Analysis of Unexpected Reactor Trips from the Perspectives of Safety I and Safety II

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1. Introduction

Most of people think safety as the condition where the number of adverse outcomes, i.e., accidents, incidents, and near misses, is as low as possible [1]. From the perspective of Safety I concept, increasing safety means reducing the number of failures by precautionary measures such as rigid policies, more rules, and additional constraints. However, the safety management and evaluation may not fit for highly-complicated industries such as nuclear power plants (NPPs). It can limit the ability of the people working in the highly-complicated system to adapt, thereby unintentionally creating a more brittle and less flexible system [2].

Hollnagel, et al., suggested that safety management should therefore move from ensuring that 'as few things as possible go wrong' to ensuring that 'as many things as possible go right' [3]. This perspective is defined as Safety II; it relates to the system's ability to mitigate under varying situations. The Safety II concept assumes that the performance variability provides the adaptations that are needed to respond to various situations, and therefore it focuses on the condition that things go right. Human factors are consequently considered as a resource necessary for system flexibility and resilience [1]. In this paper, Safety II is defined as combined concept with Safety I and resilience because Safety II focuses on things go right and trying to understand how that happens and how things go right for explaining how things occasionally go wrong.

This study attempts to analyze event reports of unexpected reactor trips from the perspectives of Safety I and II. This study reviewed 222 event reports released in the OPIS since 2003, based on the characterized resilience model for unexpected reactor trips in NPPs. Then, correlation analysis between the investigated database, i.e., the data of characterized resilience factors on each event, and event severity, has been carried out from the perspective of Safety I and II.

2. Characterized resilience model for unexpected reactor trips in NPPs

Characterized resilience model is used for analysis on the perspectives of Safety I and II. The resilience in NPPs refers to an ability of the NPP to adjust its safety-related functions prior to, during, or following emergency situations [4]. The concept of resilience is based on combined principles of Safety I and Safety II [5]. A resilient system responds to regular and irregular variability of the system either by implementing a prepared solution or by adjusting normal functioning.

This study uses the characterized resilience model as shown in Fig. 1, for analyzing the events [6]. This model is modified from the Électricité de France (EDF)'s Emergency Operating System model [7]. It is composed of five high-level attributes and corresponding low-level factors. More explanation on the high-level attributes and low-level factors are as following.

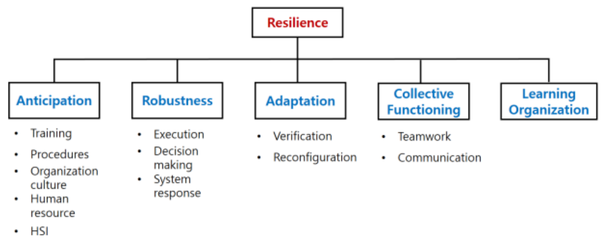

Fig. 1. Characterized resilience model for unexpected reactor trips in NPPs

Anticipation refers to the measure of NPP preparedness before an event. In order to identify the symptoms that potentially become threats and further prevent them from happening, competence personnel, completeness of the hardware, and good organization are required. This item includes emergency operating procedures, operators' training program, and human resource as it is expected to impact the crew behavior in response to an initiating event.

Robustness characterizes the way in which the NPP carries out the decided response strategy and makes sure that the strategy is correctly applied. It is related to how the NPP determines the suitable strategy (or rules) corresponding to the event and performs those actions correctly. Thus, it consists of System Response, Decision Making, and Execution.

Adaptation characterizes the way in which the NPP develops the strategy to cope with (adapt to) an initiating event or any change in the plant state that requires a change in the crew response strategy. A resilient system responds to regular and irregular threats in a robust, yet flexible, manner. Actual events may not often match the expected situations and therefore it's impossible to have ready solutions to problems [8]. In case that there is an unexpected event or the current strategy is not effective, the system needs to respond by adapting itself to the new situation instead of trying to maintain stability. Thus, Adaptation is the ability to detect deviations from expected or unexpected paths and to readjust operation accordingly [9]. In this light, Adaptation consists of Verification and Reconfiguration.

Collective Functioning is the measure on how plant personnel work as a team to complete a task or achieve a common goal. Nuclear power plant control room crew performs the plant operational tasks collectively. The resilience of complex systems such as NPPs emerges in the core of team coordination and cooperation processes [10]. Thus, Collective Functioning addresses two major components in this study: Communication and Teamwork.

Learning organization refers to the process in which the organization creates new knowledge or modifies existing knowledge. The effectiveness of learning from experience depends on which events or experiences are considered, as well as on how the events are analyzed and evaluated.

3. Method

This study reviewed 222 event reports from the OPIS since 2003. By using the characterized resilience model, contributing factors to two situations, i.e., 1) the occurrence of initiating event, and 2) the response to initiating event, are investigated. The former part is coded either "–" or "0" and arranged into the matrix form. The factors coded as "–" represent the negative effect which contributes to the event occurrence, and the factors which have no contribution will be coded as 0. On the other hand, factors coded as "+" are not measured in this part because functioning properly is not confirmed in viewpoint of initiating event.

The response to initiating event is coded as "+", "–" or "0", and then arranged into the matrix form. The factors coded as "+" mean that they function properly in the response to the initiating event and the codes of "–" and "0" have same meaning as in the occurrence of initiating event. Finally, Table I shows an example of analysis results including the information on plants, units, dates, operating modes, and initiating events.

A severity evaluation on each event was performed by applying the procedure of quantitative event severity evaluation [11]. It consists of six categories for evaluation, i.e., 1) safety function impact evaluation, 2) risk impact evaluation, 3) in-site radiation impact evaluation, 4) off-site radiation impact evaluation, 5) emergency response ability evaluation, and 6) human error impact evaluation. These should be review to quantify the final level of event severity. Lastly, final level of event severity is classified into 6 levels and quantified values, i.e., green (0), white (1), white~yellow (1.5), yellow (2), yellow~red (2.5), and red (3). Green level means relatively well-mitigated event, while Red level represents comparatively badly-mitigated event.

4. Analysis on the perspective of Safety I and Safety II

This study aims to analyze event reports of unexpected reactor trips from the perspectives of Safety I and II. The data from event reports is collected, based on the low-level factors in characterized resilience model. First, correlation analysis, between the total number of negative effects which are corded as "–" on each event and event severity with while and over, was performed on the perspective of Safety I. Event severity of "white or over" represents relatively badly-mitigated event, i.e., adverse outcomes. Second, correlation analysis, between the sum of the negative and positive effects on each event and all the event severities in the database, was performed on the perspective of Safety II. In addition, which low level factor of characterized resilience model contribute to event severity is analyzed on the perspectives of Safety I and II.

Table I: Database of event reports

No.	Plant	Unit	Date	Operation Mode	Initiating event	Occurrence of initial events – Anticipation: Training	Anticipation: Procedures	Anticipation: Org. Culture	Anticipation: Human Resource	Anticipation: HSI	Robustness: System response	Robustness: Decision making	Robustness: Execution	Adaptation: Verification	Adaptation: Reconfiguration	Collective functioning: Communication	Collective functioning: Team work
1	Hanul	5	2016-12-20	1	HW						-						
2	Shin-gori	3	2016-10-31	1	HW		-	-			-		-				
3	Wolsong	4	2016-09-12	1	EE												
4	Wolsong	3	2016-09-12	1	EE												
5	Wolsong	2	2016-09-12	1	EE												
6	Wolsong	1	2016-09-12	1	EE												
7	Shin-wolsong	12	2016-09-12	1	EE												
8	Gori	Gori 1,2,3,4, Shin-gori 1,2,3	2016-09-12	1	EE												
9	Shin-gori	3	2016-08-20	1	HW						-						
10	Hanul	5	2016-07-25	-	-												
11	Wolsong	1	2016-07-22	1	HW						-						
12	Wolsong(Shin-wolsong)	Wolsong 2,3,4, Shin-wolsong	2016-07-05	1	EE					-	-						
13	Shin-gori	3	2016-07-04	1	HW						-						
14	Shin-gori	3	2016-06-13	1	HW						-						
15	Hanul	2	2016-05-12	3	HW					-	-						
16	Wolsong	1	2016-05-11	1	HW		-						-				
17	Hanul	4	2016-05-09	1	HW						-						
18	Shin-gori	3	2016-03-29	6	HW						-						
19	Hanul	3	2016-03-04	-	-												
20	Hanbit	1	2016-02-27	1	HW						-						
21	Shin-wolsong	2	2016-01-28	1	HW						-						
22	Shin-gori	3	2016-01-24	1	HW						-		-				
23	Hanul	1	2016-01-19	1	HW						-						
24	Wolsong	2	2015-10-30	3	EE						-		-				
25	Gori	4	2015-09-03	1	HW						-						
26	Hanbit	2	2015-08-08	1	HW						-						
27	Hanbit	2	2015-06-03	1	EE						-						
28	Wolsong	4	2015-05-14	1	HE	-	-			-			-				

No.	Response of initial events – Anticipation: Training	Anticipation: Procedures	Anticipation: Org. Culture	Anticipation: Human Resource	Anticipation: HSI	Robustness: System response	Robustness: Decision making	Robustness: Execution	Adaptation: Verification	Adaptation: Reconfiguration	Collective functioning: Communication	Collective functioning: Team work	Learning Organization	Event severity evaluation	Level of severity evaluation
1		+					+	+	+	+				Green	0
2		+					+	+	+	+				Green	0
3		+				+	+	+						Green	0
4		+				+	+	+						Green	0
5		+				+	+	+						Green	0
6		+				+	+	+						Green	0
7		+				+	+	+						Green	0
8		+				+	+	+						Green	0
9							+	+						Green	0
10															0
11		+				+	+	+						Green	0
12		+				+	+	+						Green	0
13		+				-	+	+	+	+				white	1
14							+	+						Green	0
15							+	+	+	+				Green	0
16		+					+	+	+	+				Green	0
17		-					+	+	+	+				Green	0
18							+	+	+	+				Green	0
19															0
20		+	-	-		+	+	-	+	+	-	-	-	white	1
21		+					+	+					+	Green	0
22		+					+	+	+	+				Green	0
23		-				+	+	+	+	+				Green	0
24		+					+	+						Green	0
25		+				+	+	-						Green	0
26		+				+	+	+					+	Green	0
27						-	+	+	+	+				Green	0
28							+	+					-	Green	0

4.1 Analysis on the perspective of Safety I

4.1.1. Correlation analysis

Correlation analysis, between the total number of negative effects which are corded as "–" on each event and event severity with while and over, was performed on the perspective of Safety I. As a result of correlation analysis, it has correlation coefficient 0.325 (p-value > 0.05). Although this result is not satisfied with 95% confidence level, p-value is approximate to 0.05.

4.1.1. Contribution of low level factors

Contribution of low level factors with the number of negative effects to the event severity of "white and over" is investigated on the perspective of Safety I. Fig. 2 shows contribution of low level factors by total number of "–" (it includes the occurrence of initiating event, and the response to initiating event) based on the characterized resilience model. The result indicates that the system response, the execution, and decision making account for 16%, 15.43% and 10.29%, respectively.

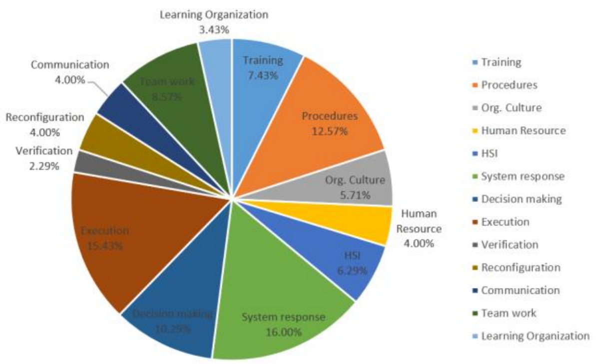

Fig. 2. Contribution of low level factors on the perspective of Safety I

4.2 Analysis on the perspective of Safety II

4.2.1. Correlation analysis

Correlation analysis, between the sum of the negative and positive effects on each event and all the event severity in the database, was performed on the perspective of Safety II. In the case of the sum of the negative and positive effects, it is assumed that positive effects may offset the negative effects. As a result of correlation analysis, it has correlation coefficient -0.585 (p-value < 0.05). This result is satisfied with 95% confidence level.

4.2.1. Contribution of low level factors

Contribution of low level factors is made on the perspective of Safety II. Left side of Fig. 3 shows contribution of low level factors by total number of "–" (it includes the occurrence of initiating event, and the response to initiating event), and the right side represents contribution of low level factors by total number of "+" according to the characterized resilience model. In addition, positive effect values in the middle of table are defined to compare the relative influences on the positive effects. The positive value is calculated by following equation:

$$\textit{Positive effect value} = \frac{\textit{The number of possitive effects}}{\textit{The number of negative effects}}$$

As a result, positive effect values are: verification (15.25%), decision making (7.45%), reconfiguration (7.13%), and etc.

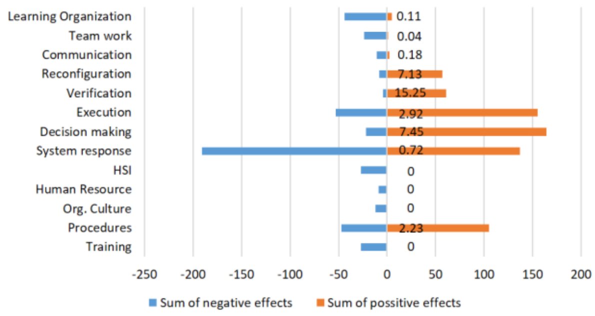

Fig. 3. Contribution of low level factors on the perspective of Safety II

5. Conclusion

This study attempts to analyze event reports of unexpected reactor trips from the perspectives of Safety I and II. This study reviewed 222 event reports released in the OPIS since 2003, based on the characterized resilience model for unexpected reactor trips in NPPs. Additionally, event severity evaluation on each event was performed by the procedure of quantitative event severity evaluation. Then, correlation analysis between the analyzed data and event severity was performed on the perspective of Safety I and II.

As a result, analysis on the perspective of Safety II shows correlation coefficient -0.585 with significance level, while that of Safety I is not satisfied with significance level. Through this results, Safety II concept may be more reasonable and adequate than Safety I in NPPs. So therefore, it needs more application to the different situation, and is necessary to support conventional safety assessment methods with Safety II concept.

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