Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

A Computer Program for Assessing Nuclear Safety Culture Impact

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1. Introduction

Through several accidents of NPP including the Fukushima Daiichi in 2011 and Chernobyl accidents in 1986, a lack of safety culture was pointed out as one of the root cause of these accidents. Due to its latent influences on safety performance, safety culture has become an important issue in safety researches. Most of the researches describe how to evaluate the state of the safety culture of the organization. However, they did not include a possibility that the accident occurs due to the lack of safety culture. Because of that, a methodology for evaluating the impact of the safety culture on NPP's safety is required. In this study, the methodology for assessing safety culture impact is suggested and a computer program is developed for its application.

2. Methods and Results

2.1 Safety Culture Indicator (SCI)

SCI is set in order to determine the levels or characteristics of safety culture of the organization. By using these indicators, the quality of safety culture can be determined and the vulnerability of safety culture can be improved before the problem occurred. It shows a software aspect such as the compliance with the procedure and represents the aspects of organizational culture such as the attitudes and behaviors of individuals and organizations [1]. In this study, SCIs are developed with reference to the literatures related to SCIs and through root cause analysis of nuclear accident/incident reports in Korea [1-4]. It is classified in three category suggested in "Traits of a Healthy Nuclear Safety Culture" and presented in Table 1.
Nuclear regulatory agency in Korea which is KINS publishes the periodic inspection reports that contain comments and recommendations to improve the safety of nuclear power plants and gives information about NPP safety operation through their website. SCI assessment method is developed by using data from the periodic inspection reports and KINS website. The details of SCI and its assessment method are indicated in prior study [5].
The impact of each SCI on the nuclear accident can be different. Thus, it is necessary to calculate the weight of the SCIs. The AHP is suitable method for calculating indicator's weight because of these advantages: weights derivation, logical consistency verification, validity of the results and objectivity enhancement. The result of the AHP is represented in Table 2. It shows that attitude has the highest weight but communication has lowest weight. This result will be reliable data because consistency index is lower than 0.1. The total score of SCI can be expressed as:

$$\text{Total score of SCI} = \sum_i SCI_i \times W_i \ , \ i = 1 \sim 7 \qquad (1)$$

Table 1: SCIs and their definitions

Category	SCI	Definition
Individual Commitment to Safety	Attitude	Behavior toward nuclear safety
	Communication	Efficiency of exchanging information
Management Commitment to Safety	Highlighting safety	Operation that keeps safety as the overriding priority
	Resource	Magnitude of the human resource
Management System	Training	Degree of training for safe operation
	Procedure	Propriety of procedure to prevent unexpected accident
	Work management	Propriety of work supervisor and work plan

Table 2: Weight of SCIs

Category	SCI	Weight
Individual Commitment to Safety	Attitude	0.277
	Communication	0.053
Management Commitment to Safety	Highlighting safety	0.091
	Resource	0.055
Management System	Training	0.224
	Procedure	0.173
	Work management	0.126
Consistency Index		0.0708

2.2 SCII Model

Since NPP is operated and maintained by humans who are influenced by the organization for which they work, good or bad safety culture should be represented in the quantification of each term in a sequence cut sets of PSA. Typically, every accident sequence consists of an initiating event, plant hardware responses and human actions required to terminate the sequence. Safety Culture Impact Index model (SCII) is to evaluate the safety culture influences using PSA. It measures the changes of CDF which might be affected by these three categories: initiating events, hardware failures and human errors. The SCII is expressed as:

$$SCII = \sum_{i=1}^{3} SCII_i \quad (2)$$

$$\mathrm{SCII_i} = \frac{\mathrm{CDF_i(SC) - CDF}}{\mathrm{CDF}} \times 100 \quad (3)$$

i=1 : initiating events (IE)
i=2 : hardware failures (HW)
i=3 : human errors (HE)
$\mathrm{CDF_i}$(SC) : Core Damage Frequency considering safety culture impact for i
CDF : Core Damage Frequency not considering safety culture impact (origin CDF in PSA report)

2.2.1 Initiating events

It is one of important matters that issue about finding initiating events and complete set of accident sequence. Existing PSA methodology couldn't consider initiating events such as Chernobyl accident which was occurred by the lack of safety culture. Initiating events such as Chernobyl may classified as other initiating events. Therefore, if quality of organization is low, frequency of other initiating event should be considered highly. The quantification method for measuring safety culture impact on initiating events will be finished in future.

2.2.2 Hardware failures

There is a good example to describe the safety culture impact on hardware failures. For example, there are two pumps working in same system. In case of two pumps are well maintained and maintenance man is well trained, the failure probability of two pumps are smaller than exiting failure probability. At this point, the level of training can be common factor of two pumps failure. The correlation between pump failures events will be exist because of maintenance man's training level. Likewise, the concept of safety culture can be used as common factor of the components failures. Common uncertainty source (CUS) method is used to consider these correlation caused by safety culture [6]. The formula used in CUS method is as follows.

$$X_i = m_i X_{i0} \sum_{j=1}^{n} X_{\cdot j}{}^{\sigma_{ij}/\sigma_{\cdot j}} \quad (4)$$

$$\rho_{ij} = \sigma_{ij}{}^2 / \sigma_i{}^2 \quad (5)$$

$$\sigma_{ij} = \sigma_i \sqrt{\rho_{ij}} \quad (6)$$

ρ_{ij}: correlation fraction coefficient reflecting the effect of uncertainty source j on X_i
σ_{ij}: standard deviation of X_{ij}
m_i: median value of X_i
X_i: lognormal random variable of basic event i
X_{i0}: independent impact of X_i
$X_{\cdot j}$: any one of $X_{1j}, X_{2j}, \ldots, X_{kj}$
i: basic event
j: common uncertainty source (j=0 : independent effect)

In PSA, a lognormal distribution is used for the component failures. When a lognormal random variable as shown in following formula (4) is used, the probability of MCS will be changed by number of defined CUS and the value of correlation fraction coefficient. The correlations between basic events will increases when they share more CUS. The safety culture impact on basic events will increase when the correlation fraction coefficient is increased. Three CUS is defined to apply safety culture impact: system, component and failure mode. It is assumed that basic events are independent when the total score of SCI is 10. In case of that total score is 0, they have perfect correlation. On the basis of this assumption, the formula to find value of ρ_{ij} is expressed as follows.

$$\rho_{i0} = \frac{\mathrm{X}}{10} \quad (7)$$

$$\rho_{i1} = \rho_{i2} = \rho_{i3} = \frac{10-\mathrm{X}}{30} \quad (8)$$

X: Total score of SCI ($0 \le$ X ≤ 10)

2.2.3 Human errors

Fukushima (2011) and Chernobyl (1986) accidents have demonstrated that safety culture is the root causes of human errors. Despite the important role of safety culture has been recognized, HRA for PSA do not include the possible impacts of safety culture. In this study, SLIM (Success Likelihood Index Method) is used for integrating safety culture into human error probabilities [7]. The following algorithm is to calculate new HEP which contains safety culture impact.

$$New\ HEP = UB^{1-SLI} \times Mean^{SLI} \quad (9)$$

$$\text{SLI = Total score of SCI / 10} \quad (10)$$

New HEP : HEP that contains safety culture impact
Mean : mean value of the HEP
LOHEP : upper bound of the HEP

2.3 SCII Assessment Program

To get a new result of the minimal cut sets considering the safety culture impact, the SCII program using the C# language has been developed. This program summarizes and visualizes the safety culture impact for the reference plant. Figure 1 shows the main screen of the program developed. When the input data is obtained properly and applied in this program, the results are produced in the format shown in Figure 2-3 which is the output displays. The important ones among the outputs include the scores of each SCI and the value of SCII. The SCI can be also displayed as the histogram graph and the pie chart. It can be used for comparing each SCI of the reference plant. These graphs show the periodic monitoring results and the measures of the SCII changes of the reference plant.

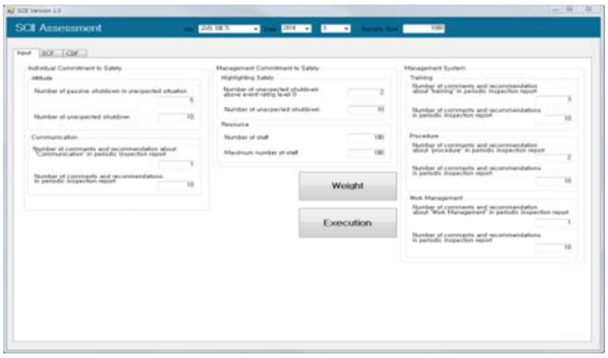

Figure 1: Main screen of the program

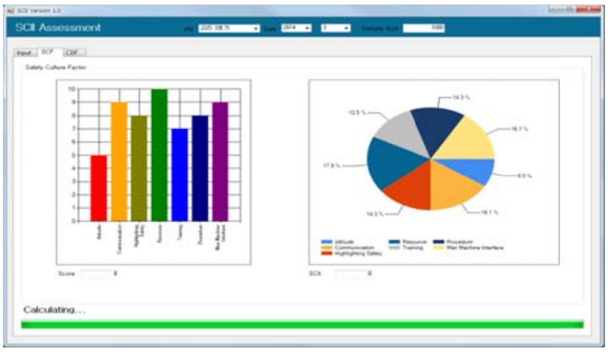

Figure 2: The output screen (SCI)

Figure 3: The output screen (SCII)

2.4 Results

In order to apply the developed SCII model to the reference nuclear power plant, the minimal cut sets are produced from by running the SAREX code. Kori Unit 3 is selected as the reference plant. For the reference plant, the number of the minimal cut sets is a value of 51,212 while the basic events are a value of 1,239. Monte Carlo method is applied to quantify the CDF results using the new minimal cut sets. The SCII values are also represented according to total score of SCI shown in Table 3. Since the impact of safety culture on hardware and human error increases, the value of SCII and CDF also increases. When the level of safety culture is the lowest, it can be confirmed that the risk is increased to 4.8 times greater. It shows that the safety culture affects the safety of nuclear power plant quantitatively.

Table 3: SCII of the reference plant

Total score of SCI	$SCII_{HW}$	$SCII_{HE}$	SCII	New CDF
10	0	0	0	7.32E-06
7.5	1.35E+01	3.06E+01	4.41E+01	1.05E-05
5	2.20E+01	8.03E+01	1.02E+02	1.48E-05
2.5	4.31E+01	1.64E+02	2.07E+02	2.25E-05
0	6.60E+01	3.10E+02	3.76E+02	3.48E-05

3. Conclusions

The SCII model which is the new methodology for assessing safety culture impact is developed. It estimates the safety culture impact quantitatively by using PSA model. The computer program is developed for its application. This program visualizes the SCIs and the SCIIs. It might contribute to comparing the level of the safety culture among NPPs as well as improving the management safety of NPP.

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