Development of a Novel Nuclear Safety Culture Evaluation Method for an Operating Team Using Probabilistic Safety Analysis

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1. Introduction

The term 'safety culture' was first introduced from the 4th report of International Nuclear Safety Advisory Group (INSAG) in International Atomic Energy Agency (IAEA) after Chernobyl accident [1]. Since there were more major issues to be concerned, such as reactor type and human factor engineering issues, apparently safety culture was not highlighted much in the past. However recent consecutive accidents, such as Fukushima accident, corruptions and concealments in domestic plants, and Sewol-ferry accident, allude the need to consider safety culture not only in nuclear industry, but also other safety-critical industries.

IAEA defined safety culture as follows:

"Safety Culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance."

Also, celebrated behavioral scientist, Cooper, defined safety culture as, "safety culture is that observable degree of effort by which all organizational members direct their attention and actions toward improving safety on a daily basis." with his internal psychological, situational, and behavioral context model.

With these various definitions and criteria of safety culture, several safety culture assessment methods have been developed to improve and manage safety culture. Representative methods are Independent Safety Culture Assessment (ISCA) developed by IAEA, Nuclear Safety Culture Assessment (NSCA) implemented by Nuclear Energy Institute (NEI) and independent Nuclear Regulatory Commission (NRC) safety culture assessment conducted by US-NRC [2-4]. Generally, experts conduct assessment with surveys (self-assessment), interviews, and observations to assess whole aspect of safety culture. Thus, there are some limitations. Assessment items are different from organizations and they are mixed with time scale. Results are only qualitative, dependent on the experts' judgment, and also dependent on the reliability of responses of individuals. Moreover, response analysis takes time, at least two weeks, to give results, so that there is a gap between the safety culture of present and the assessed time.

To resolve abovementioned limitations, we will suggest a novel team safety culture evaluations method using Probabilistic Safety Analysis (PSA) methods. We will unify and redefine safety culture assessment items for an operating team. Then, we will model a team safety culture using PSA to evaluate probability of team safety culture state. At last, we will validate the suggested method whether it is applicable to real situation or not.

2. Development of a Nuclear Safety Culture Evaluation Method

2.1. Team Safety Culture Assessment Items

To resolve the first limitation that the assessment items are different from organizations by organizations, we reviewed reports published from four nuclear-related organizations, which are Institute of Nuclear Power Operations (INPO), IAEA, NEI and US-NRC [5-10]. In redefining assessment items, we focused on team, which is the smallest acting unit in nuclear power plant. Then, Assessment items were grouped into 8 categories after reviewing the categories of the reports. Table 1 and Table 2 show the abbreviations of the categories, and detailed assessment items and their grouping for team safety culture. There are total 36 assessment items, and 3 to 5 assessment items are classified into each category.

Table 1. Abbreviations of categories

Category	Abbreviation
Operation Information Acquisition	IA
Personal Accountability	PA
Respectful Cooperation	RC
Recognition of Nuclear as Unique Technology	NU
Conservative Decision Making	CD
Questioning Attitude	QA
Regular Inspection	RI
Continuous Learning	CL

Table 2. Details of Assessment Items

Assessment Items	Category
Active use of trustable resources in workplace	IA
Understanding of not only individuals' own work but also whole plant situation	
Confirmation of safety-related deviations in workplace	
Confirmation of sub-contractors' awareness of changed resources to improve safety in workplace	
Accountability to arbitrate, manage, and correct the safety issues	PA
Recognition of accountability and authority to improve and maintain safety	
Recognition of individuals' accountability to safety that should not be imputed or damaged in any way	
Recognition and comprehension of safety culture principles	
Leadership taking the lead for safety actions	
Cooperation with users to decide safety-related improvements	RC
Action without dogmatic decision-making	
Alerting peers of their unsatisfactory accountability	
Trust and respect within peers	
Leadership not to give non-occupational stress	
Compliance with designed safety margin	NU
Special attention to work that can affect reactivity	
Special attention to work that can affect radiation confinement	
Prior consideration of safety issues	
Consideration of the profession, competences, and experiences of workers as valuable properties	
Compliance with procedures	CD
Reconsideration of decision-making with external and internal assessment	
Attitude to ask experts' opinions in unexpected situations	
Suspension and reexamination of work having uncertain results	
Understanding of importance to keep safety criteria	
Immediate reporting of violence or doubt in safety issues	QA
Reexamination of violence or doubt in safety issues	
Recognition of possibility of an unexpected situation occurring	
Leadership not to give a penalty for suggesting a different opinion	
Continuous self-assessment and independent supervising about tasks	RI
Continuous self-assessment for safety culture	
Maintaining and administrating systems and components so as not to interrupt decision-making	
Periodic monitoring of workplace	
Sharing and evaluating one's experience or working customs among peers	
Periodic learning and training	CL
Open-minded attitude to learn	
Leadership training	

2.2. Application of Probabilistic Safety Analysis

From the developed list of assessment items, we proceed to apply level 1 PSA to team safety culture. To apply level 1 PSA, event tree and fault tree must be developed first. Event tree describes how mitigation systems relieve the risk when initiating event occurs, and each failure probability of mitigation system is drawn with fault tree for each branch of event tree. Therefore, mitigation system itself is the top event of fault tree.

The assessment items we defined are the basic events of fault tree, which is the lowest rank of assessment. Therefore, intermediate events are naturally the categories of assessment items, but the top event is not easily conjecturable, which will be explained in the following paragraph.

Team safety culture can be divided into 4 parts, which are attitude to handle event when event occurs, attitude to prevent event recurrence after termination of the event handling, fundamental attitude the team should have, and attitude to cooperate. From the PSA point of view, each attitude can be interpreted differently.

Fundamental attitude is the attitude, the team should have, which implies, if this attitude is absent, it will affect to all other attitudes. Therefore, fundamental attitude will work as a common-cause failure of the team safety culture, so 'continuous learning' and 'personal accountability' categories are included in the fundamental attitude. The second attitude, which to cooperate can be treated as a recovery, since cooperation is revealed when someone feel others are carrying insufficient. 'Questioning attitude' category can be treated as an actuator of cooperation, and 'respectful cooperation' is the cooperation itself.

Other two attitudes, attitude to handle event and attitude to prevent event recurrence, are the ones could be affected by common-cause failure and recovery. 'Attitude to handle event' includes, 'information acquisition', 'recognition of nuclear technology as unique' and 'conservative decision making', which resembles monitoring, response planning, and response implementation process of the information process of the cognitive model. 'Attitude to prevent event

recurrence' only have one category, which is 'regular inspection'.

Therefore, 'Attitude to handle event' and 'attitude to prevent event recurrence' are the mitigation system of the event tree and the top event of the fault tree. In short, in my hypothesis, we could measure team safety culture by measuring two groups of attitude.

Based on this supposition, we developed event tree and fault tree of team safety culture. Figure 1 shows the event tree of team safety culture. Four states of team safety culture is defined depending on the success of two mitigation systems, attitude to handle event and attitude to prevent event recurrence.

Safe success state is the most desirable state among four, which infers the team have ability to both handle event and prevent event recurrence in safety culture point of view. Likewise, other 3 states were defined.

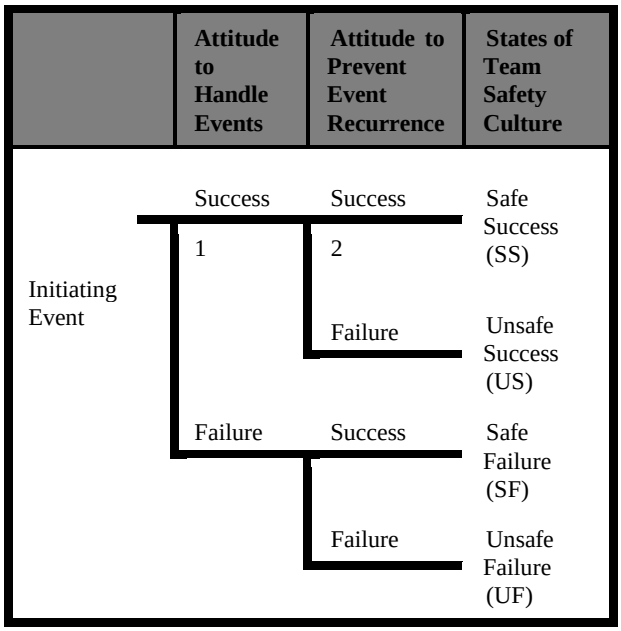

Fig 1. Event tree of team safety culture

In 1 and 2 branch, we could build success trees which have categories for intermediate events, and corresponding assessment items as basic events. The reason why we built success tree, not a fault tree, because safety culture is oriented from the success of safety culture. Success tree is developed mainly by ourselves, but we also considered the references of experts enough. Figure 2 and Figure 3 show the fault tree of each branch. Assessment items with subscript 'F' means final success probabilities, which common-cause failure and recovery is considered, whereas ones without it are nominal success probabilities. Figure 2 is describing the success tree of having attitude to handle events, and the figure 3 shows the success tree of having attitude to prevent event recurrence.

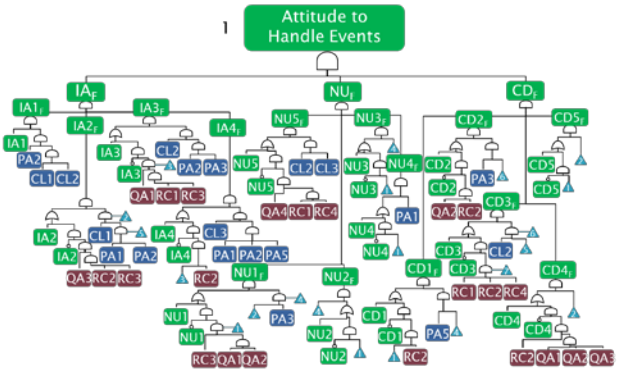

Fig 2. Success tree of having 'attitude to handle events'

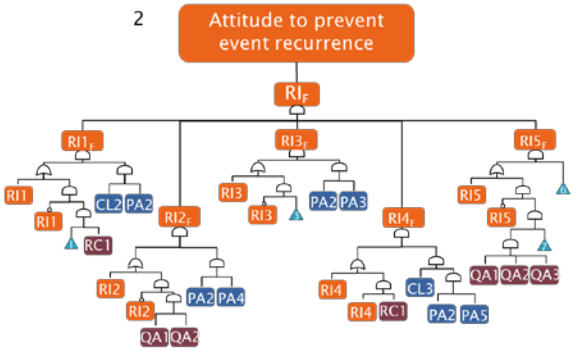

Fig 3. Success tree of having 'attitude to prevent event recurrence'

2.3. Method to Obtain Nominal Success Probabilities of Assessment Items

From section 2.3, we explained the how the team safety culture evaluation model was built. In this section, how to obtain nominal success probabilities of assessment items will be introduced, where nominal probability is the probability that the effect of common-cause failure and recovery are not considered.

The hardest issue in measuring safety culture is, it is hard to quantify the assessment items. There were metric index approach and scaled self-assessment approach, but the effectiveness was low. In this study, we tried to apply 'operational definition' to get nominal success probabilities of assessment items. Operational definition is a method frequently using measure in phycology to figure out one's mental state and corresponding attitudes by listing the concrete actions or other observable facts of the mental states can have. Table 3 shows the operational definition of each assessment item for an operating team. It is hard to list all the success cases and failure cases of each assessment item, since about 3 cases are arranged in each assessment item, so Table 3 shows only the 5 assessment items of the list.

Table 3. Operational definition of each assessment item

Assessment Items	Normal Cases	Failed Cases
-Accountability to arbitrate, manage and correct the safety issues (PA1)	-No one pointed out, eve the process is going wrong -No one pointed out and ignored the failure symptom or variables -Ignorance of other opinion	-Active discussion when different opinion is brought -Active discussion about failure symptom and variables
-Recognition of accountability and authority to improve and maintain safety (PA2)	-No one pointed out and ignored the failure symptom or variables -Unsatisfied actions what have to be done	-Perfectly fulfilled action within the task
-Recognition of individuals' accountability to safety that should not be imputed or damaged anyhow (PA3)	- Blaming others - Blaming others for a failure cause	-Groping solution even if teammate made mistake -Perfectly fulfilled action within the task
-Understanding of importance to keep safety criteria (CD1)	- Violation of procedure	-Complied with procedure
-Compliance with procedures (CD2)	-Insufficient 3-way communication when making a decision -Violation of simultaneous confirmation step -Proceeding procedure without enough discussion within a team	-Fulfillment of 3-way communication and simultaneous confirmation step -Reexamination when problem occurs -Reexamination when failure symptom or variables are found

With these operational definition of an operating team, we could calculate the nominal probability.

$$\text{Nominal Success Prob. of an Assessment Item} = \frac{\text{Total \# of success cases}}{\text{Total \# of all cases}} \quad (1)$$

$$p\{\text{Attitudes to Handle Events}\} = \prod_{i=1}^{3}\prod_{j=1}^{k}[\,p\{\text{Assessment Items inducing failure of } i_j \text{ in CL}\} \times p\{\text{Assessment Items inducing failure of } i_j \text{ in PA}\} \times [\,p\{i_j\} + p\{\overline{i_j}\}\cdot p\{\text{Assessment Items for Recovering } i_j \text{ in QA}\} \times p\{\text{Assessment Items for Recovering } i_j \text{ in RC}\}]] \quad (2)$$

$$p\{\text{Attitude to Prevent Event Recurrence}\} = \prod_{l=1}^{5}[\,p\{\text{Assessment Items inducing failure of } i_l \text{ in CL}\} \times p\{\text{Assessment Items inducing failure of } i_l \text{ in PA}\} \times [\,p\{RI_l\} + p\{\overline{RI_l}\}\cdot p\{\text{Assessment Items for Recovering } i_l \text{ in QA}\} \times p\{\text{Assessment Items for Recovering } i_l \text{ in RC}\}]] \quad (3)$$

By Equation 1, nominal success probability of each assessment items can be given, and the success probabilities of 'attitude to handle event' and 'attitude to prevent event recurrence' can be calculated from the nominal success probabilities. Finally, the probabilities of having safety culture states are given as a result of suggested safety culture evaluation method. This profile of 4 probabilities, having certain state of team safety culture, might be unique team characteristic.

3. Validation of Suggested Safety Culture Evaluation Method

To prove whether the result of the suggested team safety culture evaluation method is trustable or not, we proceeded validation of the method. We assume that probability of 'attitude to handle event' implies the ability to handle event of an operating team, so it will show relevance with performance. In other words, we assumed the higher probability of 'attitude to handle event', the higher the performance of the operating team will have. Audio-visual recording data collected from a full scope main control room simulator of a NPP in Korea was analyzed. The data were independently analyzed with suggested method and performance measure. We used Operational Performance Assessment System (OPAS) to quantify the performance.

Table 4. Probability of 'attitude to handle events' and OPAS score

	Probability of 'Attitude to Handle Events' (p{SS}+p{US})	OPAS Score
Team1	0.036	39
Team2	0.138	68
Team3	0.254	74
Team4	0.902	83

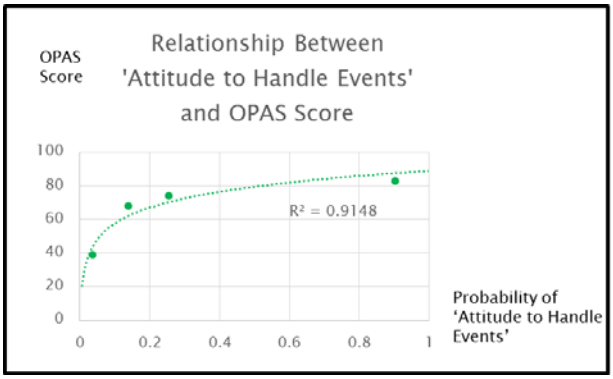

Figure 4. Relationship between probability of 'attitude to handle event' and OPAS score

Table 4 and Figure 4 show the relationship between probability of 'attitude to handle event' and OPAS score.

The result showed probability of 'attitude to handle events' increased, as the OPAS score increased. From the regression analysis result, there was a meaningful positive correlation between them, with R^2=0.9148, as we expected. The interesting finding was that, in high OPAS score range, suggested measure made more detailed analysis possible.

4. Summary & Conclusion

What we did in this study can be divided into 2 parts. The first part is the development of the quantitative safety culture evaluation method, and the second part is the validation of the suggested evaluation method.

To develop a new quantitative safety culture evaluation method for an operating team, we unified and redefined safety culture assessment items. Then we modeled a new safety culture evaluation by adopting level 1 PSA concept. Finally, we suggested the criteria to obtain nominal success probabilities of assessment items by using 'operational definition'.

To validate the suggested evaluation method, we analyzed the collected audio-visual recording data collected from a full scope main control room simulator of a NPP in Korea. Then we calculated the probability of 'attitude to handle events', which implies the probability of the two states, safe success and unsafe success. We compared this probability with OPAS score to find the meaningful insights, and the actual result showed positive relationship between probability of 'attitude to handle events' and performance. Moreover, we found that the suggested method will be useful in interpreting the operating team with high-leveled performance.

5. Further Study

For further study, failure mode and effect analysis (FMEA) will be applied to give prior assessment items to be solved to raise success probability of team safety culture. Most of the safety-critical assurance program recommends to use PSA and FMEA together for critical components [11]. Application of FMEA could suggest not only prior assessment items to be solve, but also solution to resolve it.

Additionally, more precise verification of whole process of suggested method might be required to be used in actual industry.

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