | 9.96E-03 | |
| 1PTR-OPHS-RWST-RF | 480 | 360 | No | MH | SBS | Good | FIELD |
| | Good | Average | Yes | 4.23E-03 | 1.00E-03 | 5.23E-03 | |
| 1RCV-OPHS-EMB | 55 | 52 | Yes | VH | SBS | Good | MCR |
| | Good | Average | No | 1.32E-04 | 4.00E-03 | 4.13E-03 | |
| 1RCV-OPHS-SEALINJ | 30 | 28 | Yes | VH | SBS | Good | MCR |
| | Average | Average | No | 7.24E-04 | 1.20E-02 | 1.27E-02 | |
| 1RIS-OPHS-HLL-RECIRC | 240 | 238 | Yes | OPT | SBS | Good | MCR |
| | Good | Average | No | 1.72E-04 | 3.75E-04 | 5.47E-04 | |
| 1RRA-OPHS-RRAOP | 300 | 240 | Yes | MH | SBS | Good | FIELD |
| | Good | Good | No | 2.80E-05 | 2.50E-03 | 2.53E-03 | |

Though we don't have enough HFEs for comparison which have various PSF attributes, as can be seen in the table above, most of the HEPs look appropriate relatively each other considering the PSF impact on HEPs as described in TABLE I. Some discussions for this appropriateness and potential deviations are provided below;

O As is shown in Table II, in general, the resultant HEPs are well explained by the PSF attributes which have either positive or negative human performance thus impact on HEP. The impact on HEP by PSF-C through PSF-J varies in association with the time available. This means that for an HFE with less time available, the impact of PSFs on HEP is greater and vice versa. This well satisfies the intent of the K-HRA methodology development philosophy.

O 1HFE-OPHS-ACD-SGTR and 1HFE-OPHS-ACD-SLOCA are essentially the same HFEs (failure of aggressive RCS cool down using SG steam dump) but have different total available time and diagnosis time. The difference in time available affects diagnosis error probability directly and stress level indirectly thus the resultant total HEP. This is judged to be reasonable in the aspect of the relationship between total time available and stress level/diagnosis time available.

O 1HFE-OPHS-BLD-RCPS, 1HFE-OPHS-BLD-RCPS-SGTR, 1HFE-OPHS-FBD-RCPS and 1HFE-OPHS-FBD-LATE are essentially the same HFEs (failure of feed and bleed operation) but have different total available time and diagnosis time. The difference in time available affects diagnosis error probability directly and stress level indirectly thus the resultant total HEP. This is judged to be reasonable in the aspect of the relationship between total time available and stress level/diagnosis time available.

O 1PTR-OPHS-RWST-RF is an HFE of failure of refilling RWST during SGTR accident sequence. Though we have sufficient time available for this HFE, the resultant HEP is not very low. In the aspect of diagnosis, this HFE is not a main stream task in the accident context and the execution is performed in the field. However, it is believed that the recovery possibility both diagnosis and execution could be applicable by shift change as is shown in TABLE II. K-HRA methodology doesn't support shift change for diagnosis and execution error recovery.

O 1ASG-OPHS-WSRC, 1PTR-OPHS-RWST-RF and 1RRA-OPHS-RRAOP are the HFEs of which execution is performed in the field. As is shown in TABLE II, the execution error probability is relatively high even though time available is long and the other PSFs are relatively positive to human performance. In K-HRA methodology, if the execution is performed in the field, it affects stress level and task type negatively. That's why the HEPs of the HFEs above are estimated high. This is judged to be reasonable in the aspect of the PSFs related however some recovery potential might be considered if we have sufficient time.

Through the discussion of the FP internal event HRA results in the aspect of PSFs which are considered important on human performance for FP internal event PRA, conclusions below were derived.

O Generally FP HRA results are well explained by the PSFs considered important

O Recovery potential by shift change needs to be considered in K-HRA methodology.

O For tasks performed in the field, there is tendency of high execution HEP even though time available is sufficient

### II.D. HRA Results Appropriateness Evaluation for LPSD PRA

In this section, the appropriateness of HRA results was evaluated for the selected HFEs (Human Failure Events) of LPSD internal event PRA considering the PSFs selected above. HRA results for Framatome plant which is very similar to the Westinghouse 3 loop NSSS plant were provided with the PSFs and their attributes in the TABLE III. below.

TABLE III. HRA Results Summary for LPSD Internal Event PRA

| HFE | PSF-A | PSF-B | PSF-C | PSF-D | PSF-E | PSF-F | PSF-G |
|---|---|---|---|---|---|---|---|
| | PSF-H | PSF-I | PSF-J | HEP(diag) | HEP(exec) | HEP(total) | |
| HR-RS-S2P03 | 21 | 20 | Yes | MH | SR | Good | MCR |
| | Good | Good | No | 2.84E-03 | 1.00E-03 | 3.84E-03 | |
| HR-RS-S2P04 | 180 | 179 | Yes | OPT | SR | Good | MCR |
| | Good | Good | No | 3.19E-05 | 5.00E-05 | 8.19E-05 | |
| HR-RS-S2P05 | 8 | 7 | Yes | MH | SR | Good | MCR |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Good | Good | No | 2.61E-02 | 1.00E-03 | 2.71E-02 | |
| HR-RS-S2P06 | 50 | 49 | Yes | OPT | SR | Good | MCR |
| | Good | Good | No | 1.80E-04 | 2.00E-04 | 3.80E-04 | |
| HR-RS-S2P10 | 135 | 134 | Yes | OPT | SR | Good | MCR |
| | Good | Good | No | 3.56E-05 | 5.00E-05 | 8.56E-05 | |
| HR-RS-S2P11 | 47 | 46 | Yes | OPT | SR | Good | MCR |
| | Good | Good | No | 2.18E-04 | 2.00E-04 | 4.18E-04 | |
| HR-RS-S2P12 | 233 | 232 | Yes | OPT | SR | Good | MCR |
| | Good | Good | No | 2.85E-05 | 5.00E-05 | 7.85E-05 | |
| HR-RS-S2P13 | 154 | 153 | Yes | OPT | SR | Good | MCR |
| | Good | Good | No | 3.39E-05 | 5.00E-05 | 8.39E-05 | |
| HR-SG-S2P03 | 180 | 177 | Yes | OPT | SBS | Good | MCR |
| | Good | Good | No | 3.19E-05 | 7.50E-04 | 7.82E-04 | |
| HR-SG-S2P04 | 480 | 477 | Yes | OPT | SBS | Good | MCR |
| | Good | Good | Yes | 1.92E-05 | 7.50E-04 | 7.69E-04 | |
| HR-SG-S2P13 | 915 | 912 | Yes | OPT | SBS | Good | MCR |
| | Good | Good | Yes | 1.09E-05 | 7.50E-04 | 7.61E-04 | |
| HR-FB-S2P03 | 197 | 173 | Yes | MH | SBS | Good | FIELD |
| | Average | Average | No | 5.97E-04 | 1.50E-03 | 2.10E-03 | |
| HR-FB-S2P04 | 478 | 454 | Yes | MH | SBS | Good | FIELD |
| | Average | Average | Yes | 3.68E-04 | 1.50E-03 | 1.87E-03 | |
| HR-FB-S2P05 | 107 | 83 | Yes | MH | SBS | Good | FIELD |
| | Average | Average | No | 7.71E-04 | 2.00E-03 | 2.77E-03 | |
| HR-FB-S2P06 | 71 | 47 | Yes | MH | SBS | Good | FIELD |
| | Average | Average | No | 3.56E-03 | 2.00E-03 | 5.56E-03 | |
| HR-FB-S2P10 | 556 | 532 | Yes | MH | SBS | Good | FIELD |
| | Average | Average | Yes | 3.30E-04 | 2.00E-03 | 2.33E-03 | |
| HR-FB-S2P11 | 694 | 670 | Yes | MH | SBS | Good | FIELD |
| | Average | Average | Yes | 2.76E-04 | 2.00E-03 | 2.28E-03 | |
| HR-FB-S2P12 | 893 | 769 | Yes | MH | SBS | Good | FIELD |
| | Average | Average | Yes | 2.43E-04 | 2.00E-03 | 2.24E-03 | |
| HR-FB-S2P13 | 1436 | 1412 | Yes | MH | SBS | Good | FIELD |
| | Average | Average | Yes | 1.81E-04 | 2.00E-03 | 2.18E-03 | |
| HR-GF-S2P10 | 80 | 30 | No | VH | SBS | Good | FIELD |
| | Average | Average | No | 1.86E-01 | 4.00E-03 | 1.90E-01 | |
| HR-GF-LXP10 | 80 | 30 | Yes | VH | SBS | Good | FIELD |
| | Good | Good | No | 1.53E-03 | 4.00E-03 | 5.53E-03 | |

It is believed that we have sufficient HFEs for comparison which have various PSF attributes, as can be seen in the table above. It is judged that most of the HEPs look appropriate relatively each other considering the PSF impact on HEPs as described in TABLE I. Some discussions for this appropriateness and potential deviations are provided below;

O As is shown in Table III, in general, the resultant HEPs are well explained by the PSF attributes which have either positive or negative human performance thus impact on HEP. The impact on HEP by PSF-C through PSF-J varies in association with the time available. This means that for an HFE with less time available, the impact of PSFs on HEP is greater and vice versa. This well satisfies the intent of the K-HRA methodology development philosophy.

O HR-GF-S2P10 and HR-GF-LXP10 are essentially the same HFEs (failure of feeding RCS by gravity) and all PSF attributes are the same except for the PSF of “main stream task in accident context”. This difference makes a great difference for the resultant HEPs. HR-GF-S2P10 is diagnosed and performed somewhat based on knowledge base whereas HR-GF-LXP10 is diagnosed and performed by a procedure directly led by the accident context. As is shown by these two HFEs, the PSF of “main stream task in accident context” provides a great tool to differentiate HFEs of which tasks are essentially the same but the accident context for the HFE is completely different. Performing a HRA reflecting the accident scenario context for the HFE concerned is a kind of good practices in HRA.

O HR-RS-S2P**s are essentially the same HFEs (failure of restoring residual heat removal) but have different total available time and diagnosis time. The difference in time available affects diagnosis error probability directly and stress level indirectly thus the resultant total HEP. This is judged to be reasonable in the aspect of the relationship between total time available and stress level/diagnosis time available.

O HR-FB-S2P04, HR-FB-S2P10, HR-FB-S2P11, HR-FB-S2P12 and HR-FB-S2P13 are the HFEs of which execution is performed in the field and of which time available is more than 8 hrs. As is shown in TABLE III, the execution error probability is relatively high even though time available is long and the other PSFs are relatively positive to human performance. In K-HRA methodology, if the execution is performed in the field, it affects stress level and task type negatively. That’s why the HEPs of the HFEs above are estimated high. It is judged to be reasonable in the aspect of the PSFs. However, it is believed that the recovery possibility both diagnosis and execution could be applicable by shift change as is shown in TALBLE III. Currently, K-HRA methodology doesn’t support shift change for diagnosis and execution error recovery.

O HR-SG-S2P03 and HR-SG-S2P13 are essentially the same HFEs (failure of providing feed water and removing steam). We have very sufficient time available for the HFEs and all the PSFs are very positive. The resultant HEPs are almost the same even though there is a big difference in the time available. It is believed that the recovery possibility by shift change should be reflected as is shown in TABLE III to differentiate the proven recovery mechanism. Currently, K-HRA methodology doesn’t support shift change for diagnosis and execution error recovery.

Through the discussion of the LPSD internal event HRA results in the aspect of PSFs which are considered important on human performance for LPSD internal event PRA, conclusions below were derived.

O Generally LPSD HRA results are well explained by the PSFs considered important

O K-HRA methodology provides a tool to differentiate HFEs of which tasks are essentially the same but they are performed in completely different accident contexts. It provides a PSF of “main stream task in accident context” to reflect them.

O Recovery potential by shift change needs to be considered in K-HRA methodology.

O For tasks performed in the field, there is tendency of high execution HEP even though time available is sufficient

## III. CONCLUSIONS

K-HRA methodology is a kind of HRA methodology developed by KAERI with cooperation of KEPCO-E&C in 2005. One of the most important purposes of the K-HRA methodology development is the standardization of the HRA process and clarification of all input data used to estimate HEP. It makes PRA practitioners, though not HRA experts, can perform the HRA tasks with very little variation among analysts for the HRA Results.

In this study, most of the PSFs generally considered in HRA were reviewed. Among them, some PSFs were selected which is judged to affect HRA results greatly for FP and LPSD internal event PRAs. We evaluated appropriateness of the HRA results for FP and LPSD internal event PRA in consideration with the PSFs selected. Based on the evaluation, conclusions below were derived.

O Generally LPSD HRA results are well explained by the PSFs considered important

O K-HRA methodology provides a tool to differentiate HFEs of which tasks are essentially the same but they are performed in completely different accident contexts. It provides a PSF of “main stream task in accident context” to reflect them.

O Recovery potential by shift change needs to be considered in K-HRA methodology.

O For tasks performed in the field, there is tendency of high execution HEP even though time available is sufficient

If the derived considerations above are reflected into K-HRA methodology, it is believed that the K-HRA methodology will be more self-consistent and robust HRA methodology for FP and LPSD internal event PRA. In addition, the PSFs which are not very important for internal event PRA for example, instrument availability for cue, workload, quality of working environment, accessibility, etc. will be dominant ones to HRA results for external event PRA. Therefore, the K-HRA methodology to be used for all scopes of PRA as a reliable tool, it is necessary to revise the K-HRA process to fully incorporate the effect of the PSFs mentioned.

## ACKNOWLEDGMENTS

The authors wish to acknowledge all the HRA experts in Korea who suggested the improvement items for K-HRA from the lessons learned through the PRA model development project. We specially wish to acknowledge Ho Joon Jeong, Tae Young Shin and Jang Hwan Na of CRI, Ho Seok and Jae Gab Kim of KEPCO-E&C, Jae Hwan Kim, Jin Hee Park and Dong San Kim of KAERI, Young Seok Lee and Gun Hyo Jeong of FNC, Bum Seok Kim, Bub Lin Kim and Koo Sam Kim of ACT.

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