Research and Application of Time-PSF Calculation Method for HRA in Nuclear Power Plant

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Abstract. This paper studies the quantitative method of Time-PSF in HRA of nuclear power plant, and determines the precondition of quantitative calculation, and combs the quantification process, also introduces the key steps of quantification process in detail. Taking the "Medium Break LOCA (superimposed cooling failure)" event as an example, the processing flow based on SOP (state oriented operation procedures) and SEOP (symptom oriented operation procedures) emergency response procedures is analyzed respectively, and the time required is quantified by the method introduced in this paper. The method proposed in this paper solidifies the process, and ensures that the analysis has reasonable preconditions, and solves the problem of difficulty in obtaining basic data and difficult to quantify, this method makes the Time-PSF assessment more accurate and reliable on the basis of quantitative calculation, and then improves the accuracy of evaluating the probability of human error (HEP) in the digital main control room, so as to provide reference for HRA staff. In addition, through the implementation of the calculation method, it is helpful to obtain relevant actions with high probability of human error, and further optimize the function allocation and system design.

Keywords: Time-PSF · HRA · SOP · SEOP

1 Introduction

In recent years, more and more people's behaviors and activities are considered in the safety evaluation of large-scale complex industrial systems. Human reliability analysis (HRA) (important personnel action analysis) is an important element in human factors engineering. HRA is a method or system process to analyze and evaluate human reliability. The purpose of human reliability research is to analyze, and predict, also improve human contribution to system reliability, reduce and prevent human error, Also the purpose is to ensure the safety and reliability of system operation [1]. In probabilistic safety analysis (PSA), HRA is an essential part. The International Atomic Energy Agency (IAEA) points out that HRA quality is one of the important indicators to measure the quality of PSA report [2, 3].

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HRA is used for qualitative and quantitative analysis of human reliability. HRA has been studied and applied for more than 50 years. The commonly used HRA methods include Swain's human error rate prediction (THERP), human cognitive reliability and operator reliability experiment (HCR and ORE), Reason based decision tree model (CBDTM) and Standardized Plant Analysis Risk Human Reliability Analysis (SPAR-H) [4–6].

SPAR-H method divides human action into two parts: diagnosis part and operation part. According to their own knowledge and experience, diagnosis part understands current conditions, plan and optimize behaviors, and determine reasonable actions. Operation execution part includes operation equipment, equipment layout, pump start-up, setting value, test and other actions according to the procedures or orders of nuclear power plant. SPAR-H method considers the influence of eight PSFs on human behavior and reflects them in the process of quantification. The eight PSFs (Performance Shaping Factor) factors are: time, pressure, complexity, training and experience, procedures, ergonomics and human-system interface, responsibility suitability, process [7].

In the quantitative calculation, it will be divided into diagnosis human error analysis and operation human error analysis, which mainly includes three steps: 1. The human error probability of diagnosis and operation can be quantified by determining 8 PSFs factors; 2. The distribution calculation of uncertainty; 3. Correlation processing. The biggest difficulty is to obtain the basic data, especially the time evaluation, when determining the 8 PSF values.

To evaluate the time value of diagnosis and operation, the premise is to obtain two kinds of basic data: available time and required time; the former is obtained through thermal engineering calculation, while the latter is realized by interviewing the operation professionals. Subjectivity has certain influence on quantitative calculation. The method proposed in this paper solidifies the process, gives the required time according to the interviewing with operators (or simulator tracking), and analyzes the rationality of the result, so as to ensure the rationality of the analysis scenario, plant, procedures, operation experience, etc., and solve the problem of difficult to obtain basic data and difficult to quantify, so as to make the Time-PSF assessment more accurate and reliable on the basis of quantitative calculation, thus improving accuracy of evaluating the probability of human error (HEP) in digital main control room. In order to provide reference for HRA staff, in addition, through the implementation of the calculation method, it is helpful to obtain relevant actions with high probability of human error, and further optimize the function allocation and system design. In addition, through the implementation of the calculation method, it is helpful to obtain relevant actions with high probability of human error, and further optimize the function allocation and system design.

2 Research of Time-PSF Calculation Method for HRA

2.1 General Introduction of the Method

SPAR-H method divides human action into two parts: diagnosis part and operation part. In the process of quantitative calculation, it is necessary to determine the human error probability of diagnosis and operation by determining eight PSF factors. Among them, time evaluation needs to be evaluated after quantitative calculation. The following difficulties need to be solved in the process:

a) The basic human error data include the human errors of diagnosis and operation, which are not fully studied in current research;
b) To evaluate the time value of diagnosis and operation, the premise is to obtain both the available time and the required time; the former is obtained through thermal engineering calculation, and the latter is achieved by interviewing the operation professionals, so subjectivity has a certain impact on the quantitative calculation;
c) The main human behaviors of nuclear power plant operation safety are concentrated in the main control room (MCR). In the accident scenario, the MCR operator has the decision-making power to deal with the power plant accident. At present, the accident procedures used by operators are mainly "symptom oriented emergency operation procedures" and "oriented emergency operation procedures". Different procedure systems and staffing lead to different basic data required for operator diagnosis and operation time evaluation;
d) In specific analysis, the time for personnel to complete an operation may be different, which has a certain impact on the quantitative results. In personnel reliability analysis, the PSF and its level involved in HFE are determined through scenario analysis and task analysis. This paper proposes a method for obtaining basic data of diagnosis and operation when the Time-PSF is taken, and then solves the problem of operator diagnosis and operation time difficult to quantify accurately in the SPAR-H method.

Premise of Quantitative Calculation.
The basic assumption of personnel error analysis is: personnel response is carried out according to operation specifications and procedures, and the main control room is a digital main control room based on digital control system (DCS), and the procedures can adopt SOP and SEOP, and the management and operation documents shall meet the following requirements:

a) All quality related or the safety related operation must be carried out according to the approved detailed written procedures;
b) The documents are compiled in accordance with the guidelines HAF 0405 "Quality Assurance In The Commissioning And Operation Of Nuclear Power Plants" issued by NNSA, and the procedures are prepared according to the general principles of quality assurance of nuclear power plants and the actual operation experience;
c) The operation procedures that during the normal operation of the power plant and after an event or accident, the system or equipment shall be prepared. All procedures shall be developed and approved before they are used to carry out the specified safety activities.

Time-PSF Quantitative Process.
To quantify the Time-PSF of SPAR-H method, first of all, it is necessary to determine the human error event information to ensure that the operator can obtain uniform input information; different accident response strategies may lead to different time required, which also needs to be taken into account; on this basis, the time required is calculated and the assessment is completed according to the standards. The process is shown in the following Fig. 1.

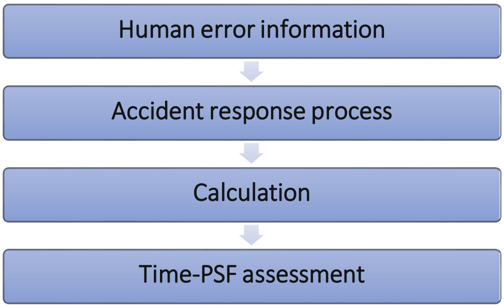

Fig. 1. Time-PSF quantitative process

2.2 Key Steps of the Method

Take the "MBLOCA Superimposed Cooling Failure" event as an example, this section introduce the key steps.

Human Error Information.
The upstream information includes: human error event description, time window, key signal, event tree, accident process, etc.

Accident Response Procedures.
The scenario and background are the basic conditions for quantifying PSF. The accident response procedures, personnel allocation, training, etc. of the unit are determined in the scenario selection module. This paper only focuses on the time PSF related scenarios.

At present, the mainstream accident response procedures are SOP, SEOP and EOP (event oriented operation procedures), which will not be discussed any more. Due to the different design methods of the above accident response procedures, operators may have different accident diagnosis and operation time when executing the procedures (Fig. 2).

SOP does not depend on the specific initiating event, and it is based on the state of the unit and combined with the actual parameters to guide the corresponding accident response procedures. It can be understood as: integrating event oriented guidance into the process of state parameter cycle diagnosis, i.e. state oriented & event oriented. SOP procedure realizes closed-loop control: diagnosis-action-supervision-reorientation-action. SOP adopts cycle structure to diagnose the unit status and equipment availability.

SEOP uses event orientation to deal with accidents in time. When complex accidents such as superimposed accidents occur, it uses symptom guidance to diagnose and deal

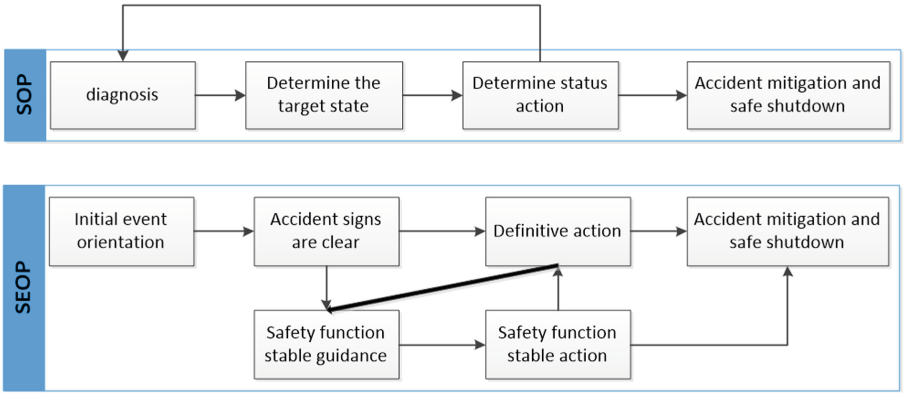

Fig. 2. Accident response strategy

with them, that is, event oriented + symptom oriented. SEOP adopts linear structure and its design principle is simple and efficient.

There are great differences in the staffing of different accident response procedures. These are the key scenarios that affect the basic data of operator diagnosis and operation time, which need to be determined first.

Response Process

After the initial accident is determined, the response process is completed under the specific accident procedures. There is great differences between SOP and SEOP (Figs. 3 and 4).

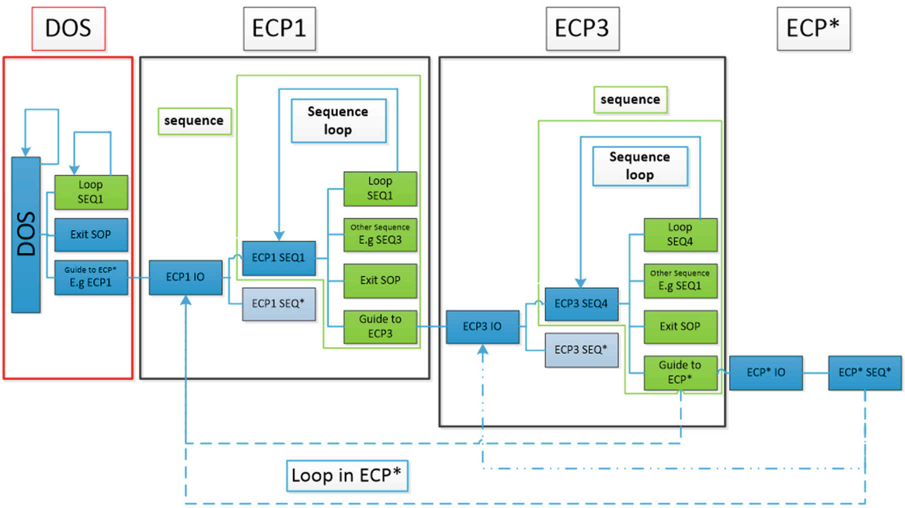

Fig. 3. SOP process

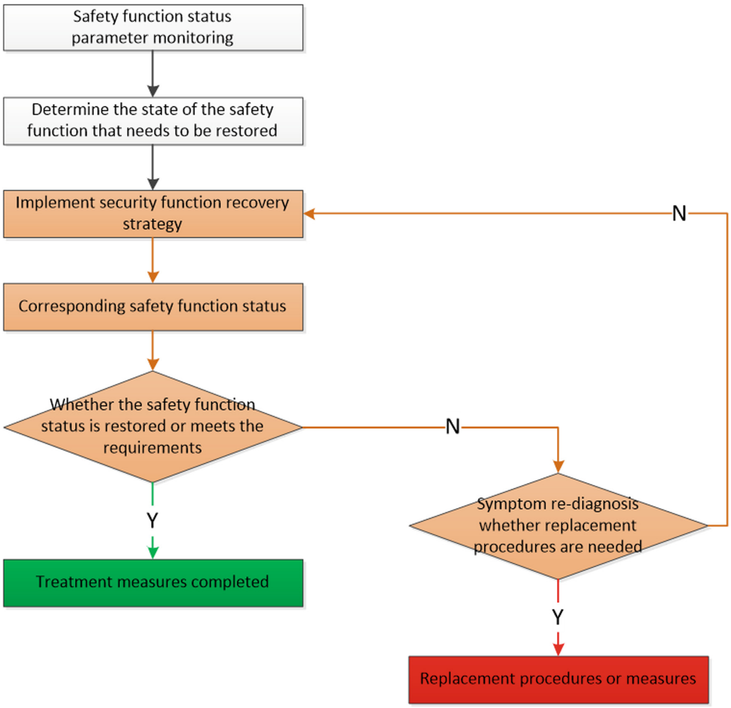

Fig. 4. SEOP process

Taking SOP as an example, the processing flow is as follows:

Step 1: determine the calculation example (taking "MBLOCA (superimposed cooling failure)" as an example;
Step 2: determine the first accident;
Step 3: enter DOS to start diagnosis;
Step 4: enter ECP2 according to DOS diagnosis;
Step 5: enter ECP4 according to ECP2-SEQ2;
Step 6: ……

It should be noted that step 2 is determined, and step 3 to the subsequent steps can be implemented in strict accordance with the requirements of the procedures (while SEOP shall implement procedures E and F as required). The whole process includes diagnosis and action. The basic data of diagnosis and operation time are generated in this module.

Calculation Method

The data acquisition and calculation module performs the data acquisition and calculation work in the above processing flow. For SOP, the calculation formula is as follows:

$$T_d = \sum_1^n (T_{Dn} \times k) + \sum_1^m (T_{Dm} \times k) + \sum_{q=1}^{7} \left\{ \left[\sum_{i=1}^{N_{Ii}} \left(T_{Iiq} \times k\right) + \sum_{j=1}^{N_{Sj}} \left(T_{Sjq} \times k\right) \right] \times k \right\}$$

$$T_e = \sum_1^r (T_{Er} \times k)$$

Where:
T_d = diagnosis time.
T_e = action time.
T_{Dn} = time for DOS procedure diagnosis.
T_{Iiq} = time for executing ECPq-IO procedure diagnosis.
T_{Sjq} = time for executing ECPq-IO procedure diagnosis of item Q.
N_{Ii} = total number of pages executed by Q-ECPq-IO procedure.
N_{Sj} = total pages executed by ECPq-SEQ procedure.
T_{Dm} = time for DOS procedure action.
T_{Er} = time for ECP procedure action.
$k = 1$ If the processing flow needs to execute item Q or page I or page J,
$k = 0$, if the processing flow does not need to execute item Q or page I or page J;
Note:
ECPq-IO: IO part of procedure ECPq, such as ecp4-io;
ECPq -SEQ: SEQ part of procedure ECPq, such as ECP4-SEQ4.

It should be noted that:

1. At the beginning of the interview, it is necessary to make clear the accident situation with the operator;
2. The operation time depends on the operator's implementation process and accident development process;
3. The processing time of each page of procedures is the basic data to be collected.

For SEOP, the calculation formula is as follows:

$$T_d = \sum_1^a (T_{Ea} \times k) + \sum_1^b (T_{Fb} \times k)$$

$$T_e = \sum_1^x (T_{Ex} \times k) + \sum_1^y \left(T_{Fy} \times k\right)$$

Where:
T_d = time needed for diagnosis,
Te = time required for action,
T_{Ea} = time for performing step a diagnosis of procedure e,
T_{Fb} = time for performing step B diagnosis of procedure F,
T_{Ex} = time for performing step X of procedure e,

T_{Fy} = time for performing step y of procedure F,
$k = 1$, if step a or b or x or y is required for processing flow;
$k = 0$, if step a or b or x or y is not required for processing flow.

Time-PSF Assessment

The Time-PSF was evaluated according to NUREG/ CR-6883, the section of Time-PSF value selection is shown in the following Table 1 [8]:

Table 1. Table of time-PSF assessment.

	PSF Level	Accident diagnosis value	Detailed reasons for selecting this PSF level are described in this column
Power operation diagnosis part	Not enough time	P(failure) = 1.0☐	
	Just enough time (≈ 2/3 times nominal time)	10 ☐	
	Nominal time	1 ☐	
	Sufficient time (1–2 times of nominal time and >30 min)	0.1 ☐	
	A lot of time (>2 times nominal time and >30 min)	0.01 ☐	
	Lack of information	1 ☐	
Power operation action part	Not enough time	P(failure) = 1.0☐	
	Just enough time (≈ required time)	10 ☐	
	Nominal time	1 ☐	
	Sufficient time (≥5 times the required time)	0.1 ☐	
	A lot of time (≥50 times the time required)	0.01 ☐	
	Lack of information	1 ☐	
Low power operation diagnosis part	Not enough time	P(failure) = 1.0☐	
	Just enough time (≈ 2/3 times nominal time)	10 ☐	
	Nominal time	1 ☐	
	Sufficient time (1–2 times of nominal time and > 30 min)	0.1 ☐	

(*continued*)

Table 1. (*continued*)

	PSF Level	Accident diagnosis value	Detailed reasons for selecting this PSF level are described in this column
	A lot of time (>2 times nominal time and > 30 min)	0.1–0.01 ☐	
	Lack of information	1 ☐	
Low power operation action part	Not enough time	P(failure) = 1.0☐	
	Just enough time (≈ required time)	10 ☐	
	Nominal time	1 ☐	
	Sufficient time (≥5 times the required time)	0.1 ☐	
	A lot of time (≥50 times the time required)	0.01 ☐	
	Lack of information	1 ☐	

3 Examples of Application of the Method

In this part, the quantitative process of Time-PSF will be described in detail. Taking "MBLOCA (superimposed cooling failure)" as an example, the diagnosis time depends on the accident response procedures.

3.1 Quantitative Process Based on SOP

Based on the calculation method of SOP, the following steps are carried out:

Step 1: Determine the calculation example
This example takes the "MBLOCA (superimposed cooling failure)" event as an example;

Step 2: Determine the accident response procedures
The implementation example takes SOP as an example;

Step 3: The task analysis of this example
The initial accident: the reactor building radioactive alarm appears, the primary circuit pressure continues to drop, resulting in the automatic shutdown and safety injection;

Step 4: Time calculation of this example
Example step 1 DOS diagnosis: execute the first page to the fifth page of DOS procedure, and the execution time of each page is 2 min, 3 min, 0.5 min, 0.5 min and 1 min.

The diagnostic time of DOS $= \sum_1^n (T_{Da} \times K)\ 2 + 3 + 0.5 + 0.5 + 1 = 7$ min;
Similarly, ECP2 diagnosis time = 4 + 1 + 5 + 1 + 1 = 12 min;
ECP2 action time = 4 + 5 = 9 min;
ECP4 diagnosis time = 4 + 1 + 1 + 1 + 2 = 10 min;
ECP4 action time = 4 min.

Step 5: Time-PSF value evaluation
Diagnosis time: 38 min, compared with the available diagnosis of thermal engineering calculation, value according to the table;

Action time: 4 min, compared with the available action of thermal engineering calculation, take value according to the table (Fig. 5).

3.2 Quantitative Process Based on SEOP

The calculation method based on SEOP performs the following steps:

Step 1: Determine the calculation example
This example takes the "MBLOCA (superimposed cooling failure)" event as an example;

Step 2: Determine the accident response procedures
The implementation example takes SEOP as an example;

Step 3: The task analysis of this example
The initial accident: the reactor building radioactive alarm appears, the primary circuit pressure continues to drop, resulting in the automatic shutdown and safety injection;

Treatment process: in SEOP, the reactor trip and safety injection are triggered after the primary circuit break, and E00 diagnostic procedures are implemented. Suppose that the three SGs lose all water supply and F31 red light is on, the time of entering F31 procedure is close to SG failure time.

Step 4: Time calculation of this example
According to e procedure, the expected time is 5 –10 min. The time of each step is as follows:1−0.5 m, 2−1 m, 3−0.5 m, 4−0.5 m, 5−1 m, 6−0.5 m, 7−1 m, 8−2 m, 9−1 m, 10−3 m, 11−1 m, 12−2 m, 13−2 m, 14−2 m, 15−1 m, 19−1 m, 20−1 m, 21−0.5 m, 22−1 m, 23−3 m, 24−1 m.

Diagnosis time = 0.5 + 1 + 0.5 + 0.5 + 1 + 0.5 + 1 + 2 + 1 + 3 + 1 + 2 + 2 + 2 + 1 + 1 + 1 + 0.5 + 1 = 2.5 + 10 + 8 + 3 = 23.5 min,

Action time = 4 min.

Step 5: Time-PSF value evaluation
Diagnosis time: 23.5 min, compared with the available diagnosis of thermal engineering calculation, value according to the table;

Action time: 4 min, compared with the available action of thermal engineering calculation, take value according to the table (Fig. 6).

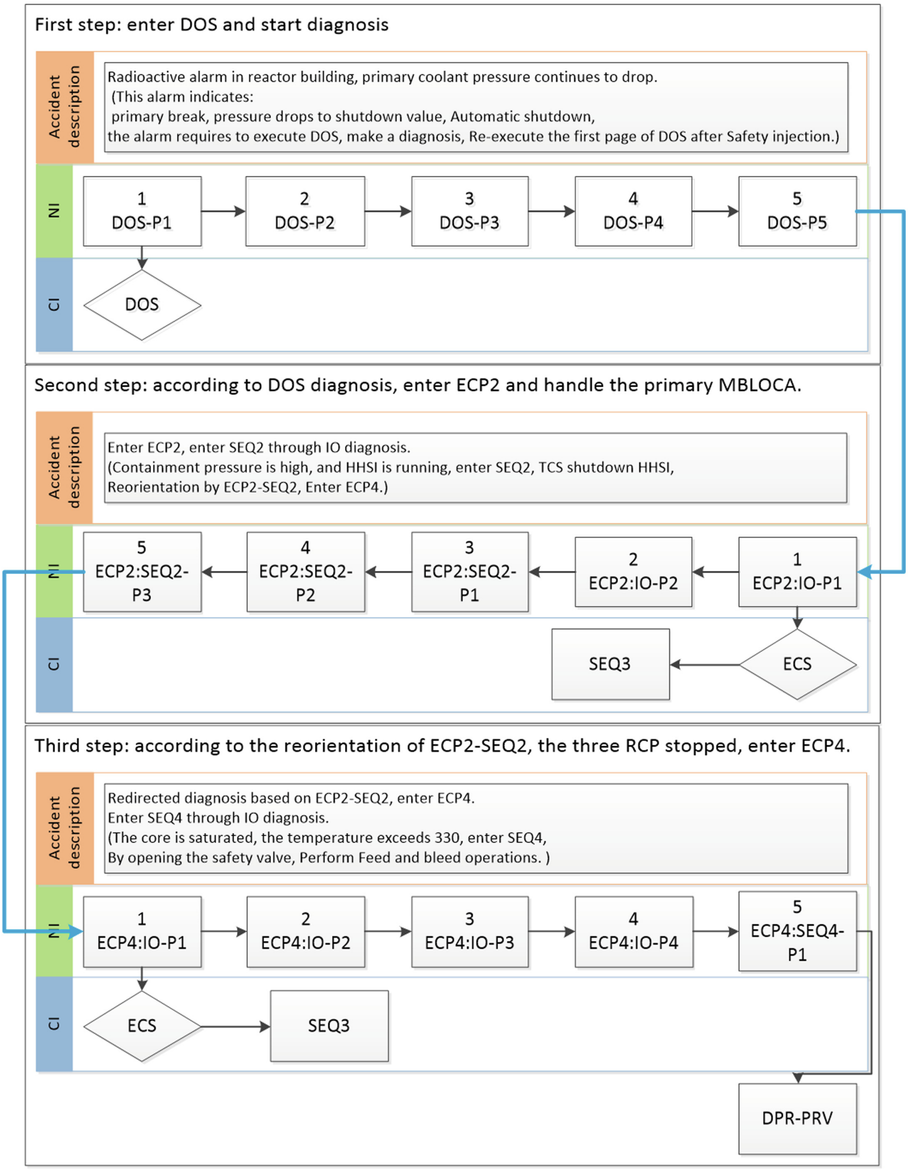

Fig. 5. Example of accident response process for SOP

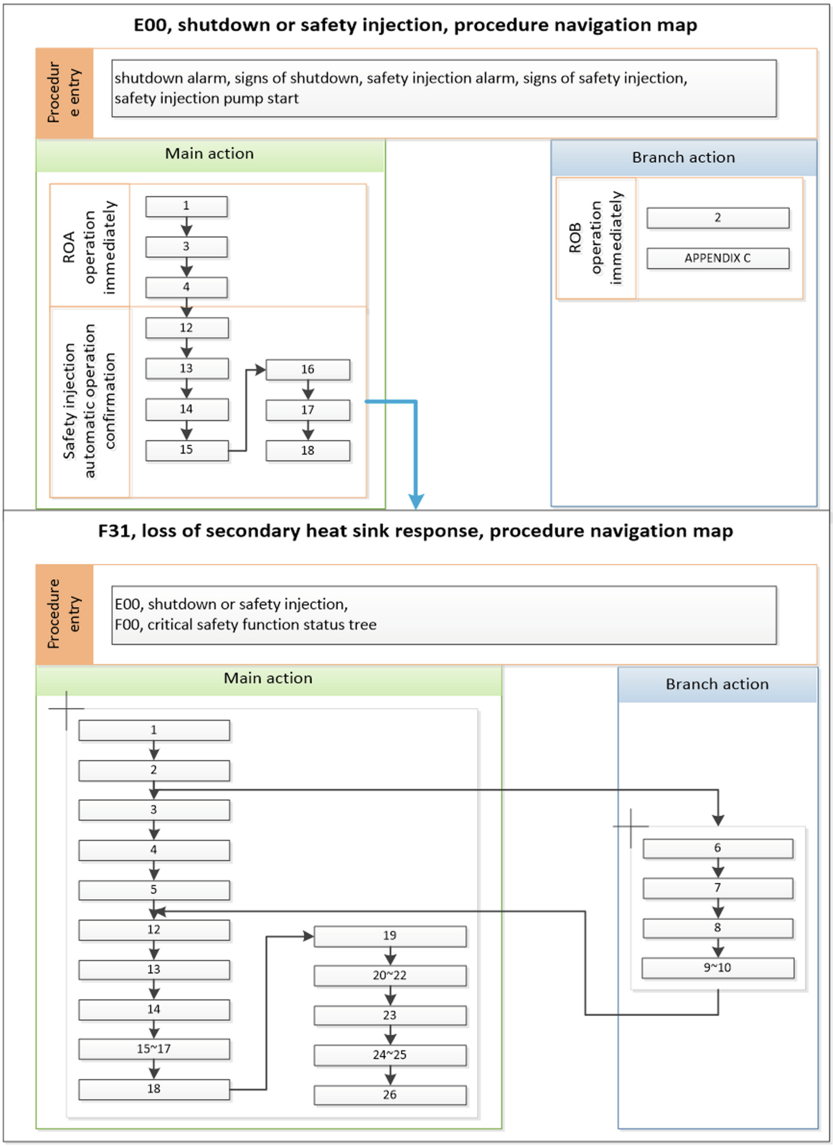

Fig. 6. Example of accident response process for SEOP

4 Conclusions

In this paper, the quantitative process of Time-PSF in HRA of nuclear power plant is introduced. Taking “MBLOCA (superimposed cooling failure)” event as an example, the processing flow based on SOP and SEOP accident response procedures is analyzed respectively. Through the quantitative methods and application examples, it can be seen that clear human error event information is helpful for interviewees to obtain highly consistent cognition, and different accident response strategies may obtain different accident response time. The method proposed in this paper solidifies the process, ensures that the analysis has reasonable and consistent preconditions, solves the problem of difficult acquisition of basic data, makes time PSF assessment more accurate and reliable, and improves the accuracy of personnel error probability (HEP) evaluation in digital main control room, so as to provide reference for HRA staff. In addition, through the implementation of the calculation method, it is helpful to analyze the relevant actions with high probability of human error, and further optimize the function allocation and system design.

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