A Comparison of Human Reliability Analysis Methods for Post-Initiators

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HERA Lab. Human Engineeing & Risk Analysis

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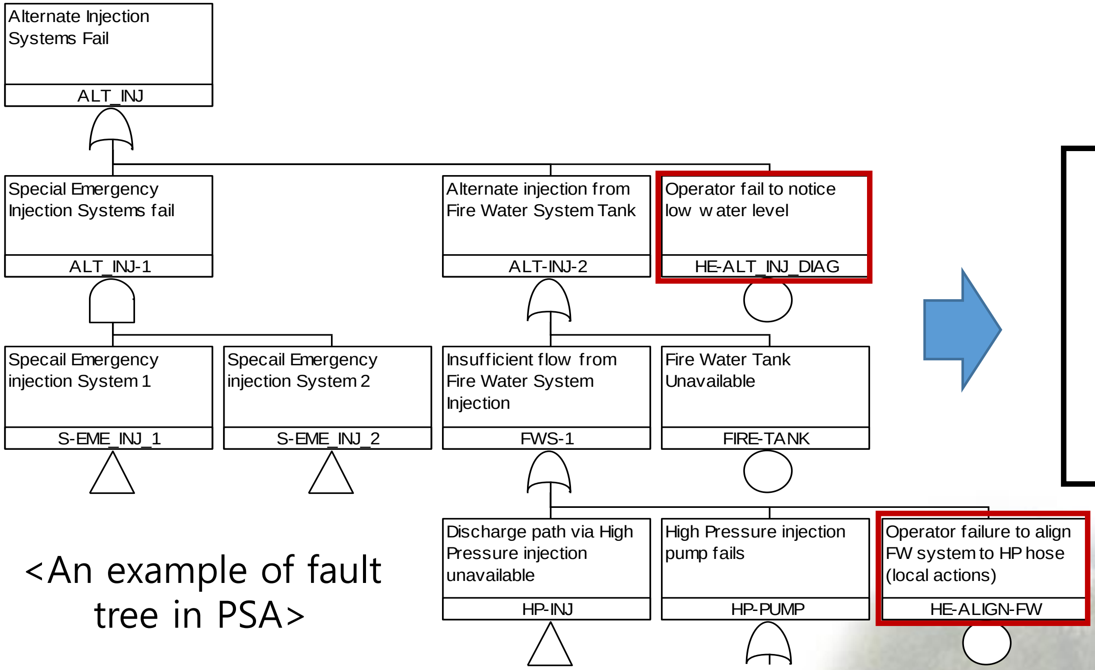
1. Introduction

HERA Lab. Human Engineeing & Risk Analysis

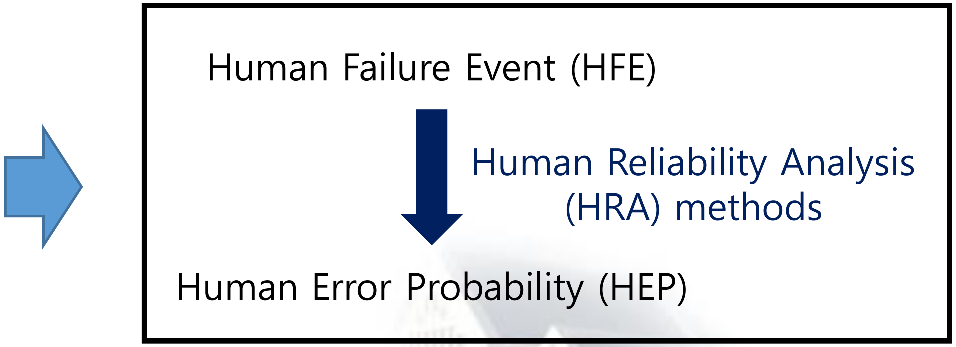
1.1 Motivation

▶ What is human reliability analysis (HRA)?

- A method for evaluating human errors and providing human error probabilities for application in Probabilistic safety assessment (PSA)
- The main purpose of HRA in the context of the PSA is to identify, analyze and quantify all human failure events (HFEs) represented in the logic structure of the PSA, before and during the accident, which contributes to plant risk as defined in the PSA.



<An example of fault tree in PSA>



1.1 Motivation

▶ Challenges of HRA

- The field of HRA has been considered as one of the areas with high uncertainty in the PSA, because it has several challenges;
    1) data scarcity for predicting human behavior
    2) limited representation of the cognitive aspects of human performance,
    3) Significant differences in HRA results from different HRA analysts with the same method

- Up to date, there has not been an universally accepted or unified HRA method for the estimation of HEPs.
    - Only a few HRA methods, such as Technique for human error-rate prediction (THERP), Accident sequence evaluation program (ASEP), Human cognitive reliability (HCR), Cause based decision tree (CBDT), and Standardized plant analysis risk HRA (SPAR-H) have been applied in different industries, plants, and units.
        - ➢ Korea → THERP, ASEP and K-HRA
        - ➢ U.S. → THERP, ASEP, CBDT, HCR, and SPAR-H

1.1 Motivation

▶ Comparison studies for HRA methods

- Evaluation of various HRA methods regarding the respective strengths, limitations, and quantification characteristics
  - NUREG-1842, "Evaluation of human reliability analysis methods against good practices", U.S. NRC, 2006.
  - NEA/CSNI/R(2015)1, "Establishing the appropriate attributes in current human reliability assessment techniques for nuclear safety", OECD/NEA, 2015.
- Studies with comparison of human error probabilities on the selected HRA methods

	Mohammadfam, I., M. Movafagh, and S. Bashirian	Hogenboom, I. and A.S. Kristensen	Heo, E.M., et al.
Objective	Selection of the most suitable method for application to different fields		
Approach	Comparison of HEPs		
Application field	Nursing practice	Sluice complex	Small Modular Reactor
HRA methods	CREAM and SPAR-H	THERP, CREAM and SPAR-H	THERP and NARA

→ **Even though most HRA methods have been developed for use in the nuclear field, only a few comparison studies of human error probabilities were conducted on the events in NPPs.**

→ **Existing researches may not explicitly provide why the human error probabilities estimated from different HRA methods are different and what makes them different.**

1.2 Objective

▶ Purpose of this presentation

- **A comparison of human reliability analysis methods for post-initiators**
  - Comparing the HEPs of HRA methods based on events in NPPs (Post-initiators)
  - Understanding how the quantification approaches are different depending on HRA methods

※ *Post-initiators* : Actions in response to disturbance by operators after an initiating event

▶ Contents

Selection of 4 HRA methods ⇨ Performance of HRA on 7 HFEs ⇨ A comparison of HEPs by four HRA methods ➡ **"Findings"**

Selection of 4 HRA methods:
- ASEP
- CBDT/HCR+THERP
- SPAR-H
- K-HRA

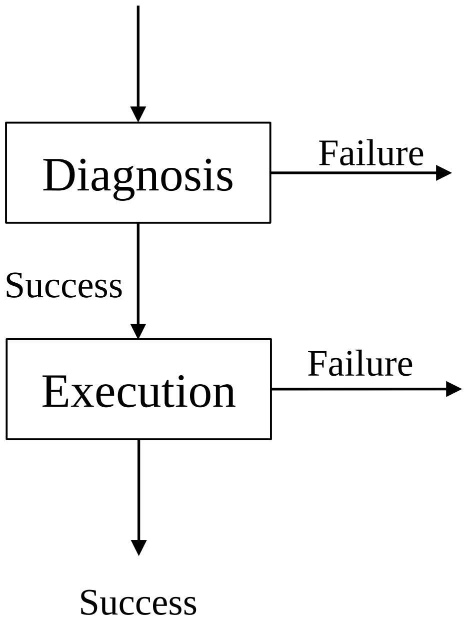
Performance of HRA on 7 HFEs:
- 7 HFEs stand for main post-initiators in OPR1000 type of NPPs.
- No recovery factor and dependency between HFEs

A comparison of HEPs by four HRA methods:
- Diagnosis HEPs
- Execution HEPs
- Final HEPs

2. HRA methods

2. HRA methods

2.1 Calculation of HEPs in general HRA methods



$$HEP_{diagnosis} = Basic\ HEP_{diagnosis} \times\ Adjustment\ by\ PSFs$$

$$+$$

$$HEP_{execution} = Basic\ HEP_{execution} \times\ Adjustment\ by\ PSFs$$

$$||$$

Final Human Error Probability

※ Performance Shaping Factor (PSF): any factor that influences human performance such as experience, workload, task complexity, etc.

2.2 HRA methods

▶ Introduction to selected HRA methods

	ASEP	CBDT/HCR+THERP	SPAR-H	K-HRA
Institute (Document)	U.S. NRC (NUREG/CR-4772)	EPRI (EPRI TR-100259) and U.S. NRC (NUREG-1278)	U.S. NRC (NUREG/CR-6883)	KAERI (KAERI/TR-2961/2005)
Characteristics	• Simplified version of THERP	• Commination of CBDT, HCR and THERP	• Easy to use • Employs a beta distribution	• Based on THERP and ASEP method
Reason for selection	• Widely applied method at the beginning of domestic NPPs	• Widely used for domestic NPPs (applied for Barakah NPPs)	• The most recently developed HRA method by U.S. NRC	• The most likely HRA method for subsequent utility use in Korea

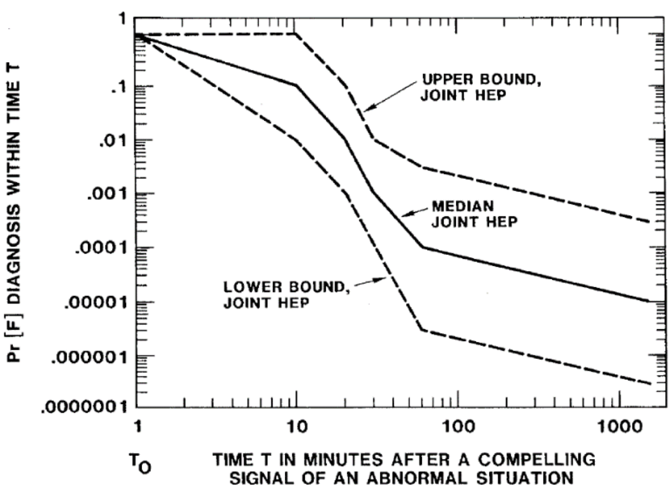
No	PSA 과제명	PSA성격	수행기관	보고서 발행연도	분석 방법
1	고리3,4 및 영광1,2	운전원전 PSA	KOPEC	1992	HCR/THERP
2	영광3,4	설계원전 PSA	KAERI	1993	ASEP/THERP
3	월성2,3,4	설계원전 PSA	KAERI	1997	ASEP/THERP
4	울진3,4	설계원전 PSA	KAERI	1997	ASEP/THERP
5	KNGR	설계원전 PSA	KOPEC	1999	THERP
6	영광5,6	설계원전 PSA	KAERI	2001	ASEP/THERP
7	영광5,6 (정지/저출력)	설계원전 PSA	KAERI	2001	THERP
8	울진5,6	설계원전 PSA	KEPRI	2002	ASEP/THERP

- ASEP: Accident sequence evaluation program
- CBDT/HCR+THERP: Cause based decision tree method / Human cognitive reliability + Technique for human error rate prediction
- SPAR-H: Standard Plant Analysis Risk HRA
- K-HRA: Korean standard HRA

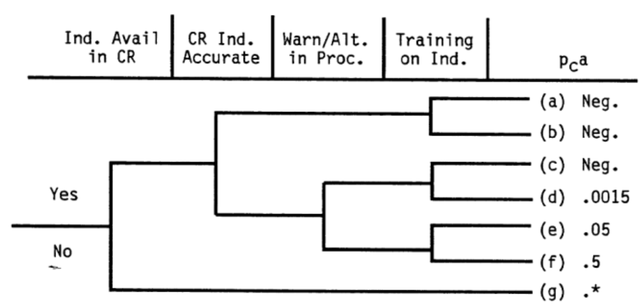
2.2 HRA methods

▶ Quantification approach (Diagnosis HEPs)

	ASEP	CBDT/HCR+THERP (CBDT/HCR)	SPAR-H	K-HRA
Diagnosis HEPs	• Estimating HEPs by THERP time curve (i.e., time reliability correlation curve)	• Using CBDT and HCR • HCR (by HCR time curve) and CBDT (by 8 error mechanisms with decision trees on the basis of PSFs) • Determination of final HEP as the higher value	• Basic diagnosis HEP : 1.0E-2 • 8 SPAR-H PSFs • Estimation of HEPs $HEP = BHEP \cdot \prod_{1}^{8} PSF\ multiplier_i$ $HEP = \frac{BHEP \cdot \prod_{1}^{8} PSF\ multiplier_i}{BHEP \cdot \prod_{1}^{8}(PSF\ multiplier_i - 1) + 1}$	• Estimating basic HEPs by THERP curve, then adjusting it by 5 K-HRA PSFs



<Time reliability correlation curve (THERP)>



<Decision tree on error mechanism 'a' (CBDT)>

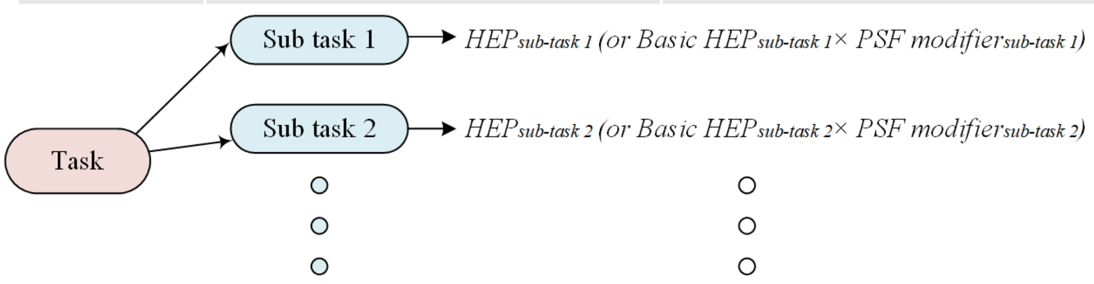
SPAR-H PSFs	SPAR-H PSF Levels	SPAR-H Multipliers
Available Time	Inadequate Time	*P(failure) = 1.0*
	Time available = time required	10
	Nominal time	1
	Time available ≥ 5 x time required	.1
	Time available > 50 x time required	0.01
Stress/ Stressors	Extreme	5
	High	2
	Nominal	1
Complexity	Highly complex	5
	Moderately complex	2
	Nominal	1

<Example of SPAR-H PSFs, PSF levels, and multipliers>

2.2 HRA methods

▶ Quantification approach (Execution HEPs)

	ASEP	CBDT/HCR+THERP (THERP)	SPAR-H	K-HRA
Execution HEPs	• Decomposing operator's task • Estimating HEPs of sub-tasks based on stress level and task type PSFs • Summation of all the estimated HEPs of sub-tasks	• Using THERP • Decomposing operator's task • Selecting basic HEPs of sub-tasks based on THERP data • Multiplying PSFs (stress level, task type and operator experience) • Summation of all the estimated HEPs of sub-tasks	• Basic execution HEP : 1.0E-3 • 8 SPAR-H PSFs • Estimation of HEPs $HEP = BHEP \cdot \prod_{1}^{8} PSF\ multiplier_i$ $HEP = \frac{BHEP \cdot \prod_1^8 PSF\ multiplier_i}{BHEP \cdot \prod_1^8 (PSF\ multiplier_i - 1) + 1}$	• Decomposing operator's task • Estimating HEPs of sub-tasks based on stress level and task type



$$\therefore Execution\ HEP = \sum HEP_{sub-task\ i}$$

<Decomposition approach>

No.	Task type	Stress level	HEPs
1	Step-by-Step	Moderately high	0.02
2	Dynamic	Moderately high	0.05
3	Step-by-Step	Extremely high	0.05
4	Dynamic	Extremely high	0.25

<An example of HEPs for sub-tasks (ASEP)>

3. Selected human failure events

▶ 7 HFEs

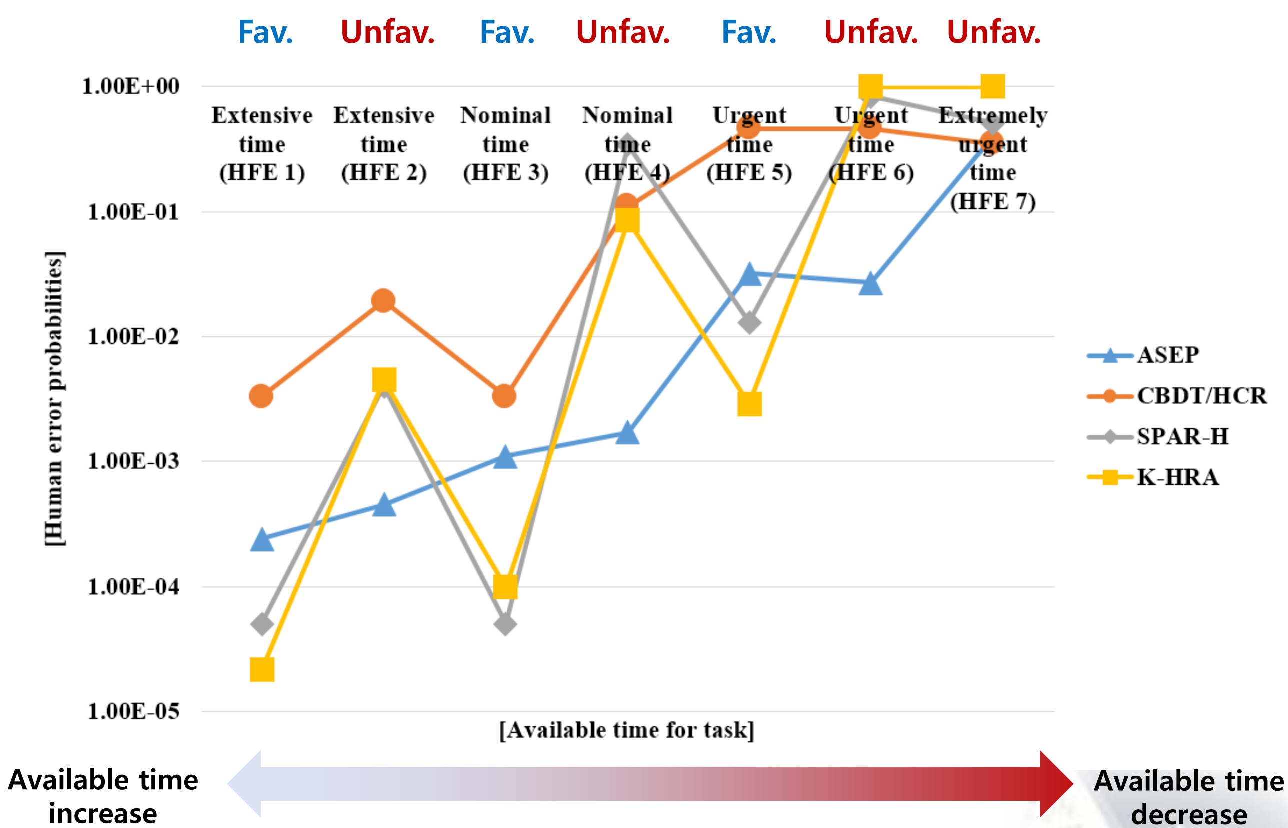
- **Reflecting conditions with time and PSF condition**
  - Time condition: Extensive time, nominal time, urgent time and extremely urgent time (assumed from THERP and K-HRA)
  - PSF condition: Favorable and unfavorable
- **Standing for main post-initiators in OPR1000 type of NPPs**

HFE No.	Time condition (Available time for task)	PSF condition	Description	Location (Actor)	Scenarios	Available time for task	PSFs				
							Stress	Experience/ Training	Task complexity	Procedure level	Decision burden
1	Extensive time (>60)	Favorable	Operator fails to isolate ADVs of faulted SG.	MCR	SGTR	360	Moderately high	High	Nominal	High	Low
2		Unfavorable	Operator fails to perform F&B operation within 2.5 hr (Late).	MCR	Transient	150	Moderately high	Low	High	Nominal	High
3	Nominal time (>30 and <=60)	Favorable	Operator fails to start AAC DG-01E and connect to 4.16KV bus.	MCR	LOOP	60	Moderately high	High	Nominal	High	Low
4		Unfavorable	Operator fail to manually open ADVs in local (with local hand pump).	LOCAL	Transient	60	Extremely high	Low	High	Low	High
5	Urgent time (>10 and <=30)	Favorable	Operator fails to generate SIAS manually in the Medium LOCA.	MCR	MBLOCA	20	Extremely high	High	Nominal	High	Nominal
6		Unfavorable	Operator fails to initiate RCS agressive cooldown and depressurization for LPSI within	MCR	SBLOCA	23	Extremely high	Low	High	Low	High
7	Extremely urgent time (<=10)	Unfavorable	Operator fails to perform F&B operation within 10 min (ATWS).	MCR	ATWS	10	Extremely high	Low	High	Nominal	High

4. Comparison of HRA methods

4.1 Comparison of diagnosis HEPs

▶ Results of HRAs on 7 HFEs



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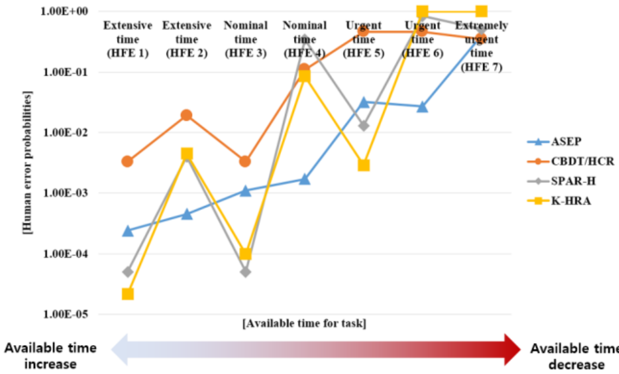
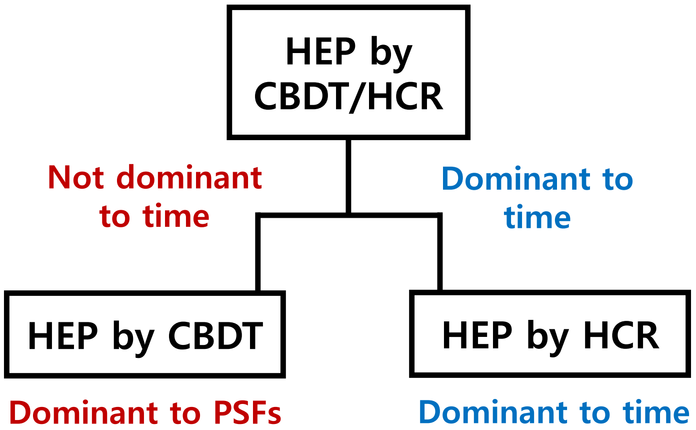
4.1 Comparison of diagnosis HEPs

▶ Finding #1

- CBDT/HCR has a tendency to make relatively higher diagnosis HEPs.





HEPs by CBDT (dominant to PSFs)

Available time increase

Available time decrease

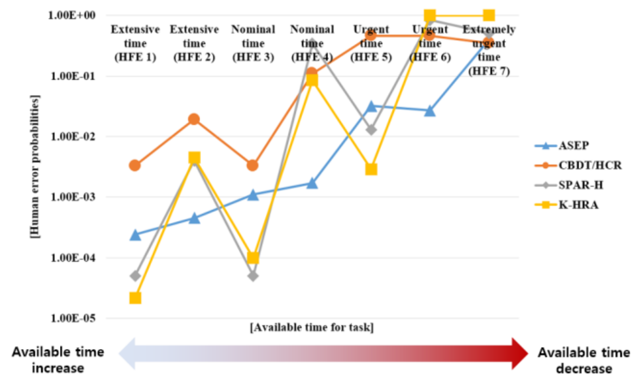
HFE No.	ASEP	CBDT/HCR+THERP			
	HEP	CBDT	HCR	Determined HEP	
HFE 1	2.40E-04	3.30E-03	2.00E-07	3.30E-03	CBDT
HFE 2	4.50E-04	1.90E-02	1.30E-06	1.90E-02	CBDT
HFE 3	1.10E-03	3.30E-03	2.40E-03	3.30E-03	CBDT
HFE 4	1.70E-03	5.90E-02	1.10E-01	1.10E-01	HCR
HFE 5	3.20E-02	3.00E-03	4.60E-01	4.60E-01	HCR
HFE 6	2.70E-02	5.90E-02	4.60E-01	4.60E-01	HCR
HFE 7	4.00E-01	1.90E-02	3.50E-01	3.50E-01	HCR

HEPs by HCR (dominant to time)

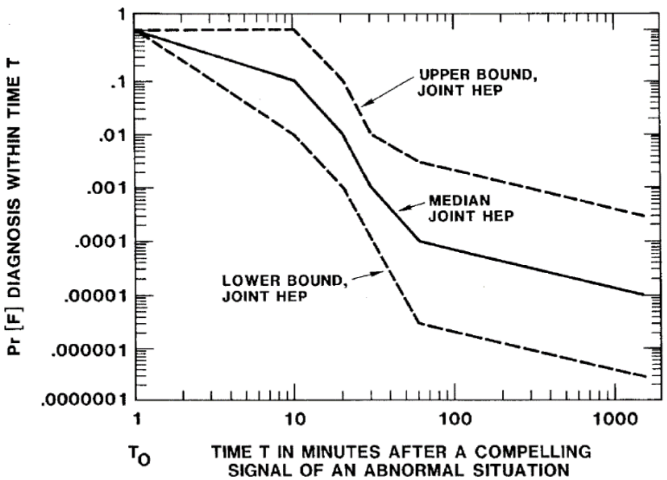
4.1 Comparison of diagnosis HEPs

▶ Finding #2

- **When available time for diagnosis is over 40min, diagnosis HEPs by HCR curve decrease more steeply than THERP curve.**



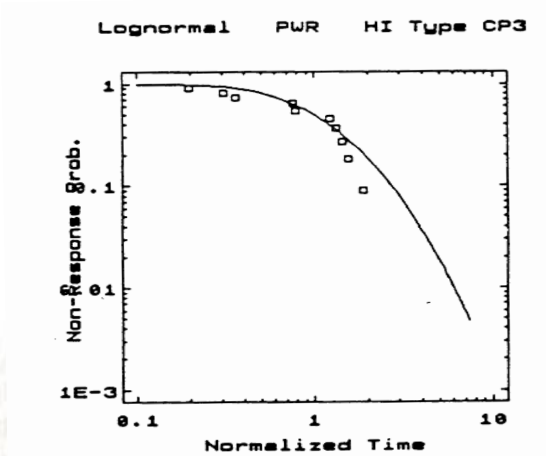
- ASEP
  - THERP curve
    - ➢ Available time for diagnosis



- HCR
  - HCR curve

$$p_c = Prob\,(T_r > T) = 1 - \Phi\left[\frac{ln\,(T/T_{1/2})}{\sigma}\right]$$

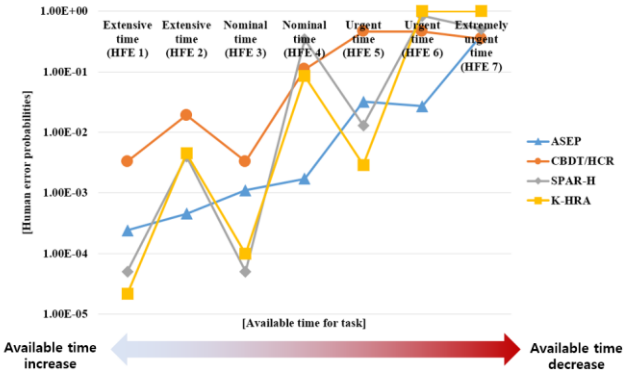
    - ➢ Available time for diagnosis (T)
    - ➢ Median response time ($T_{1/2}$)
    - ➢ Standard deviation according to diagnosis type 1, 2 & 3 suggested by HCR

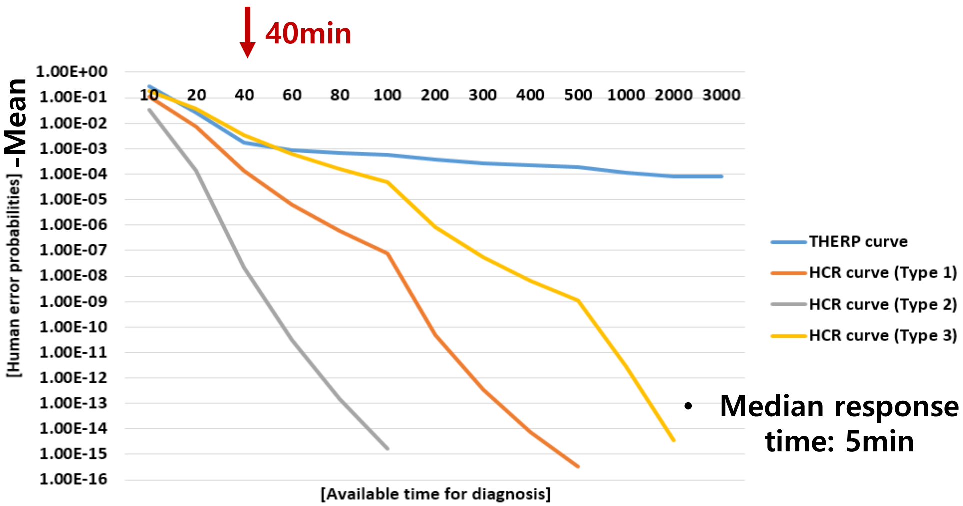


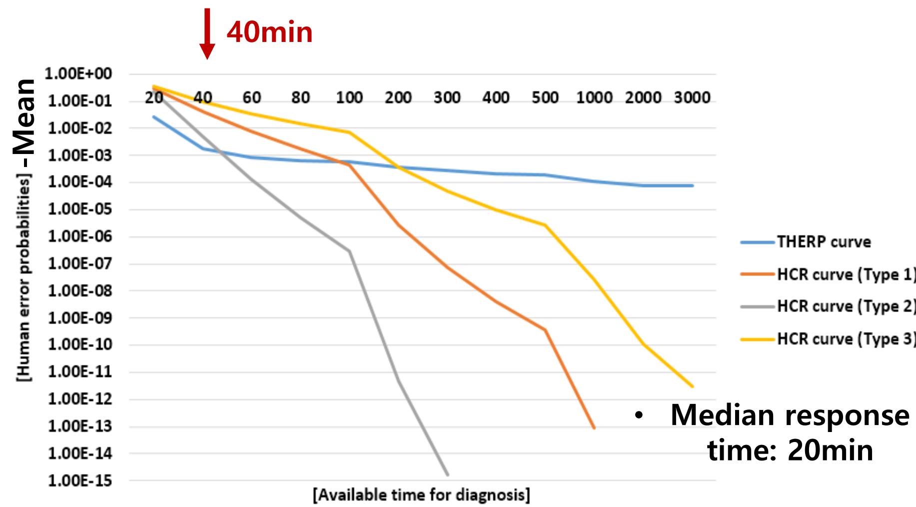
4.1 Comparison of diagnosis HEPs

▶ Finding #2

- When available time for diagnosis is over 40min, diagnosis HEPs by HCR curve decrease more steeply than THERP curve.







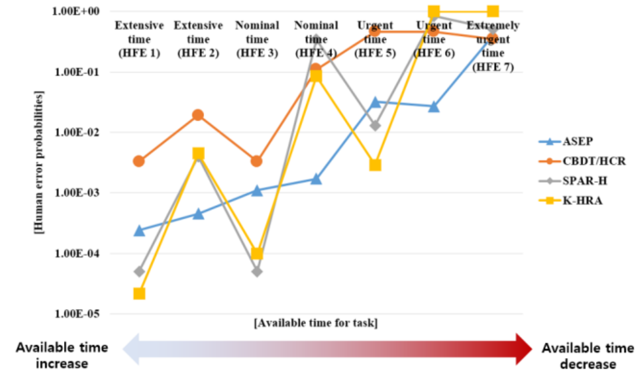
Available time for diagnosis decrease — Available time for diagnosis increase

Available time for diagnosis decrease — Available time for diagnosis increase

4.1 Comparison of diagnosis HEPs

▶ Finding #3

- **Diagnosis HEPs of K-HRA, SPAR-H and CBDT are sensitive to the PSF condition, while ASEP and HCR are not sensitive to it.**



- Not-sensitive HRA methods to PSF condition
  - ASEP and HCR

Time condition	PSF condition	HFE No.	ASEP	HCR
Extensive time (>60)	Favorable	HFE 1	2.40E-04	2.00E-07
	Unfavorable	HFE 2	4.50E-04	1.30E-06
Nominal time (>30 and <=60)	Favorable	HFE 3	1.10E-03	2.40E-03
	Unfavorable	HFE 4	1.70E-03	1.10E-01
Urgent time (>10 and <=30)	Favorable	HFE 5	3.20E-02	4.60E-01
	Unfavorable	HFE 6	2.70E-02	4.60E-01
Extremely urgent time (<=10)	Unfavorable	HFE 7	4.00E-01	3.50E-01

Diagnosis HEPs Increase ↓

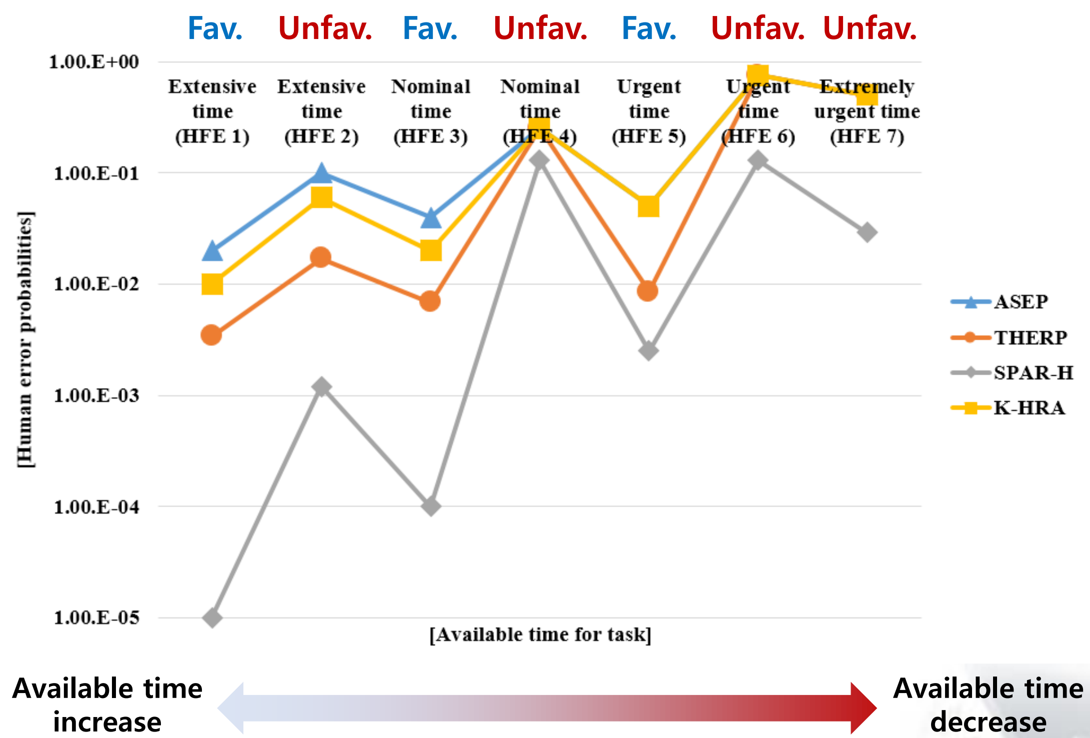
- Sensitive HRA methods to PSF condition
  - CBDT, SPAR-H and K-HRA

Time condition	PSF condition	HFE No.	CBDT	SPAR-H	K-HRA	
Extensive time (>60)	Favorable	HFE 1	3.30E-03	5.00E-05	2.16E-05	HEP ↓
	Unfavorable	HFE 2	1.90E-02	4.00E-03	4.50E-03	HEP ↑
Nominal time (>30 and <=60)	Favorable	HFE 3	3.30E-03	5.00E-05	9.90E-05	HEP ↓
	Unfavorable	HFE 4	5.90E-02	3.40E-01	8.50E-02	HEP ↑
Urgent time (>10 and <=30)	Favorable	HFE 5	3.00E-03	1.30E-02	2.88E-03	HEP ↓
	Unfavorable	HFE 6	5.90E-02	8.30E-01	1.00E+00	HEP ↑
Extremely urgent time (<=10)	Unfavorable	HFE 7	1.90E-02	5.10E-01	1.00E+00	HEP ↑

4.2 Comparison of execution HEPs

▶ Results of HRAs on 7 HFEs

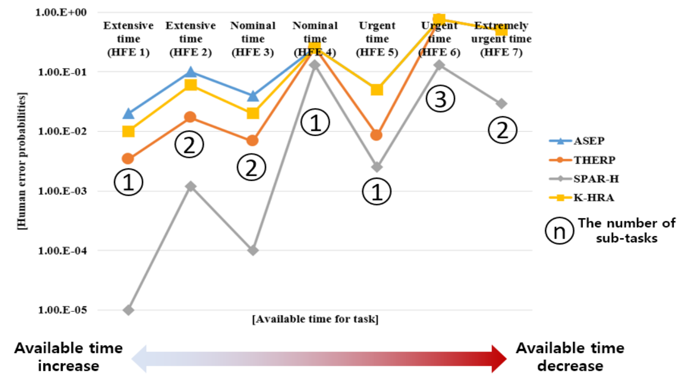
- ASEP > K-HRA > THERP > SPAR-H



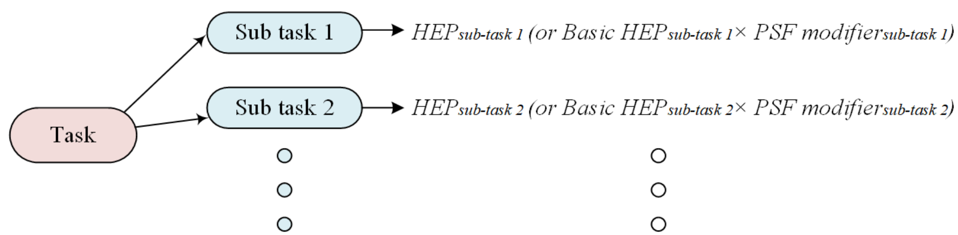
4.2 Comparison of execution HEPs

▶ Finding #4

- **ASEP, THERP and K-HRA have similar pattern of execution HEPs. However, these assume different basic HEPs, PSF levels and values on sub-tasks.**



- Common point
  - Based on THERP method
  - Same approach to estimating execution HEPs (Decomposition approach: Task → sub-tasks)



$$\therefore\ Execution\ HEP = \sum HEP_{sub-task\ i}$$

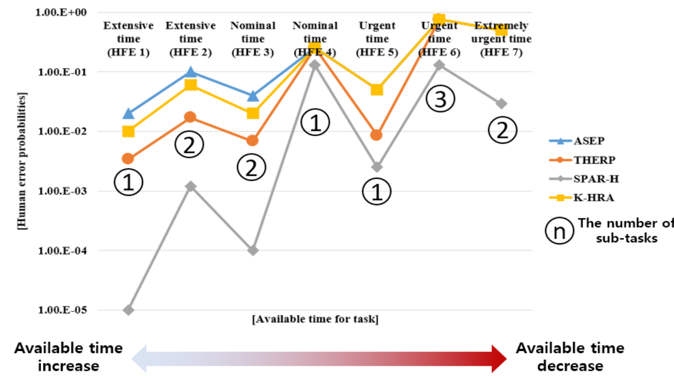
Condition with same PSF levels **Different number of sub-tasks**

HFE No.	Task type	Stress level	The number of sub-tasks	ASEP BHEP	ASEP Adjusted HEP	THERP BHEP	THERP PSF multipliers	THERP Adjusted HEP	K-HRA BHEP	K-HRA Adjusted HEP
HFE 1	Step	Moderately high	1	2.00.E-02	2.00.E-02	1.70E-03	2	3.40.E-03	1.00.E-02	1.00.E-02
HFE 3	Step	Moderately high	2	2.00.E-02	4.00.E-02	1.70E-03	2	6.80.E-03	1.00.E-02	2.00.E-02

4.2 Comparison of execution HEPs

▶ Finding #4

- **ASEP, THERP and K-HRA have similar pattern of execution HEPs. However, these assume different basic HEPs, PSF levels and values on sub-tasks.**



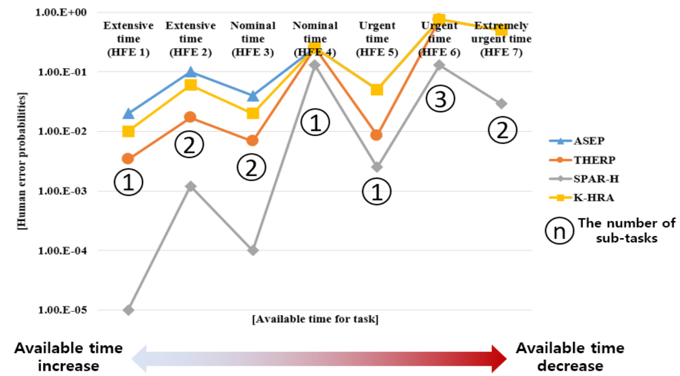
- Different point
  - Each method assumes different basic HEPs, PSF levels and their values on sub-tasks.

Time condition	PSF condition	HFE No.	Task type	Stress level	The number of sub-tasks	ASEP	THERP			K-HRA
							BHEP	PSF multipliers	Final execution HEPs	
Extensive time (>60)	Favorable	HFE 1	Step	Moderately high	1	2.00.E-02	1.70E-03	2	3.40.E-03	1.00.E-02
	Unfavorable	HFE 2	Dynamic	Moderately high	2	1.00.E-01	1.70E-03	5	1.70.E-02	6.00.E-02
Nominal time (>30 and <=60)	Favorable	HFE 3	Step	Moderately high	2	4.00.E-02	1.70E-03	2	6.80.E-03	2.00.E-02
	Unfavorable	HFE 4	Dynamic	Extremely high	1	2.50.E-01	2.60E-03	-	2.50.E-01	2.50.E-01
Urgent time (>10 and <=30)	Favorable	HFE 5	Step	Extremely high	1	5.00.E-02	1.70E-03	5	8.50.E-03	5.00.E-02
	Unfavorable	HFE 6	Dynamic	Extremely	3	7.50.E-01	1.70E-03		7.50.E-01	7.50.E-01

4.2 Comparison of execution HEPs

▶ Finding #5

- **SPAR-H has a tendency to estimate relatively lower execution HEPs than ASEP, THERP and K-HRA.**
  - SPAR-H assumes lower basic HEPs (i.e., 1.0e-3) than the other HRA methods.
  - Available time for execution is not dominant to estimating execution HEPs by ASEP, THERP and K-HRA, while SPAR-H considers available time for execution as a PSF.
  - SPAR-H does not classify the task into sub-tasks like ASEP, THERP and K-HRA.

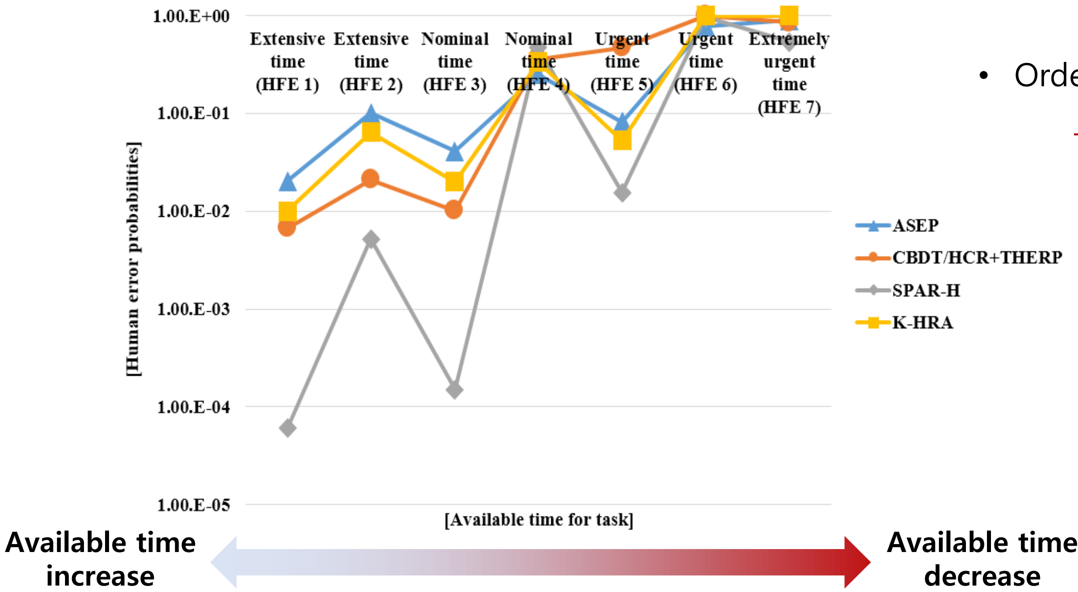


Basic HEPs (ASEP) **Basic HEPs (THERP)** **Basic HEPs (SPAR-H)** **Available time PSF** **Basic HEPs (K-HRA)**

HFE No.	Task type	Stress level	ASEP		THERP		SPAR-H											K-HRA	
								PSFs											
			BHEP	Adjusted HEP	BHEP	Adjusted HEP	BHEP	Available time	Stress/ stressors	Experience /training	Complexity	Ergonomics /HSI	Procedures	Fitness for duty	Work processes	PSF influences	Adjusted HEP	BHEP	Adjusted HEP
HFE 1	Step	Moderately high	2.00.E-02	2.00.E-02	1.70E-03	3.40.E-03	1.00.E-03	Time available is >= 50x the time (0.01)	High (2)	High (0.5)	Nominal (1)	Nominal (1)	High (1)	Nominal (1)	Nominal (1)	0.010	1.00E-05	1.00.E-02	1.00.E-02
HFE 2	Dynamic	Moderately high	5.00.E-02	1.00.E-01	1.70E-03	1.70.E-02	1.00.E-03	Time available >= 5x the time (0.1)	High (2)	Low (3)	High (2)	Nominal (1)	Nominal (1)	Nominal (1)	Nominal (1)	1.200	1.20E-03	3.00.E-02	6.00.E-02
HFE 3	Step	Moderately high	2.00.E-02	4.00.E-02	1.70E-03	6.80.E-03	1.00.E-03	Time available >= 5x the time (0.1)	High (2)	High (0.5)	Nominal (1)	Nominal (1)	High (1)	Nominal (1)	Nominal (1)	0.100	1.00E-04	1.00.E-02	2.00.E-02

4.3 Comparison of final HEPs

▶ Results of HRAs on 7 HFEs



- Order of differences between the min. and max. final HEPs
  - SPAR-H > CBDT/HCR+THERP > K-HRA > ASEP

	Minimum Final HEP	Maximum Final HEP
ASEP	2.2e-2	9.0e-1
CBDT/HCR +THERP	6.7e-3	1.0e+1
SPAR-H	6.0e-5	9.6e-1
K-HRA	1.0e-2	1.0e+1

▶ Finding #6

- **Final HEPs of SPAR-H show the biggest difference between the final HEPs of minimum and maximum, while those of ASEP have the least one.**

5. Conclusion

5. Conclusion

HERA Lab. Human Engineeing & Risk Analysis

Summary

- **A comparison of human reliability analysis methods for post-initiators**
  - Comparing the HEPs of HRA methods based on events in NPPs (Post-initiators)
  - Understanding how the quantification approaches are different depending on HRA methods
- **Contents**

Selection of 4 HRA methods → Performance of HRA on 7 HFEs → A comparison of HEPs on four HRA methods → "6 Findings"

- Selection of 4 HRA methods
  - ASEP
  - CBDT/HCR+THERP
  - SPAR-H
  - K-HRA
- Performance of HRA on 7 HFEs
  - 7 HFEs stand for main post-initiators in OPR1000 type of NPPs.
- A comparison of HEPs on four HRA methods
  - Diagnosis HEPs
  - Execution HEPs
  - Final HEPs

Conclusion

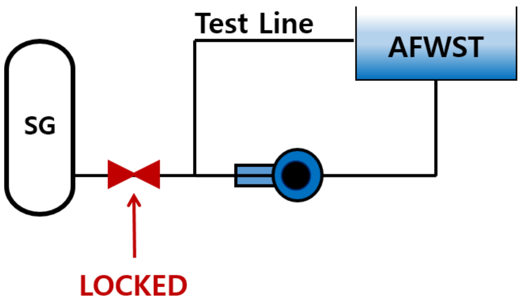
- The result of this study could be used as reference data to compare the human error probabilities from four HRA methods.
- It could also aid to understand why the human error probabilities estimated from four HRA methods are different and what makes them different.
- It is expected to contribute to overcoming the uncertainties and limitations of HRA by deriving acceptable values for the HRA results and select the proper method based on its intended use of application.

Thank you !

2.1 Human Reliability Analysis (HRA)

▶ Types of Human failure events (HFEs)

- **Pre-initiators**
  - Contributors to unavailability of systems (latent error)
  - Mis-calibration and failure to restore after test and maintenance
  - Ex) valve in wrong configuration after test or maintenance in TMI accident



- **Human-induced initiators**
  - Actions leading to initiating event
  - Not typically found in PSA model, but implied in the initiating event frequency

- **Post-initiators**
  - Actions in response to disturbance by plant staff after an initiating event
  - Ex) Performing procedure, opening valves, and operating pumps by operators in MCR, etc.

2.2 ASEP

▶ What is ASEP ?

- **Accident Sequence Evaluation Program (ASEP)**
  - Developed by U.S. NRC (NUREG/CR-4772)
  - Simplification of Technique for human error-rate prediction (THERP)
  - Guidance for quantification of pre- and post- initiating events
  - Made to enable analysts at reasonable cost, with minimum support and guidance from experts in HRA

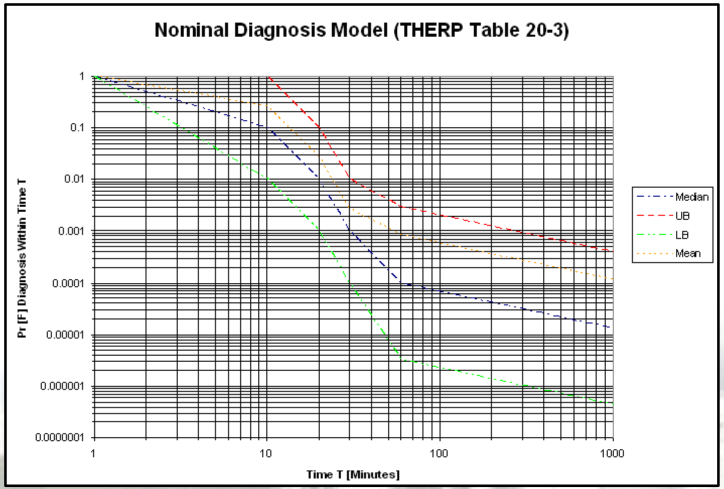
- **Technique for Human Error Rate Prediction (THERP)**
  - Developed by U.S. NRC (NUREG-1278)
  - Applied in WASH1400 which is the first PSA report
  - Probably used more than any other HRA technique because it offers a lot of data
  - identifies, models, and quantifies human failure events (HFEs) in a PSA
  - Does not provide enough guidance for how to handle a wider set of PSFs
  - Needs for HRA expertise with resource intensive and time consuming

2.2 ASEP

▶ Diagnosis HEPs

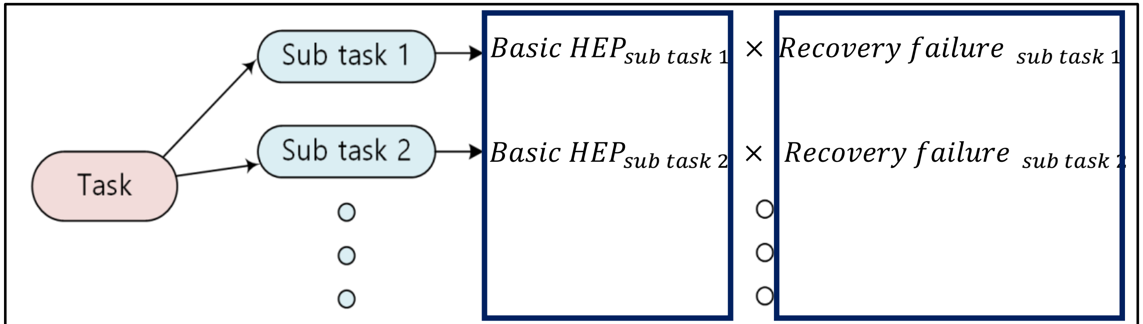
- Diagnosis HEP is estimated by operator's available time for diagnosis.
  - Operator's available time for diagnosis = T(sw)-T(m)-T(d)
    - ➢ $T(sw)$: total system time window associated with disturbance
    - ➢ $T(\mathrm{m})$: manipulation (execution) time
    - ➢ $T(1/2)$: median response (diagnosis) time / ANSI/ANS-58.8-1994 ("Time response design criteria for safety-related operator actions")
    - ➢ $T(\mathrm{d})$: delay time

  ※ Time window: time available to complete the action before plant condition become unacceptable
- Time Reliability Correlation (TRC);



2.2 ASEP

▶ Execution HEPs



$$\therefore \text{Execution HEP} = \sum(\text{Basic } HEP_{sub\ task\ i} \times \text{Recovery failure}_{\ sub\ task\ i})$$

No.	Task type	Stress level	Basic HEPs
1	Step-by-Step	Moderately high	0.02
2	Dynamic	Moderately high	0.05
3	Step-by-Step	Extremely high	0.05
4	Dynamic	Extremely high	0.25

<An example of basic HEP in ASEP>

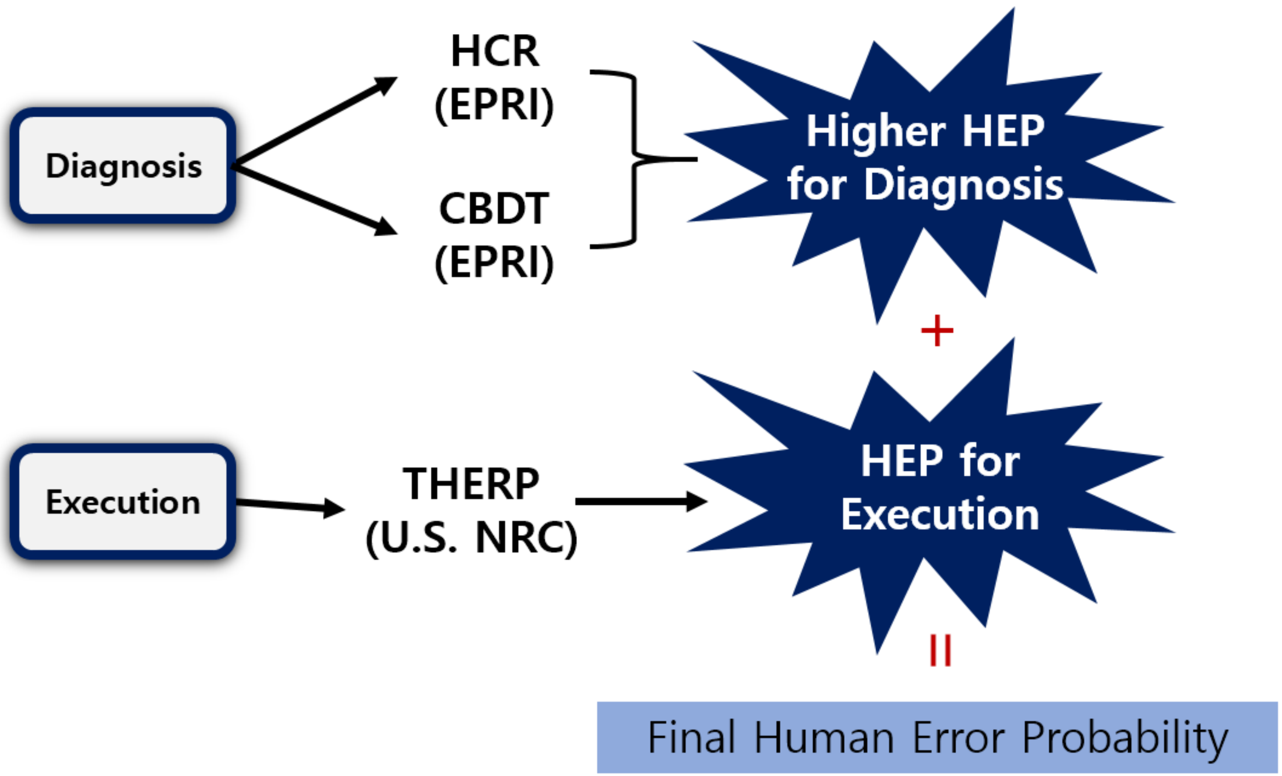
No.	Task type	Stress level	Recovery failure prob.
1	Step-by-Step	Moderately high	0.2
2	Dynamic	Moderately high	0.5
3	Step-by-Step	Extremely high	0.5
4	Dynamic	Extremely high	0.5

<Recovery failure probabilities on stress and task type>

2.3 CBDT/HCR+THERP

▶ What is CBDT/HCR+THERP ?

- **EPRI methods**
  - HCR (Human Cognitive Reliability) and CBDT (Cause-Based Decision Tree) developed by EPRI (EPRI TR-100259) with THERP method

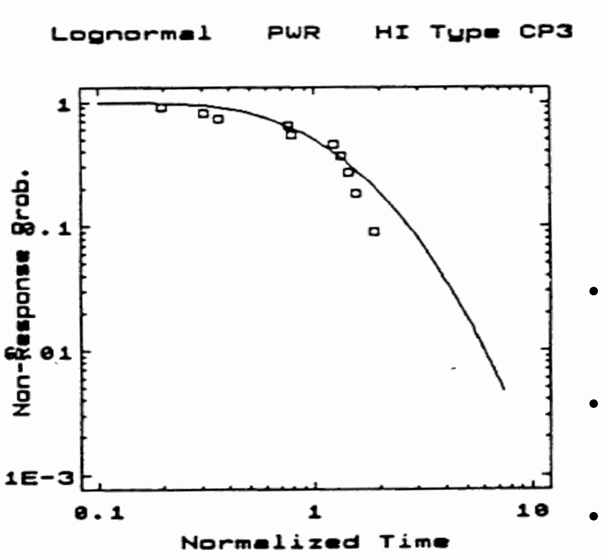


2.3 CBDT/HCR+THERP

▶ Diagnosis HEPs

- **HCR (Human Cognitive Reliability)**
  - Estimating non-response probability for post-initiating events
  - Simulator data from Operator Reliability Experiments (ORE) project by EPRI
    - ➢ ORE project aims to collect and analyze data on operating crew responses from full-scale nuclear power plant control room simulators.
- If operator's available time is long, accuracy and estimated probabilities are become lowered.
- An example of time Response Curve (TRC);

$$p_c = Prob\ (T_r > T) = 1 - \Phi\left[\frac{ln\,(T/T_{1/2})}{\sigma}\right]$$



- T_r : the time of response
- T : available time window for cognitive response
- $T_{1/2}$: the median response time
- σ : logarithmic standard deviation of normalized time

- 유형 1: 알람이나 감시중인 변수 값의 변화와 같은 Cue를 운전원이 인지하고 즉각적으로 반응하는 형태 (예, 밸브가 열리는 것과 같은 변화에 대한 운전원의 반응)
- 유형 2: Cue를 인지하였으나 해당 직무가 특정 값에 도달해야 운전원이 직무를 수행할 수 있는 형태 (예, 온도나 압력이 어느 값을 초과하였을 때에 대한 운전원의 반응)
- 유형 3: Cue를 인지하였으나 해당 직무가 Critical value에 도달하기 전에 직무를 수행해야 하는 형태 (온도나 압력이 어떤 값에 도달하기 전에 취해야 하는 운전원의 반응)

2.3 CBDT/HCR+THERP

▶ Diagnosis HEPs

- **CBDT (Cause-Based Decision Tree)**
  - Estimates diagnosis HEPs
  - Originally developed by EPRI to address 1) when HCR/ORE produces very low probability values and 2) extrapolation of HCR/ORE TRC could be extremely optimistic

Failure Mode 1: Failures of the Plant Information-Operator Interface

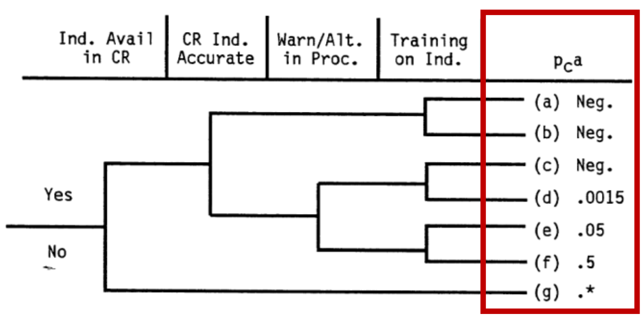
Four mechanisms are identified for this failure mode:

$p_c a$. The required data are physically not available to the control room operators.

$p_c b$. The data are available, but are not attended to.

$p_c c$. The data are available, but are misread or miscommunicated.

$p_c d$. The available information is misleading.



<An example of decision tree>

Failure Mode 2: Failure in the Procedure-Crew Interface

Given that the existence of a possible cue state has been recognized, four ways have been identified in which the crew may fail to reach the correct interpretation (for Type CP HIs, "correct interpretation" means execute an action or proceed to the next appropriate instruction as contingent on the cue state):

$p_c e$. The relevant step in the procedure is skipped.

$p_c f$. An error is made in interpreting the instructions.

$p_c g$. An error is made in interpreting the diagnostic logic (this is a subset of $p_c f$, but is treated separately for convenience).

$p_c h$. The crew decides to deliberately violate the procedure.

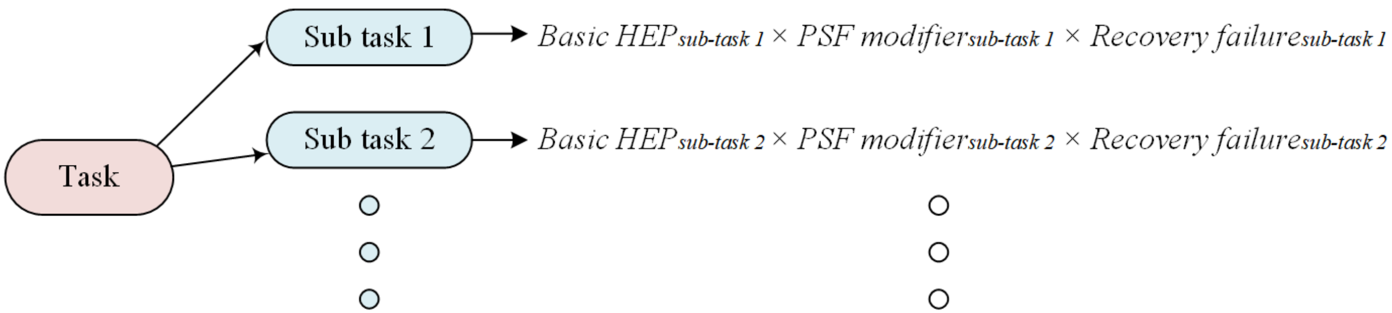
- **Recovery failure probability (Positive recovery effect)**
  - Self review: 1.0e-1
  - Extra crew: 5.0e-1 or 1.0e-1
  - STA review: 1.0e-1
  - Shift change: 5.0e-1 or 1.0e-1

$$Diagnosis\ HEP = \sum Error\ probability\ of\ each\ error\ mechanism \times Recovery\ failure\ probability$$

2.3 CBDT/HCR+THERP

▶ Execution HEPs

- **Technique for human error-rate prediction (THERP)**



$$\therefore Execution\ HEP = \sum (Basic\ HEP_{sub-task\ i} \times PSF\ modifier_{sub-task\ i} \times Recovery\ failure_{sub-task\ i})$$

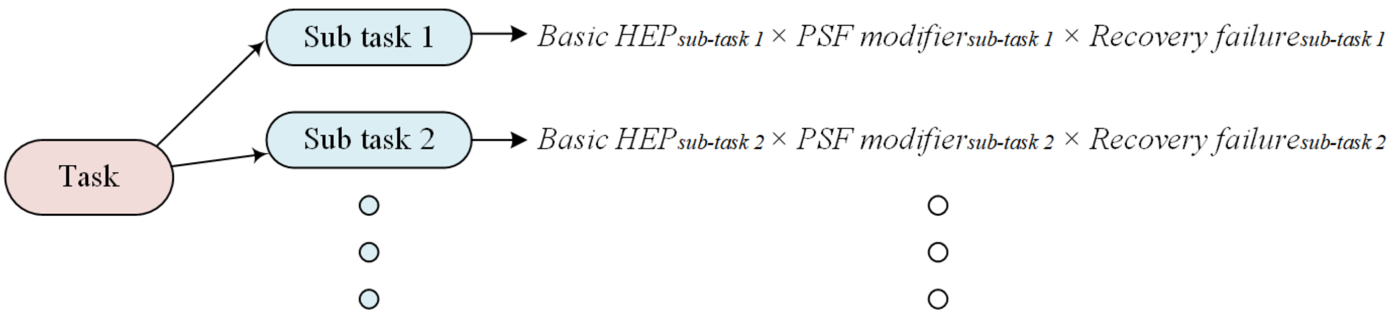
Location	Basic HEP	Description	References
MCR	1.7E-3	Omission per item of instruction when using a step-by-step procedure.	Table 20-7 Item ref. # 1
		Select wrong control on a panel from an array of similar-appearing controls which are part of a well-defined mimic layout.	Table 20-12 Item ref. # 4
LOCAL	2.6E-3	Estimated probabilities of errors in recalling oral instruction items not written down – Oral instructions are detailed.	Table 20-8a Item ref. # 1
		Locally operated valves.	Table 20-13 Item ref. # 1

<An example of basic HEP from THERP data>

2.3 CBDT/HCR+THERP

▶ Execution HEPs

- **Technique for human error-rate prediction (THERP)**



$$\therefore Execution\ HEP = \sum (Basic\ HEP_{sub-task\ i} \times PSF\ modifier_{sub-task\ i} \times Recovery\ failure_{sub-task\ i})$$

No.	Task type	Stress level	Multipliers for basic HEPs	
			Skilled	Novice
1	-	Very low	X 2	X 2
2	Step-by-step	Optimum	X 1	X 1
3	Dynamic	Optimum	X 1	X 2
4	Step-by-step	Moderately high	X 2	X 4
5	Dynamic	Moderately high	X 5	X 10
6	Step-by-step	Extremely high	X 5	X 10
7	Dynamic	Extremely high	0.25 (Not multiplier, but actual HEP)	0.50 (Not multiplier, but actual HEP)

<Modifiers for BHEP on stress, experience, and task type>

- **Recovery failure probability → <u>dependencies between sub-tasks</u> (Positive recovery effect)**
  - Zero dependence (ZD): $Recovery\,failure = P_o$
  - Low dependence (LD): $Recovery\,failure = (1+19^{*}P_o)/20$
  - Moderate dependence (MD): $Recovery\,failure = (1+6^{*}P_o)/7$
  - High dependence (HD): $Recovery\,failure = (1+P_o)/2$
  - Complete dependence (CD): $Recovery\,failure = 1.0$

※ $P_o = Basic\ HEP_{sub-task\ i} \times PSF\ modifier_{sub-task\ i}$

2.4 SPAR-H

▶ What is SPAR-H ?

- Standard Plant Analysis Risk HRA (SPAR-H) is developed by U.S. NRC (NUREG/CR-6883)
- In addressing uncertainty, error factors were not used, and the use of a lognormal distribution was not assumed (SPAR-H employs a beta distribution, which can mimic lognormal distribution.).

▶ Diagnosis and execution HEPs

- Calculation methods of diagnosis and execution HEPs are same.
- It assumes basic HEP, and adjusts it by PSFs
  - Basic HEP: 1.0E-2 (Diagnosis BHEP) / 1.0E-3 (Execution BHEP)
  - 8 SPAR-H PSFs : Available time, Stress and stressors, Experience and training, Complexity, Ergonomics, Procedures, Fitness for duty, Work processes

$$HEP = BHEP \cdot \prod_{1}^{8} PSF\ multiplier_i$$

$$HEP = \frac{BHEP \cdot \prod_1^8 PSF\ multiplier_i}{BHEP \cdot \prod_1^8 (PSF\ multiplier_i - 1) + 1}$$

SPAR-H PSFs	SPAR-H PSF Levels	SPAR-H Multipliers
Available Time	Inadequate Time	*P(failure) = 1.0*
	Time available = time required	10
	Nominal time	1
	Time available ≥ 5 x time required	.1
	Time available > 50 x time required	0.01
Stress/ Stressors	Extreme	5
	High	2
	Nominal	1
Complexity	Highly complex	5
	Moderately complex	2
	Nominal	1

<An example of SPAR-H PSFs>

2.5 K-HRA

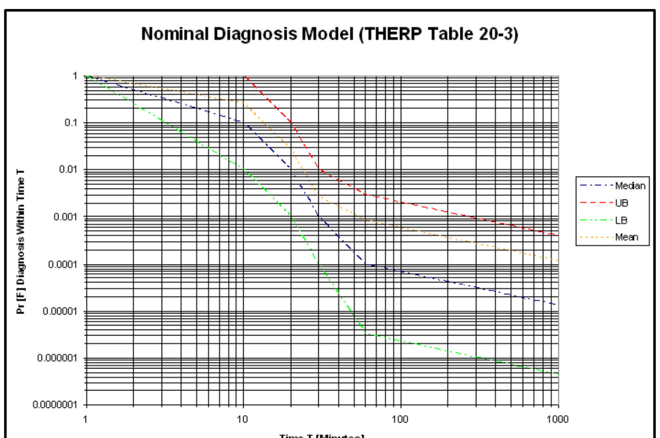
What is K-HRA ?

- Korean standard HRA (K-HRA) is developed by KAERI (KAERI/TR-2961/2005)
- Based on THERP and ASEP method
- Focusing on standardizing and specifying the analysis process, quantification rules and criteria to minimize the deviation of the analysis results caused by different analysts

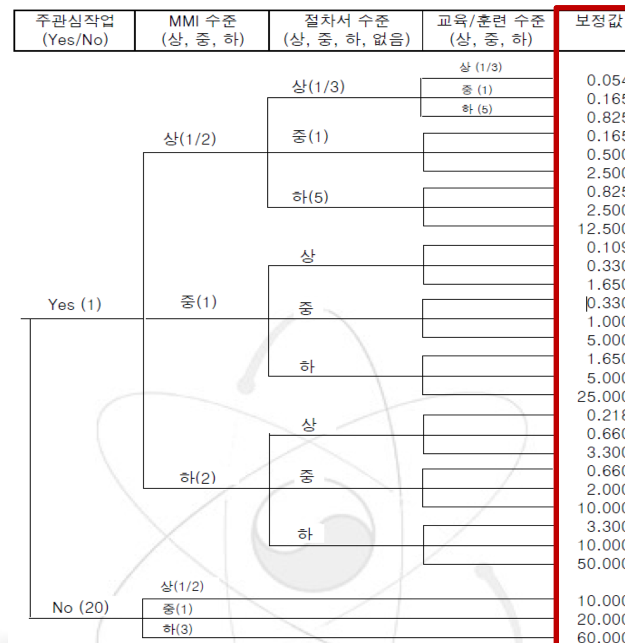
Diagnosis HEPs

- Diagnosis HEP = Diagnosis BHEP X adjustment of PSFs

THERP curve



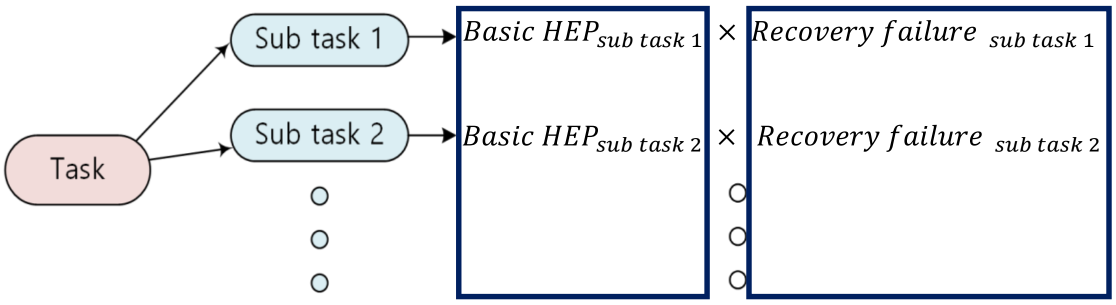
PSFs: Primary attention task, MMI (or HSI), Procedure level, Training/experience, burden for decision



<Adjustment multipliers of PSFs>

2.5 K-HRA

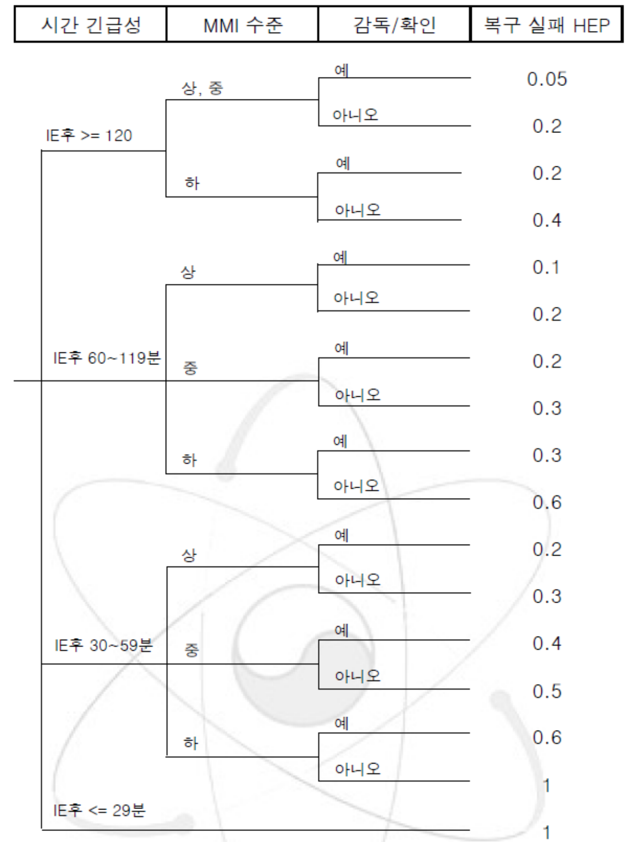
▶ Execution HEPs



$$\therefore\ Execution\ HEP = \sum(Basic\ HEP_{sub\ task\ i} \times Recovery\ failure_{\ sub\ task\ i})$$

작업성격	스트레스 수준	기본 오류 확률(mean)	오차인자	THERP 단위 직무 HEP 분포 (median)
Simple Response	Low	0.002	3	
	Optimum / Moderately High	0.001	3	
	Very high / Extremely High	0.003	3	
Step-by-Step	Low	0.01	3	0.001 ~ 0.01
	Optimum	0.005	3	0.0005 ~ 0.005
	Moderately High	0.01	3	0.001 ~ 0.01
	Very high	0.02	3	
	Extremely High	0.05	5	0.0025 ~ 0.025
Dynamic	Low	-	5	0.001 ~ 0.01
	Optimum	0.01	5	0.0005 ~ 0.005
	Moderately High	0.03	5	0.0025 ~ 0.025
	Very high	0.08	5	
	Extremely High	0.25	3	0.25

<Basic HEPs on task type and stress level>



<Decision tree for determining recovery failure prob.>

Nominal Diagnosis Model

Use Upper Bound if:

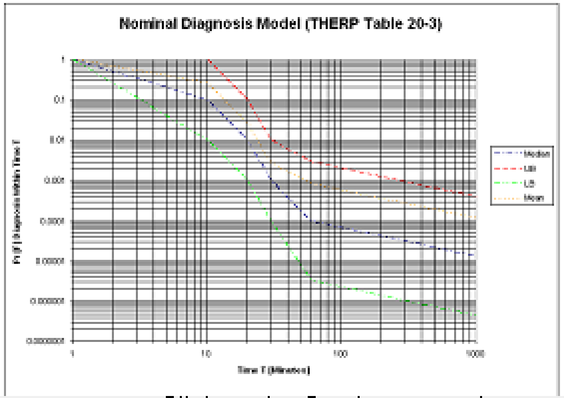
(a) the event is not covered in training. OR (b) the event is covered but not practiced except in initial training of operators for becoming licensed. OR (c) the talk-through and interviews show that not all operators know the pattern of stimuli associated with the event.

Use Lower Bound

(a) the event is a well-recognized classic (e.g., TMI-2 incident), and the operators have practiced the event in the simulator requalification exercises. AND (b) the talk-through and interviews indicate that all the operators have a good verbal recognition of the relevant stimulus patterns and know what to do or which written procedures to follow.

Use Nominal HEP

(a) the only practice of the event is in simulator requalification exercises and all operators have had this experience. OR (b) None of the rules for use of upper or lower bound apply.



Click on the Graph to zoom in

Time	EF	Median ...	Mean	UB	LB
1	10	1	1.0	1	1
10	10	0.1	0.3	1	0.01
20	10	0.01	0.03	0.1	0.001
30	10	0.001	0.003	0.01	0.0001
60	30	0.0001	0.0008	0.003	3.33E-06
1500	30	0.00001	0.00008	0.0003	3.33E-07
Actual Time	Calculated Val...				
19.00	10	1.2e-02	3.2e-02	1.2e-01	1.2e-03

Notes/Assumptions

HEP: 3.2e-02