An Introduction of Simulator Exercises and Operator Interviews in support of C-2 Human Reliability Analysis

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Abstract: To support the human reliability analysis of CHASHMA nuclear power plant unit 2 (C-2), a plant visit was carried out for simulator exercises, data collection and operator interviews. In this paper, the method of HRA data collection from nuclear power plants is briefly described firstly, then the relevant work for C-2 nuclear power plant was presented. The operators' response process, actual time used for diagnosis and execution, and other information and data were recorded and obtained through the videos and operator log files of the simulator exercises and operator interviews. Besides, together with two PSA/HRA members from the plant, some simulator data and information were recorded using prepared forms manually. In summary, most of the required data for C-2 human reliability analysis were obtained, which provided a fundamental basis for the HRA work.

Keywords: Human Reliability Analysis, Simulator Exercises, Operator Interviews.

1. INTRODUCTION

The Probabilistic Safety Analysis (PSA) of CHASHMA nuclear power plant unit 2 (C-2) was initiated in late 2015. As scheduled in the contract, a plant visit was carried out in May 2017 for simulator exercises, data collection and operator interviews to support the C-2 human reliability analysis in the PSA project.

There are three main objectives of this plant visit:

- For the typical event scenarios with the risk-important human actions, operator responses to the events on the simulator were observed, as well as the information and data associated with the event mitigation were obtained.
- For the other human actions that were not exercised on the simulator due to limited time during this visit, operator interviews were conducted to obtain the information and data associated with the event mitigation.
- The prepared questions about the C-2 PSA modeling and information about plant configuration and operation were discussed.

In this paper, the method of collection of HRA data from nuclear power plant simulators was briefly described first, and then the relevant work for C-2 nuclear power plant was presented. The C-2 plant visit provided a fundamental basis for the C-2 HRA.

2. METHODOLOGY OF HRA DATA COLLECTION

Collecting simulator data to support HRA requires robust experimental design and process. The five experimental design characteristics are [1]:

- Performance measures should relate to success and failure as defined in the PSA;
- Simulator contexts should be representative of PSA events;
- Data collection should include the opportunity to observe human failure events of interest;
- Data collection should include objective human performance measures of success or failure;
- Data collected should describe relevant aspects of performance and the factors that affect that performance.

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The process of conducting an HRA simulator data collection effort can be described in four main phases: preparation, data collection, data analysis, and reporting. Figure 1 depicts these four phases and their respective sub-steps.

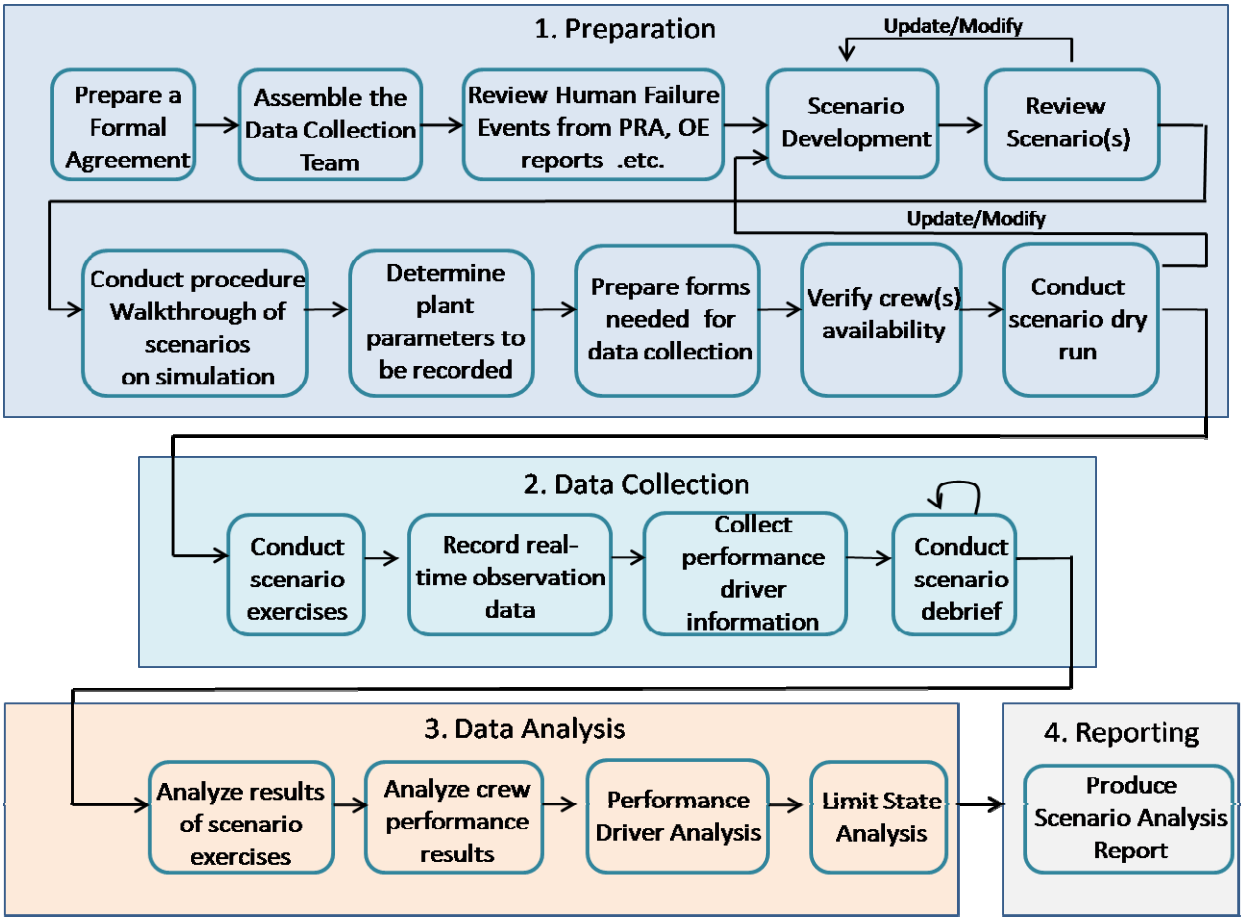

Figure 1 HRA Simulator Data Collection Process

For the detailed information of HRA simulator data collection method, refer to [1].

Another effective way of HRA data collection is operator interviews. The main steps usually include: planning of the operator interviews, preparation and determination of the forms and questionnaires used for the interviews, conduction of the operator interviews during the plant visit, and data analysis and reporting. The operator interviews can be done with simulator data collection during the same plant visit.

3. C-2 SIMULATOR EXERCISES AND OPERATOR INTERVIEWS

3.1. Preparation for Data Collection

The C-2 plant visit was carried out in May 2017 and lasted for one week. Considering the limited time, an adequate preparation was arranged before the plant visit. The data collection team requirement, dominant human failure events, selected scenarios to be used for the simulator data collection and operator interviews, relevant forms and required data to be recorded were extensively discussed and determined by HRA experts in SNERDI and sent to the C-2 PSA group leader and simulator trainer more than one month earlier before the visit. All the information were reviewed and confirmed by the simulator trainer before the plant visit.

Examples of the selected event scenarios for simulator exercises were as follows：

1) After a steam generator tube rupture (assuming SG A tube rupture) with failure of the pressurizer normal spray, operator fails to recognize the need and open one of the two relief valves on intact SG to cool down SRC (reactor coolant system), or fails to open one pressurizer relief valve (SRC-V02A or B) to depressurize SRC.
2) Following a loss of offsite power with failure of two emergency diesel generators DGA and DGB, operator fails to recognize the need and manually actuate the AAC (alternative AC power)
3) During loss of main feedwater system with failure of all the feedwater to SGs, operator fails to recognize the need and actuate the SHI or open two pressurizer relief valves to complete the "SRC feed-bleed cooling".
4) Following a small loss-of-coolant accident with success of SRC cooldown and depressurization, operator fails to recognize the need and put SRH (residual heat removal system) into service, or fails to recognize the need and close the motor valves on the charging lines to ensure that the charging flow can be injected through the charging pressure drop orifice on the bypass lines.

The relevant information of two selected scenarios is summarized in Table 1 as examples. The format of record forms of the operator responses in the scenarios is presented in Table 2. After each of the event scenario exercises, a discussion about the exercise process with the crew was arranged immediately and the crew was required to fill in a questionnaire to collect the exercise information and data. Considering the HRA method used in C-2 PSA project, the content of questionnaire is designed as shown in Table 3.

For the human actions that could not be exercised on the simulator during this visit, operator interviews were conducted to obtain the information and data associated with the event mitigation. The questionnaire for these HFEs are similar to that in Table 3, except that the following additional information should be included: 1) descriptions of operator responses such as diagnosis process and action implement process and the place; 2) time used to recognize the need of the expected action and time to implement the expected action, etc.

Table 1: Example of selected Human Failure Events & scenarios of C-2 NPP

No	Simulator Initial Condition	Initiators and Definition	Success Function	Inserted Malfunction	Expected Human Actions	Expected Operator Responses	Associated Human Failure Event in PSA
1	100% rated power operation	Steam Generator A Tube Rupture (a complete double ended rupture in a single steam generator tube)	Reactor trip, Auxiliary Feedwater and High Pressure Safety Injection are all successful. Valves on Fault SG reset.	Pressurizer normal spray fails; condenser malfunction (could not dump steam to condenser from SG)	Open one of the two relief valves (SSR-V005B/D) on intact SG to cooldown SRC. Open one pressurizer relief valves (SRC-V02A/B) to depressurize SRC. Terminate SI to stop primary to secondary leakage.	E-0 step 1 → step22→E-3 step1 →step 6 (cool down SRC) → step 17 (depressurize SRC) →step 20 (stop SHI pump)	SPRO-RV02--HEO2 SSRO-RV05BDHEO1 SHI-TRIP-HEO
2	100% rated power operation	Loss of offsite power	Reactor Trip	Failure of house load operation; both emergency diesel generators (DGA and DGB) fail	Actuate the AAC (EAG-801DG)	E-0 step 1 → step 4→ECA-0.0 step 1 → step 7 (actuate the AAC)	EMG--AAC---HEO

Table 2: Record Forms of Simulator Scenarios Exercises

Description of the scenario: _____
Date: _____ Crew No. __
The responses following the initiating event：

Time	Content (including the step No. of the procedure used)	Note

Table 3: Questionnaire for Post-Scenario Debriefing (Part of the Form)

Description of the Scenario： _____

Human Failure Event ID：_____

PSF	Diagnosis		Action	
	PSF level	**select（tick）**	**PSF level**	**select（tick）**
Stress/ stressors	Extreme		Extreme	
	High		High	
	Nominal		Nominal	
Complexity	Highly complex		Highly complex	
	Moderately complex		Moderately complex	
	Nominal		Nominal	
	Obvious diagnosis		——	
Experience/ Training	Low		Low	
	Nominal		Nominal	
	High		High	
Procedures	Not available		Not available	
	Incomplete		Incomplete	
	Available, but poor		Available, but poor	
	Nominal		Nominal	
	Diagnostic/symptom oriented procedure		——	
Ergonomics/ HMI	Missing/Misleading		Missing/Misleading	
	Poor		Poor	
	Nominal		Nominal	
	Good		Good	

Notes：

1) “Diagnosis” means the time beginning from the response of the event until recognize the need of the expected action. “Action” means the execution of the expected action.

2) If no sufficient information is available to choose among the alternatives, leave it blank**.**

All the definitions and measures of the performance shaping factors included in the above form were described in a table and explained in detail to the plant operators before they filled in the forms.

3.2. Data Collection of Simulator Exercises and Operator Interviews

Before the beginning of each scenario exercise, the detailed scenario and the inserted malfunction in simulator were discussed with the simulator trainer again to ensure the simulator exercises running smoothly.

The staffs in C-2 main control room are as follows: one shift supervisor (SS), one deputy shift supervisor (DSS), three operators (one reactor operator (RO), one turbine operator (TO) and one electrical operator (EO)) for each crew. The control room crew numbers and their qualifications under different plant conditions were confirmed. The prepared scenarios were exercised on the simulator and the required data and information as described in section 3.1 were recorded and collected. Due to the limited time, the responses of three operator crews to the planned event scenarios were observed. The operator responses to the events on the simulator were observed and the information and data associated with the event mitigation were obtained. The information and data included the crews’ actual response process following each event scenario, the time parameters of the diagnosis and action, the performance shaping factors (PSFs) levels of the operators and so on. The video of the operator event response process, log files of the instructors and operators, the completed questionnaires, etc were all collected and used to support the data analysis. An example of the record form of operator responses is shown in Table 4.

For the human actions that were not exercised on the simulator during this visit, operator interviews were conducted and the relevant forms were filled in with required information and data associated with the event mitigation. An example of the questionnaire for operator interviews is presented in Table 5.

Table 4: Record Forms of Simulator Scenarios Exercises (an example of C-2 NPP)

Scenario 1

Description of the scenario: After the initiating event of SGTR(assume SG A tube rupture), and assume that the PRZR normal spray fails, operator needs to recognize the need and open one of the two relief valves on intact SG to cooldown SRC. And open one pressurizer relief valves（SRC-V02A/B) to depressurize SRC.

Date: 15-05-17 Crew (2)

The response following the accident:

Time	Content(include the step No. of the procedure used)	Note
14:12:00	Plant is in normal operation	
14:13:30	N-16 alarm appear. activity high on secondary side	
14:14:36	SG-A level is increasing	
14:14:48	Stand by SCV pump is started	
14:15:17	Manual Reactor is tripped by operator	
14:15:58	SI actuated manually	
14:16:13	SEOP E-0 Step1, Verify Reactor trip	
14:18:59	SEOP E-0 Step 9, Verify CTMT Isolation	
14:20:00	SEOP E-0 Step10, Check if Main Steam line should be isolated	
14:22:01	SEOP E-0 Step13, Verify SI flow	
14:24:56	SEOP E-0 Step18, Check PRZR PORVs, Block and Spray valves	
14:25:09	SEOP E-0 Step19, Check if RCPs should be stopped	
14:25:42	SEOP E-0 Step 20, initiate monitoring of CSF status tree using F-0	
14:26:28	SEOP E-0 Step 22, Check if SG tubes are not Ruptured, now shifted to E-3	
14:28:30	SEOP E-3 Step 3, Isolate flow from ruptured SG	

Table 5: An Example of the Questionnaire for Operator Interviews (Part of the Form)

Questionnaire of C-2 HRA for the Internal Event PSA

Description of the accident and human action: After the initiating event of SLOCA, and assume that the AFW fails, operator needs to recognize the need and open one pressurizer relief valves (SRC-V02A/B) to carrying out the "bleed action" of "SRC feed-bleed cooling".

Human Failure Event ID: SPRO-RV02--HEO1

1. The response following the accident

Diagnosis process: Operator initiates E-0 when the reactor trip signal occurs, when the SAF fails and SG narrow level less than 9.3m, operator would initiate FR-H.1 by the RED PATH of Lossing HEAK SINK according to the foldout of procedure. in step 19, open one pressurizer relief valves to carrying out the "bleed action" of "SRC feed-bleed cooling".

Action implement process and the place: open one pressurizer relief valves (SRC-V02A/B)

2. The time needed to recognize the need of the expected action: 20 min

The time needed to execute the expected action: 10 min

PSF	Accident Diagnosis		Action Implement	
	PSF level	select (tick)	PSF level	select (tick)
Stress/ stressors	Extreme		Extreme	
	High	✓	High	✓
	Nominal		Nominal	
Complexity	Highly complex		Highly complex	
	Moderately complex		Moderately complex	
	Nominal	✓	Nominal	✓
	Obvious diagnosis		——	
Experience/ Training	Low		Low	
	Nominal		Nominal	
	High	✓	High	✓
Procedures	Not available		Not available	
	Incomplete		Incomplete	
	Available, but poor		Available, but poor	
	Nominal	✓	Nominal	✓
	Diagnostic/symptom oriented procedure		——	

Some suggestions are given based on the plant observations and PSA model, and two examples are as follows:

1) During the simulator exercises, it is found that the SSs, DSSs and ROs are well experienced, while some TOs and EOs may be less-experienced. It is suggested that the TOs/EOs should be trained more frequently and the SSs/DSSs should pay more attention to them to ensure they act correctly, especially during a loss of offsite power.

2) It is found that some procedures or procedure steps for some specific event scenarios and operator actions are incomplete or unavailable, for example 1) The procedure for mitigation of totally loss of essential service water is not available, 2) The reciprocating charging pump in chemical and volume control system is designed to provide seal water injection for the SRC pumps after failure of the centrifugal charging pumps, however, no procedure step of actuation of the reciprocating charging pump is included in the relevant operating procedures. It is

suggested that some procedures should be further developed and optimized, and operators should be trained more frequently with the optimized procedures to enhance the plant safety.

4. CONCLUSION

A plant visit was performed to support the C-2 human reliability analysis last year. Totally three crews' responses to the planned event scenarios were observed on the simulator. The operators' response process, actual time used for diagnosis and execution, and other information and data were recorded and obtained through the videos and operator log files of the simulator exercises and operator interviews. Besides, together with two PSA/HRA members from the plant, some data and information were recorded using prepared forms manually.

In summary, most of the required data for C-2 human reliability analysis were obtained, which provided a good basis for the HRA work. In addition, some suggestions are provided to enhance the plant safety.

References

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