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Identification of Error of Commissions in the LOCA Using the CESA Method

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1. Introduction

Errors of commission (EOCs) refer to the incorrect performance of such a task or the performance of an extraneous task with the potential to contribute to some system-defined failure, whereas errors of omission (EOOs) refer to the failure to perform a system-required task [1]. More practically, an EOC can be defined as the performance of any inappropriate action that aggravates the situation. The primary focus in current PSA is placed on those sequences of hardware failures and/or EOOs that lead to unsafe system states. Although EOCs can be treated when identified, a systematic and comprehensive treatment of EOC opportunities remains outside the scope of PSAs. However, some past experiences in the nuclear industry show that EOCs have contributed to severe accidents.

Some recent and emerging human reliability analysis (HRA) methods suggest approaches to identify and quantify EOCs, such as ATHEANA [2], MERMOS [3], GRS [4], MDTA [5], and CESA [6]. The CESA method, developed by the Risk and Human Reliability Group at the Paul Scherrer Institute, is to identify potentially risk-significant EOCs, given an existing PSA. The main idea underlying the method is to catalog the key actions that are required in the procedural response to plant events and to identify specific scenarios in which these candidate actions could erroneously appear to be required [7].

This paper aims at identifying EOCs in the LOCA by using the CESA method. First, this paper introduces the CESA method. This study is focused on the identification of EOCs, while the quantification of EOCs is out of scope. Then, this paper applies the CESA method to the emergency operating procedure (EOP) of LOCA for APR1400. Finally, this study presents potential EOCs that may lead to the aggravation in the mitigation of LOCA.

2. The CESA method

The CESA's process to identify EOCs complies with scheme action-system-scenario. Once a set of actions is defined by their consequences in terms of specific system states, two stages of screening become applicable. First, it is possible to screen on the basis of system failure importance measures, since the links between actions and system failures are deterministic. For a precisely defined action it can be determined explicitly whether it would result in a fault tree top or basic event, and (if so) which. Second, it is possible to screen on the basis of scenario frequencies, since the links between system failures and scenarios are deterministic as well. It can be determined explicitly in which event sequences a given system failure is modeled. This link points to relative likely scenarios in which an action may cause an important system failure ([1], p. 201).

Method steps 1-3 in Fig. 1. serve the implementation of the CESA's search scheme, i.e., identification of EOCs. On the basis of EOPs and related practices (e.g., with respect to manipulations associated with a procedural task), possible actions are selected and cataloged in step 1. The result is a plausible set of intervention options (i.e. credible possibilities for human-induced changes of system states) .

Step 2 deals with the identification of system failures (or degradations) that may result from these actions. Prioritization of system failures is mainly performed on the basis of the importance measures of the PSA top or basic events for these system failures. It is recommended to use the Risk Achievement Worth (RAW) for this purpose. For instance, the identification may focus on the PSA top (or basic) events with RAW>10. Each combination of a PSA top or basic event with a procedural action (that would contribute to a failure state) defines an EOC event, i.e., an operator action that may contribute to a system failure in some-at this point unspecified-scenarios.

On the basis of the accident sequences in the original PSA model, the scenarios in which an EOC event may occur are identified in step 3. It is recommended to focus on event sequences with a relatively high frequency. Event sequences that have similar performance conditions are grouped, and each group is defined as a scenario with the opportunity of the EOC event in question. The combination of an EOC event with a group of similar event sequences defines an EOC split fraction, i.e. an operator action that contributes to a system failure in a specific scenario. At this point, the specific scenario evolution and personnel responses that lead to the performance of the inappropriate action have not been determined. For each EOC split fraction, the procedural decision points and the scenario conditions corresponding to the branching criteria are analyzed, in order to identify the EOC paths.

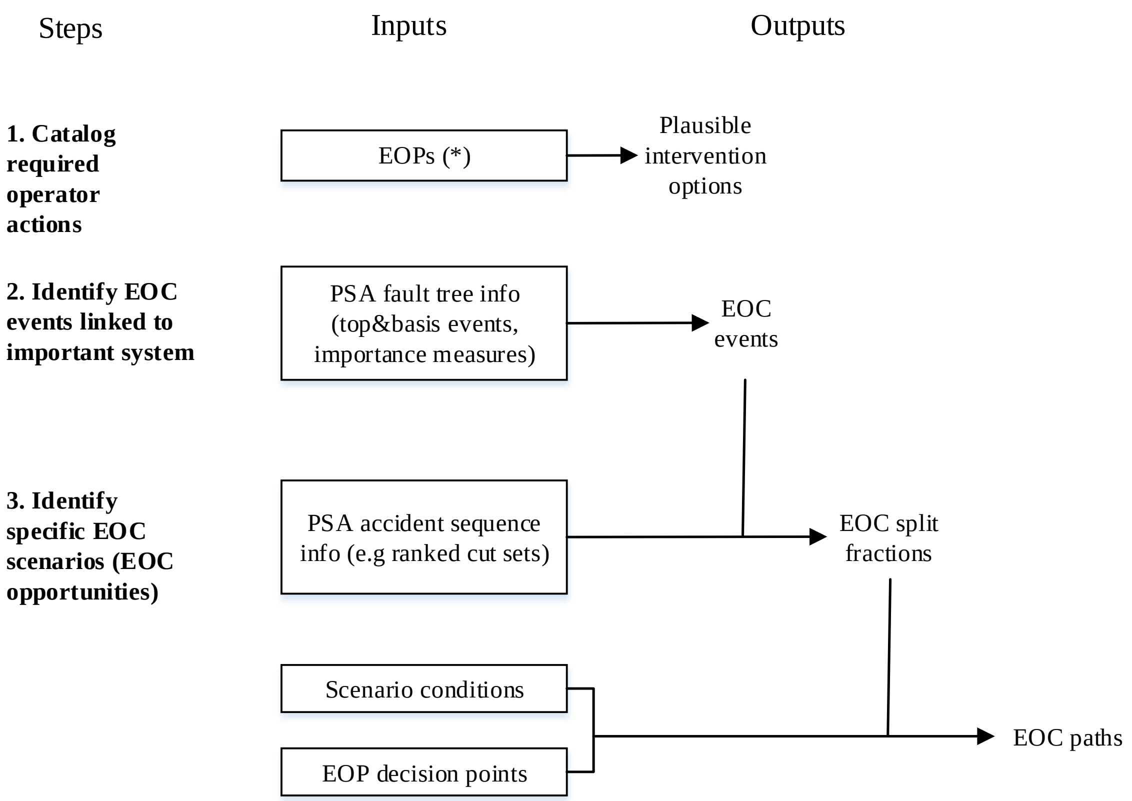

Fig. 1. Flow chart of the CESA steps [8].

3. Application of the CESA method to LOCA

This study applies the CESA method to the LOCA in APR1400. This section describes the process to identify EOCs for the accident.

3.1 Step 1: Catalog required actions

This step is to define and catalog possible operator actions to be considered as potential causes of system failure. This step catalogues the actions included in the EOP of LOCA. This study identifies the systems/components and operations actions in the EOP steps for LOCA. Table I shows a part of action catalog as an example. The complete catalog contains 54 actions in the EOP of LOCA.

Table I: Example of the action catalog of LOCA (CESA step 1)

System	Component ID	Action	Steps
Charging pumps	CV 01A CV 01B	Start	Step 5
RCP	RCP 01A/01B /02A/02B	Stop	Step 7.1
One RCP	RCP 01A/01B /02A/02B	Start	Step 29, Step 57
Affected RCPs	RCP 01A/01B /02A/02B	stop	Step 29, Step 57
Fan coolers	RCFC 001/ 002/003/004/ IHA	Operate	Step 11
Atmospheric Dump Valves	MSADV 106/ 105/108/107	Cool down	Step 14, Step 50
SI pump(s)	SIP02A/02B/ 02C/02D	Stop	Step 17, 40
SIT	SIT01A/01C/ 01B/01D	Isolate	Step 32
Containment Spray Pump	CSP01B/01A	Stop	Step 31

3.2 Step 2: Identify EOC events linked to important systems

The aim of Step 2 is to define EOC events, which are defined as operator actions that may contribute to the failure of PSA top events, i.e., the required systems or functions in the PSA safety model. The first screening is done by focusing on the PSA events with a Risk Achievement Worth (RAW) above a given threshold. Second, the catalog of candidate actions from Step 1 is compared against the fault trees for the PSA top event thus selected. The result of Step is a prioritized, more manageable number of EOC events for which specific scenarios will be identified subsequently.

Table II: Selected events with RAW>15, (CESA step 2)

EVENT ID	Description	Prob	RAW	System/function impacted
CCMPKQ4-PP01A/B/2A/B	Component cooling water system Motor driven pump	3.59E-07	6.97E+03	Motor driven pump failure
WOMPKQ4-PP01A/2A/1B/2B	Essential chilled water motor driven pump	2.06E-06	6.97E+03	Motor driven pump failure
VKHVKQ4-HV13A/13B/14A/14B	Auxiliary building controlled area HVAC cubicle cooler	2.23E-06	6.97E+03	HVAC cubicle cooler
SIMVWQ4-616/26/36/46	SI motor operated valve	1.78E-04	4.49E+02	Safety injection
SIMPWQ4-PP02ABCD	SI motor driven pump	9.94E-06	4.48E+02	Safety injection
SITKB2B-SIT01B	Safety injection tank	2.04E-06	1.93E+01	Safety injection
VGAHKQ4-AH01A/1B/2A/2B	ESW intake structure/CCW Hx building HVAC Blower fan	8.52E-06	6.97E+03	HVAC Blower fan
PGXMKQ4-ABCD	480V load center class 1E system transformer (480V>)	2.52E-08	6.95E+03	Class 1E system
EFGXKO8-PA03ABCD	Engineering safety features actuation system	4.29E-07	4.75E+01	LCA-DET
CSMVWD2-003/004	Containment spray system	1.44E-04	2.78E+01	Motor valve
CSCVWD2-V1007/1008	Containment spray system	1.05E-05	2.78E+01	Check valve
RPBPWO8-BSALL	Reactor protection system computational module for bistable, RP bistable processor	1.30E-05	1.93E+01	RP bistable processor

Table III: Candidate EOC events from the CESA search (CESA step 2)

Description	RAW	System/function impacted	Procedure Step
Inappropriate termination of SI system	4.49E+02	Safety Injection System: motor operated valves and SI pumps	Step 17, 40
Inappropriate isolation of Safety Injection Tank	1.93E+01	Safety Injection Tank	Step 32
Inappropriate termination of Containment Spray System	2.78E+01	Containment Spray System: CS pumps, motor operated valves and check valves	Step 31

This study chose the RAW value of 15 as the threshold. From the PSA result of APR1400 [9], 152 basic events are selected as shown in Table II and can be categorized into 12 systems as follows:

- ESF component control cooling system logic controller
- Component cooling water system
- Essential chilled water
- Auxiliary building controlled area HVAC cubicle cooler
- Safety injection system
- Essential service water system
- ESW intake structure/CCW
- 480V load center class 1E system transformer
- Engineering safety features actuation system
- Containment spray system
- Reactor coolant system
- Reactor protection system

Then, this study compares the important events with the result of Step 1, i.e., the action catalog, based on the systems. The objective of this task is to find the candidate EOCs that may disable the function of important systems. As a result, this study identifies three candidates of EOCs as shown in Table III.

3.3 Step 3: Identify specific EOC scenarios

Step 3 compares the EOC events retained in Step 2 against the top PSA accident sequences to obtain the most important accident sequences with potential EOC contribution. The result of Step 3 is a set of scenario-specific EOCs.

This study reviews top 100 accident sequences from the APR1400 PSA result. Then, this analysis investigates an opportunity for the EOC event as well as contextual factors that would suggest a low likelihood of the EOC. "Finally, one EOC scenario and EOC path are identified as a result".

Inappropriate termination of SI system

In a few steps, the EOP requests the operator to terminate the safety injection when all the specific conditions are met. The termination condition includes:

- RCS subcooling margin > 15 °C
- Pressurizer level is larger than 30%, and the level is stable or increasing.
- At least one steam generator is available for RCS heat removal.
- Reactor vessel level > 15%.

In the small break LOCA, there is a possibility that these four conditions are satisfied and the operator terminates all the trains of the safety injection inappropriately. The small break LOCA and failure of safety injection is one of top accident sequences in the APR1400 PSA.

4. Conclusion

This study has identified the EOC events for APR1400 in the LOCA using CESA method. The result identified three candidate EOCs event using operator action catalog and RAW cutset of LOCA. These candidate EOC events are inappropriate terminations of safety injection system, safety injection tank and containment spray system.

Then after reviewing top 100 accident sequences of PSA, this study finally identified one EOC scenario and EOC path, that is, inappropriate termination of safety injection system. The failure of safety injection is one of top accident sequences in the APR1400 PSA.

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