Developing an HRA guide for Japanese utilities combining the NRC narrative approach with the EPRI HRA Calculator

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The Nuclear Risk Research Center (NRRC) started developing an HRA implementation guide adapting the concept of "Narrative" for qualitative analysis by IDHEAS[1] (the Integrated Decision-Tree Human Event Analysis System, NRC, draft report, 2013), and using the HRA Calculator[2] for quantitative analysis. The aim is to improve human reliability analysis (HRA) of Japanese nuclear power plants. A "Narrative" provides a detailed explanation of the actual situation in the field to develop an understanding on the basis of time sequence, psychological impact elements such as the environment and events in accordance with the situation of the scenario. Therefore, it is the process necessary to support HRA implementation regardless of the type of HRA quantification method to be used. The NRRC examined the implementation applicability of the guide by studying accident scenarios including Bleed & Feed operation for a plant. Applicability of this HRA process was examined on internal events PRA. Possibility of complicated scenarios is discussed from the instructor interviews, some of the through narrative has been developed. In addition, HEP has been quantified using HRA Calculator. Result of Narrative has been reflected in the input value (Time analysis, PSF, etc.).

I. INTRODUCTION

In Japan, the estimation method of human error probability (HEP) has been THERP[3] (the Technique for Human Error Rate Prediction, NUREG / CR-1278). But, understanding of the context that leads to failure in the process of the task is important in the evaluation of cognitive and diagnostic failure. CBDTM[4] (the Cause-Based Decision Tree Method) is one of methods of representing context which leads to errors in the human tasks using decision trees, and it was included in the EPRI HRA Calculator. Furthermore, recently in the United States, the Integrated Decision-Tree Human Event Analysis System (IDHEAS), which brings together aspects of previous multiple HRA approaches, is under development jointly by the NRC and EPRI. IDHEAS is a method that stresses context and task analysis and uses combinations of multiple decision trees in which operation teams (crews) end up making errors. Currently, efforts are being made to improve task analyses and qualitative analyses of implementation processes.

According to the results of recent HRA studies, the importance of "Narrative" is emphasized. A "Narrative" provides detailed explanation of the actual situation in the field to develop an understanding on the basis of time sequence, psychological impact elements such as including of environment and events in accordance with the situation of the scenario. Therefore, it is the process necessary to support HRA implementation regardless of the type of HRA quantification method to be used.

The Nuclear Risk Research Center (NRRC) started to develop an HRA implementation guide adapting the concept of "Narrative" approach for the qualitative analysis by IDHEAS, and using the HRA Calculator to quantitative analysis, for improving human reliability analysis (HRA) of Japanese nuclear power plants.

NRRC examined the implementation applicability of the guide by studying accident scenarios including Bleed & Feed operation for a plant. Applicability of this HRA process was examined on internal events PRA. Possibility of complicated scenarios are discussed from the instructor interviews, some of the through narrative has been developed. In addition, HEP has been quantified. Result of Narrative has been reflected in the input value (Time analysis, PSF, etc.).

II. 'Context' and 'Narrative' for Qualitative Analysis in HRA

The definition of context is specialized in its application to HRA. It is the general situation or the interrelated conditions in which something happens. In HRA, context refers to the combination of plant conditions, along with resident or triggered human factors concerns, under which an HFE occurs. Recent work in the behavioral sciences has contributed to the understanding of the interactive nature of human errors and plant behavior that characterize accidents in high-technology industries. This understanding suggests that it is essential to analyze both the human-centered factors (such as human-machine interface design, the content and format of plant procedures, and training) and the conditions of the plant that call for actions and create the operational causes for human-system interactions (e.g., misleading indicators, equipment unavailability, and other unusual configurations or operational circumstances).

The narrative is the concept of qualitative analysis and documentation method for HRA. It is a description and background information of the context leading to the accident / human error, which was based on the fact of physical analysis, operator interview results and plant information. It is to be the basis of the input data for the quantification method. These narratives tell a thorough story of the evolution of the scenario, physically, from the perspective of the information and control systems available, i.e., what the operators know and do not know about the sequences of events involved.

This information from the plant instruments provides the primary cues that trigger operator responses. The narrative examines how well the procedures support the situation, and how well the operators experience and training fit the situation. The narrative gives a detailed description and understanding of human performance based on the reality in the field, including elements such as those having a psychological impact and a time sequence of events and environment in keeping with the scenario conditions.

Because these concepts of HRA were not familiar to Japanese utilities, there was a need to share the understanding by the HRA workshops.

III. Overview of NRRC HRA guideline with narrative development

All HRA methods require a qualitative analysis prior to quantification. In the SHARP1[5] process, (EPRI 1992) this analysis is embedded in the identification and definition step, in ATHEANA[6], (USNRC 2000) it is considered explicitly, and in the embedded process for the IDHEAS qualitative analysis process.

Unfortunately, for many other HRA methods, it falls upon the experience and skill of the analyst.

A primary finding of the International Empirical Studies (Broberg[7] (2008), Dang[8] (2008), Forester[9] (2008)) was that guidance is needed for performing qualitative HRA in most methods, including how to identify operational conditions that could influence performance and how to discuss these issues with operators and trainers to obtain important information.

The reports stressed the importance of 'narratives' that help analysts understand the situations in which crews must act.

They also identified the need to recognize the significance of crew-to-crew variability.

The NRRC contribution is to guide the systematic method of qualitative analysis, and the use of the narrative to input information into the EPRI HRA Calculator.

III.A. HRA Team Organization

The HRA should involve a multi-disciplinary team that interacts with the rest of the PRA team in addressing each accident scenario at each stage of the analysis. The HRA should be an integral part of the PRA (not performed as an isolated task in the PRA process) whereby the inputs from the following disciplines are used together to define the PRA structure, including which human events need to be modeled, how they are defined and modeled in the PRA, and the considerations used to quantify the associated HEPs.

It is recommended to organize the HRA team as follows.

A) Operation training instructors (or operators), B) PRA Specialist – (accident sequence modeler) , C) HRA practitioners (i.e., someone trained or experienced in HRA), D) Thermal-hydraulics analysts, E) Human performance specialist (or industrial psychologist), F) Other disciplines experts as necessary (e.g., structural engineers if the timing of an action is dependent on when and how the containment might fail)

A facilitator/integrator who can also represent one of the disciplines A-F is needed to ensure that information for the disciplines is used appropriately. Appendix Y explains the role of the facilitator/integrator.

III.B. Structure of HRA guideline

The implementation steps in the HRA guideline shown in Fig.1.

- Step 1. Define a base/reference case scenario for each PRA scenario (including the collection of information)

- Step 2 . Perform a preliminary review that is based on information from an existing PRA by the PRA analyst. (Preliminary consideration of Crew Response Tree (CRT); identification of key tasks and subtasks)
- Step 3 . HRA team discussions (Including Operator Interviews) for narrative: Prepare for interviews (Customized questions list for the analysis of HFE, etc.), and interview with operation training instructors (or operators) for considering the HFE for base case scenario or complicating factors / scenario deviations.
- Step 4 . Analyze the results as input data for Failure Mechanisms of HRA Calculator. (Default Crew Composition, Time analysis, Cognitive Unrecovered, Cognitive Recovered, Execution PSFs , Stress Factors)
- Step 5 . Narrative Documentation (include results of interview questions list, Plant information, etc.,)
- Step 6. Quantify HEP in Base Case (by HRA Calculator)
- Step 7 . Consider possibility of deviation scenarios and/or new HFEs from the results of Steps 4 and 5.

(If necessary: Narrative development for deviation scenarios, Feedback the results to PRA Models)

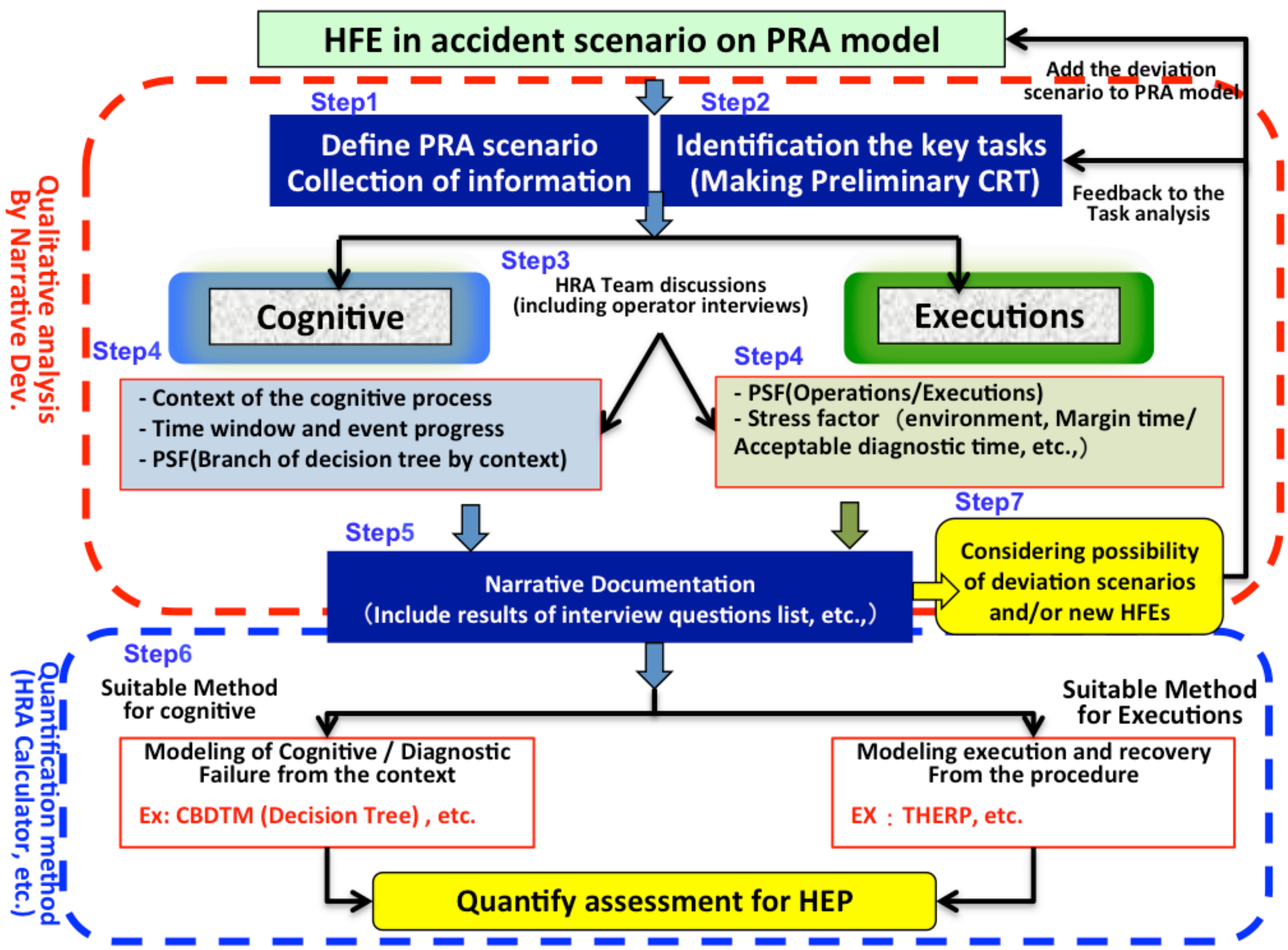

Fig. 1. Overview of the NRRC HRA Implementation Guide

III.C. Development of the HFE Narrative

An HFE is defined in the ASME/ANS PRA Standard[10] (ASME 2009) as a PRA logic model element that represents a failure or unavailability of a component, system, or function that is caused by human inaction, or an inappropriate action. Our focus is on HFEs that represent a failure of the operating crew to respond correctly to a plant upset condition, such as an initiating event, or the failure of an operating train of a support system.

The narrative is an operational story that documents a task analysis of the overall response to identify opportunities for the plant operators to make choices or errors. Those opportunities and their associated contexts are input to the quantification of the HEPs. Each of these opportunities requires an identification and definition of the key tasks in the performance of the response. In the following, a key task is identified with the significant transition points in the response, such as entering a procedure, transitioning to another procedure, deciding to begin implementation, and execution. Success in performing a key task may require the successful performance of one or more specific activities such as collecting data, and comparing data to a decision criterion; these are referred to as key sub-tasks. These subtasks represent both cognitive and execution activities. Failure to perform any of the key subtasks leads to failure of the key task and, therefore, results in the HFE.

There may be opportunities for the operating crew to recover from a failure of a key task within the time window for success, thereby avoiding the failure of the required mission, the narrative also identifies opportunities for such recoveries.

III.C.1. Step1. Define a base/reference case scenario for each PRA scenario (including the collection of information)

The base case scenario is defined and characterized for PRA scenario involving identified HFEs. Many HFEs are already identified in the PRA. The base case scenario represents the most realistic description of expected plant and operator behavior for the selected issue and initiator provides a basis from which to identify and define deviations from such expectations (which will be performed in III.E).

The goal in the reviews of procedures, historical data, and interviews is to identify ways in which crews are intended to interact with the plant equipment after an initiating event. The primary source of information in determining HFEs involving response failure will be a review of all relevant plant procedures and guidelines. An additional source of information comes from actual experience in responding to operational disruptions, plant trips, etc. Walkdowns of the plant and talk-throughs of the procedures with plant operators or observations of simulator exercise may also provide useful information and help analysts with understanding the procedures and how they are implemented by the crews. For the identified HFEs, the response failures should be defined to represent the impact of the human failures at the function, system, train, or component level as appropriate. Collect such as the following information from PRA and engineering analysis,:

- Accident sequences, the initiating event, and system and operator action successes and failure subsequent to the initiating event and preceding the HFE
- Accident sequence-specific procedural guidance
- Accident sequence-specific timing of cues and the time available for successful completion
- The time available for action
- The high-level tasks required to achieve the goal of the response
- The cues and other indications for detection and evaluation of errors

III.C.2. Step2. Preliminary consideration of Crew Response Tree (CRT); identification of key tasks and subtasks

The purpose of this step of the narrative development is to identify the specific subtasks or activities in the interaction of the operators with the plant, where, if an error is made, the response cannot be successful or cases where failure of a subtask makes the response much less likely to succeed. For each subtask, what is required to be successful is defined.

The concept of a Crew Response Tree (CRT) has been developed for the purpose of communication, illustration, and documentation of the task analysis in IDHEAS by NRC. The opportunities for both errors and for recovery are represented as nodes on the CRT. This description takes into account the timing of the relevant cues and other plant status parameters. The CRT can be organized as a series of nodes along the top line (e.g., see Fig. 2). Each node represents the achievement of a key task within the base case. Each node can also be a branch representing a potential failure opportunity of the overall response. In parallel, as an essential part of developing the CRT, a time-line is developed that captures: a) the plant status trajectory in terms of the timing of cues and other plant process parameters that are required for the crew to correctly perform the required response or to realize an opportunity for recovery, and b) the time at which operators are expected to reach critical steps in the procedure.

The characterization of each key subtask should address the following issues:

- Identification of the procedurals step(s) involved
- Identification of grey areas in the procedures, where specific timing of the actual events might be different from the base case and unexpected decisions and branches are likely
- The nature of the activity:
  - For cognitive subtasks, this includes the specific cognitive activity, such as detection of a cue, reading a control panel, interpreting a piece of information that has been actively obtained, comparing a plant parameter to some criterion specified in a procedure, choosing a response path
  - For execution, the specific manipulations that need to be performed, and their ordering if important
- The basic requirements for the subtask such as: continuous monitoring of cues, use of secondary cues when the primary cues are not available, responding to key alarms, or implementing the responses within a certain time window, etc.
- Plant information perceived, collected, or otherwise used in the subtask
- The crew responsible for the subtask

- Relationship to other subtasks, e.g., if an error is made in a prior subtask is the subtask bypassed?

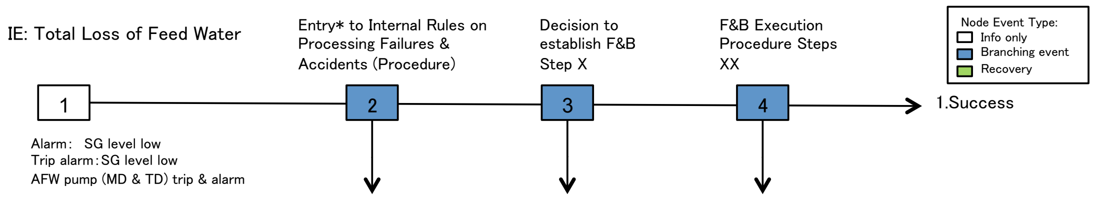

Fig. 2. Customized CRT for a Japanese PWR (adapted from Figure 4.2, IDHEAS draft report, 2013)

III.C.3. Step3. HRA team discussions (Including Operator Interviews) for narrative,
Step4. Analyze the results as input data for Failure Mechanisms of HRA Calculator.

When developing the narrative, the most important process is to ascertain and reflect the circumstances of tasks, which may be performed when an actual HFE arises, through interviews with operators and instructors other than those whose specialize in HRA or PRA. For this reason, information that will provide the input data necessary for the quantification methods should be reliably included in questions for conducting interviews.

The appendix of the HRA guideline provides general examples of questions that will be necessary in interviews in cases where the HRA calculator is utilized for quantification in the process of developing the narrative.
Actual interviews should be conducted by changing the questions somewhat so that information may be efficiently ascertained in accordance with the details of HFE operations.

Information to be provided by this qualitative analysis is information necessary for quantification of HEP and collected by systematic interviews of operation training instructors or operators. A generic question list is used in interviews to obtain the input information of HRA Calculator. It is described in TABLE I. By using this list, the information necessary for the quantification by using the HRA calculator can be efficiently obtained.

TABLE I. List of Questions for Operators (Including Effects on Analysis Results and Related Items)

No	Hearing items
- Questions used to understand the common information for the HRA Calculator	
1	How many of the following persons have been allocated in the composition of the operator team? * Shift Manager, * Shift Supervisor, * Reactor operator, * Plant operator, * Mechanics, * Electricians, * I&C Technicians, * Health Physics Technicians, * Chemistry Technicians
2	Which and how many of the team members listed in No.1 are responsible for the applicable operation?
3	How frequently are lectures and simulator training for the applicable operations conducted in a year?
4	Considering the entries in the operating procedure (called procedure hereafter) for implementing the applicable operations in the applicable accident scenario, what is the necessary cue (signal) for making the entry in the procedure immediately after the accident occurs? Please provide specific information regarding changes in parameters and sounding of alarms, including the temporal order. Is it appropriate to assume that all those cues are verifiable, and the operators can promptly recognize the cues?
5	In the applicable accident scenario, after the operator recognizes the cue mentioned in No.4, how much time is required until the entry is made in the procedure? Also, in view of the entry in the procedure, is it appropriate to assume that the operator has worked out the implementation of the applicable operation?
6	In the applicable accident scenario, how much time is required to reach the implementation steps of the applicable operation? Please include the approximate time required for each step.
7	How much time is required for executing the applicable operation (including the movement to the control panel and operation equipment when necessary)?
- Questions used to understand the information necessary to decide the bifurcation of the CBDTM Decision Tree	
8	Can the Main Control Room verify the instruments required for the applicable operations?
9	Do the instruments necessary for the applicable operations function normally in the applicable accident scenario? For example, the answer is NO if the normal functioning of the instruments that provide a cue for implementation is adversely affected by the worsening of the atmosphere at a particular place due to an accident.
10	As described in the example in No.9, when an event that hinders the normal functioning of an instrument occurs and the usually shown values cannot be relied upon, is additional information, which can enable correct operations, described in the Precautions or Notes of the procedure?
11	Is training conducted to understand the event or obtain necessary information pertaining to scenarios similar to the applicable accident scenario?
12	When the cue necessary for implementing the applicable operation is given to the operators, is the workload on the operators high or is there confusion?
13	Is it enough to verify the parameters necessary for implementing the applicable operations once, or must the parameters be monitored continuously?
14	Can the operator verify the parameters required for implementing the applicable operations from the front of the control panel, and need not leave the area in front of the control panel?
15	Is the cue necessary for implementing the applicable operation an alarm or the monitoring of instruments?

16	Is the control panel layout, classification, and labeling done in such a manner that the necessary instruments can be located easily?
17	Are there any ergonomic defects in the necessary instruments that can cause misreading of the values?
18	For the applicable operation, is the communication between the operators appropriate so that recovery is possible even if there is a mistake in transferring information between operators?
19	Do you think that all the cues necessary for implementing the applicable operation have been mentioned in the procedure? For example, if the criteria for implementing an operation is high amount of radiation from the steam line and although the steam line has been isolated and has a high amount of radiation, the instrument shows a normal value, the answer would be NO.
20	In a situation such as that illustrated in No.19, if all the cues are not listed in the procedure, are the precautions and coping strategies for cases when the cues are not given out as per the assumption, included in the procedure?
21	Has the operator received simulator training necessary for understanding the state of the plant correctly in a situation such as that illustrated in No.19?
22	In a situation such as that illustrated in No.19, have the operators been trained so that they can recognize that the cue is incorrect, and do all the operators recognize such a situation? For example, since the situation wherein the instrument shows a normal value although the steam line has been isolated and has a high amount of radiation, is a general one and hence the answer can be YES.
23	Are the related instructions in the form of steps that are individually and independently numbered and are they not described in locations that are easily overlooked such as the following: ・One of the many descriptions in a paragraph ・Description in the notes
24	While implementing the applicable operation in the applicable accident scenario, doesn't the operator reading the procedure need to reference multiple procedures?
25	Is the description of the items showing the implementation of the applicable operation more conspicuous than the other items on the flow chart?
26	Do all the operators manage the progress in steps by checking or marking the procedure so that the implemented and pending steps can be understood?
27	Do the instructions in the procedure include steps relevant to the following: ・Steps using terms that are unfamiliar to the operators and grammatical system that is not normally used ・Steps that require an explanation for understanding the intended description of the procedure. ・Steps in which the future state of the plant must be guessed for appropriate understanding of content
28	Do the steps in the procedure describe the instructed actions and all the information necessary for identifying the purpose of the actions?
29	Have the operators received training for interpreting the details of the relevant steps correctly?
30	Do the instructions in the procedure have steps that include Not Statement?
31	Do the instructions in the procedure have steps that include logic such as combining 2 or more parameters for assessing the results?
32	Do any of the steps in the procedure contain complicated logic where AND and OR come together?
33	Do the operators undergo simulator training for scenarios similar to the applicable accident scenario, and are they trained to execute the relevant steps from No.30~No.32?
34	Do the operators implement the applicable operations in simulator training for scenarios similar to the applicable accident scenario, and do they verify that the applicable operations are functioning properly?
35	If the applicable operations are implemented by following the procedure literally, does it lead to situations resulting in undesirable results such as discharge of radioactive material, damage to the plant (thermal shock to the Reactor Vessel), loss of functioning of necessary systems, and violation of rules?
36	Are there alternative means to avoid the problem situations mentioned in No.35, and is there a possibility of not implementing the applicable operation? Or, can the problem situation be avoided by delaying the implementation of the applicable operation? (Respond to the question considering the point that even if the applicable operation is delayed, there is no deviation from the procedure and violation of rules)
37	Is a policy requiring strict compliance to the Emergency Operating Procedures (EOP) and other procedure being used and implemented?
- Questions used to verify the elements that can be expected in the recovery of CBDTM (Self Review, Extra Crew, STA Review, Shift Change, ERF Review)	
38	What are the working hours of 1 shift?
39	If the applicable accident scenario occurs, can an emergency response be expected from personnel equivalent to STA (Shift Technical Advisor) and an organization equivalent to ERF (Emergency Response Facilities) in the U.S.A.? If an emergency response can be expected, how much time would be required for the respective entities to be able to participate in the emergency response?
40	If there is an oversight in verifying the cues for the applicable operation, is it appropriate to assume that the operator responsible for the oversight himself notices it and appropriately verifies the cue?
- Questions used to understand the information necessary for evaluating the probability of execution mistakes through THERP	
41	During the execution of the applicable operation in the applicable accident scenario, is the environment (Lighting, heat/ humidity, amount of radiation, atmosphere) harsh, are there specific requirements (tools, components, radiation-resistant clothing), and is it difficult to access the place of operation?
42	Does the response to the execution of the applicable operation involve complicated operations, such as performing conditioning operations while verifying the plant parameters?
43	While implementing the applicable operations, do the operators believe that the plant is under control or is in a situation that can be controlled? Or, do they believe that control of the plant is lost or control will be lost and the plant is progressing towards the undesirable situation of core damage?
44	Is the number of tasks that must be executed, greater than the number of operators? Or is it less?
45	During an accident, is the progress of the manual managed by checking the manual? Is there a check column in the procedure?
46	Do the specific implementation steps for the applicable operation (such as switching operation) include steps in continuation after the procedure, such that if an operation fails, the failure can be noticed and correct operations can be executed? If there are steps in continuation after the procedure, that make it possible to notice the failure, does the operator notice the failure and review any of the operations?

III.C.4. Step5. Narrative Documentation (include results of interview questions list, Plant information, etc.,)

The completed CRT, an example of which is shown in Fig. 3, provides a graphical representation for organizing the outputs of the task analysis. The associated narrative provide a full discussion to support the CRT
Node1: Initiating event: Loss of Main feed water
Node2: Entry into F&B procedures, because the conditions for entry are established quickly after the accident occurs.
Node3: The operation proceeds through Step X and a decision is made on implementation of the F&B operation.
Node4: In accordance with Steps XX, the SI signal is manually transmitted and an operation performed to open two pressurizer relief valves.
[Recovery nodes]
Node5: Following a trip signal for AFW pumps, the operator who performs recovery of the pump provides feedback to the shift supervisor, entry to the F&B operation procedures.
Node6: A decision to implement F&B operations based on the following parameters.
Sudden drop in steam pressure, - Rise in pressure of primary system
Node7: Notice the operation failure by the parameter confirmation

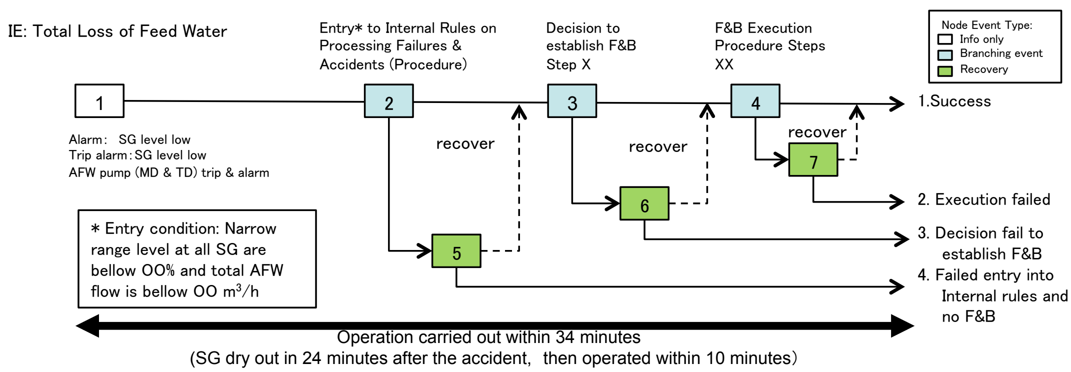

Fig. 2. Crew Response Tree (CRT) of F&B operation for Japanese PWR
(Customized CRT for Japanese PWRs adapted from Figure 4.3, IDHEAS draft report, 2013)

III.D. Quantitation of HEP (Step 6)

So that consistent assessments may be conducted, HFE quantification needs to be performed according to a systematic process. This is important for maintaining the relative importance of each HFE.

Although many HRA methods are currently being advocated, a recommended method is one that CBDTM for recognition process assessments and THERP for implementation processes. This HRA guideline used the HRA Calculator (EPRI) for quantitative analysis, in order to improve for Japanese nuclear power plants. An example was carried out in the F & B is shown in TABLE II.

Example where there was a discussion of the branch as a result of the interview. Considering brunch of "Placekeeping Aids" in CBDTM about how to take a record of the procedure steps: According to HRA Calculator manual, every crew record the check sheet for procedure steps, "Placekeeping Aids" was "Yes". But in Japanese utilities, to take the record is part of the operator. So, conservatively "Placekeeping Aids" change to "No". (Fig.3)

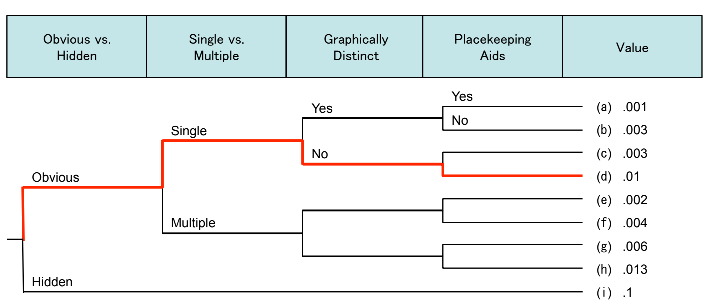

Fig. 3. Example Decision Tree, Pce: Skip a step in procedure
(One of CBDTM decision trees of dealing with cognitive aspects of HRA Calculator)
TABLE II. Example Quantification Result of HEP by HRA Calculator (Feed & Bleed operation: Base Case Scenario)

F&B Operation	Probability (Cognitive) (by CBDTM)	Probability (Execution) (by THERP)	Probability (Total)	Error Factor
SG level measuring (Cognition)	5.6E-3	1.0E-3	6.6E-3	5

III.E. Considering the possibility of deviation scenarios and/or new HFEs (Step7)

As the narrative discussion develops, additional HFEs may be developed or existing HFEs may be redefined, refined, or even split into multiple HFEs. When this occurs, return to Step 1 and develop or revise the base case for the new or revised HFEs. Finally, the narratives for each HFE will be complete and may define multiple contexts. Significant deviations from the base case scenario are troublesome for operators. New conditions challenging the operators are identified, the possibility of new HFEs or revised narrative conditions for existing HFEs is considered.

To Search for Deviation Scenarios:

- Identify physical deviations from the base case scenario
- Evaluate rules with respect to possible deviations.
- Use knowledge of system dependencies developed during the PRA systems analyses to search for possible additional causes of the initiator or possible evolutions of the scenario.
- Identify what operator tendencies and error types match the HFEs and Failure mechanisms of interest.

Considering deviation scenarios is an important point in the narrative development, but we do not have an efficient methodology yet. NRRC HRA Guide will continue to add another example for good practices.

IV. CONCLUSIONS

An HRA guideline of narrative approach for the qualitative analysis process has been developed. This approach is scheduled to apply to the HRA under extreme conditions PRA (Fire, Seismic, Tsunami, Multi units etc.,) on next step of our study.

ACKNOWLEDGMENTS

Our sincere appreciation goes to Dr. Dennis C. Bley (Buttonwood Consulting, Inc.) who provided helpful comments and suggestions for concept of narrative in HRA guide. Special thanks also go to Mr. Takahiro Kuramoto and Mr. Hiroaki Yoshikawa (NEL Ltd.) whose opinions and information have helped NRRC very much throughout the cooperation of making F&B operation examples and doing interviews with PWR plant trainers. Finally, we thank Dr. George Apostolakis, the NRRC Head, for guiding the development of this work and offering useful comments.

REFERENCES

1. Jing Xing, Mary Presley, Gareth Parry, John Forester, Stacey Hendrickson & Vinh Dang, An Integrated Decision Tree Human Event Analysis System (IDHEAS) Method for NPP internal at-power operation, (NRC/EPRI Draft Report for Peer Review, 2013).
2. EPRI, The EPRI HRA Calculator® Version 5.1, EPRI-3002004030, 2014.
3. A.D. Swain & H.E. Guttman, Handbook of human reliability analysis with emphasis on nuclear power plant applications (THERP), NUREG/CR-1278-F. U.S. NRC (1983).
4. EPRI, An Approach to the Analysis of Operator Actions in Probabilistic Risk Assessment, EPRI TR-100259 (1992)
5. EPRI, Systematic Human Action Reliability Procedure (SHARP) Enhancement Project. SHARP1 Methodology Report, EPRI TR-101711, (1992).
6. NUREG-1624, Rev. 1, Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA), U.S. NRC (2000).
7. H.Broberg, P.O. Braarud, and S. Massaiu, "The International Human Reliability Analysis Empirical Study: Simulator Scenarios, Data Collection and Identification of Human Failure Events," *PSAM-9* (2008).
8. Dang, V., J. Forester, A. Bye, et al., "A Pilot Benchmarking Study of HRA Methods – A Comparison of Method Predictions against the Outcomes Observed in the Simulator Study," *PSAM-9* (2008).
9. Forester, J., V. Dang, and E. Lois, "Defining the HRA Analysis Task in HRA Method Benchmarking – Approaches and Outcomes in the International Empirical Study", *PSAM-9* (2008).
10. ASME/ANS RA-Sa-2009, Addenda to ASM/ANS RA-S-2008, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, ASME/ANS (2009).