Approaches at KAIST NICIE Lab to quantifying safety culture in nuclear power plants

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Abstract: The aim of this study is to introduce quantitative evaluation methods for Nuclear Safety Culture (NSC) by three aspects of Nuclear Power Plant (NPP): individuals, operation team, and organization. Various NSC evaluation methods have been developed, and the Korea NPP utility company has conducted the NSC assessment according to international practice. However, the results are often qualitative, subjective, and mainly dependent on evaluator's judgement, so the assessment results can be interpreted from different perspectives. To resolve limitations of present evaluation methods, quantitative NSC evaluation methods for individual, operation team, and organization have been developed 3in Nuclear I&C and Information Engineering (NICIE) Lab. at Korea Institute of Science and Technology (KAIST). In this study, three methods will be introduced and verification process and applications of the methods will be reviewed.
Keyword: nuclear safety culture; quantitative evaluation; individual; operation team; organization

1 Introduction

The concept of Nuclear Safety Culture (NSC) was first appeared after the nuclear industry specific situation; the Chernobyl accident in 1986, while the professionals in newly organized group called the International Nuclear Safety Advisory Group (INSAG) under the auspice of International Atomic Energy Agency (IAEA) investigated and discussed about the accident. [1]

The concept of NSC is well defined in the IAEA Safety Report Series No.75, INSAG-4: "Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance" The nuclear industry worldwide had paid attention to NSC since. Institute of Nuclear Power Operations (INPO) and Nuclear Energy Institute (NEI) published methods and guidelines to strengthen NSC for respective Nuclear Power Plants (NPPs). [2-[4] Also, the United States Nuclear Regulatory Commission (U.S.NRC) announced Safety Culture Policy Statement in 2011, [5] and the leading organizations' effort to remind every nuclear related entity of NSC.

One field of efforts to strengthen NSC was to develop NSC assessment methods. Although there exist different assessment methods, the target of each NSC assessment is all to manage and improve characteristics and attitudes of individuals and organizations. Independent Safety Culture Self-Assessment (ISCA) [6] developed by the IAEA, Independent NRC Safety Culture Assessment [7] from the U.S. NRC, and the Nuclear Safety Culture Assessment (NSCA) survey process [8] developed by the NEI are mostly adopted NSC assessment methods throughout the world. These methods commonly contain the survey, interview, and observation modules with different items of assessment. Since all methods have the similar frameworks, result forms are more or less the same; qualitative and subjective. In addition, the reliability of results is often dependent on respondents, and the analysis process takes several days to weeks to provide results including preparation and schedule arrangement. To resolve the limitations, Nuclear Instrumentation & Control and Information Engineering (NICIE) Lab. at Korea Advanced Institute of Science and Technology (KAIST) have been endeavored several years to develop quantitative

Received date: August 24, 2018
(Revised date: September 7, 2018)

NSC evaluation methods within individual, operation team, and organization aspects.

In this paper, three methods will be reviewed, and verification process and applications of the methods will be introduced.

2 Development of quantitative NSC evaluation methods

Quantitative NSC evaluation methods developed by NICIE Lab. have focused on three different perspectives of NPP: individual, operation team, and organization. In this section, three of each method will be introduced.

2.1 Individual NSC

Development of individual NSC competency assessment was projected and conducted with the support of ministry of industry and commerce of Korea. To quantify NSC of individual, we adopted competency concept to NSC. Spencer said "competency is underlying characteristics of an individual that are causally related to effective or superior performance in a job with one's internal psychological, situational, and behavioral context model." [9] Therefore, for individuals, competencies towards NSC will act important roles to maintain NPP safe. Competency includes both implicit and explicit that are related to understanding and prediction of work performance. General competency model of an individual is shown in Fig. 1.

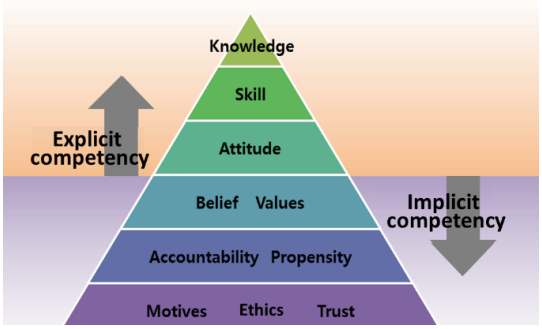

Fig. 1 General comptency model of an individual.

Elements in each competency have been derived within three levels of individuals: Executive manager, manager, and worker. Total 34 competencies were derived for executive manager level employee, 138 competencies were derived for manager, and 270 competencies for worker.

To evaluate competencies of individual, competency assessment methods were reviewed. Representative competency assessment methods are index utilization, role playing, behavioral observation, presentation, and survey. [10] Among the methods, index utilization and behavioral observation have been chosen to assess explicit competencies, and survey has been chosen to assess implicit traits of competencies.

After methodology has been settled, individual NSC competency evaluation method has been programmed into a software and extended to a system, which includes assessment portable terminal, individual database and personal computer. The schematic figure of a system and implemented methods are shown in Fig. 2.

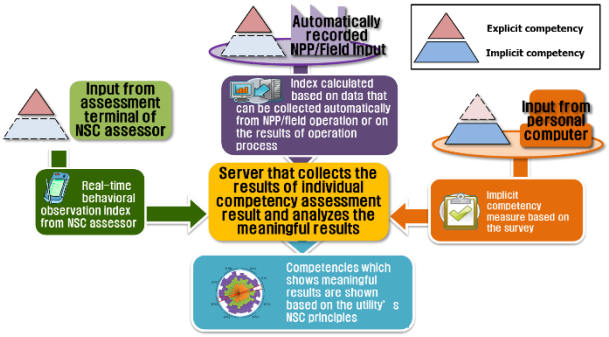

Fig. 2 Schematic figure of individual NSC asssessment system.

Three inputs, behavioral index, performance index, and survey result were collected from NSC assessor terminal, automatic recording or documentation from NPP/field, and personal computer, respectively. Server combined with database collects the inputs and analyzes individual competency for the meaningful results. Then the competency evaluation results were projected to utility's NSC principles to help real users to understand the result easily.

Developed individual NSC competency assessment has strength that it resolves the chronic limitation of survey, such as reliability and respondent-dependent issues. The method could sort out the surveys, such as excessive self-confidence about oneself, or inconsistent responses, which would lead NSC in a wrong direction, by comparing the converted score of indexes and survey. The result which shows a gap between index score and survey score will be represented with warning red-box. Addition to the

false response of the survey, absolutely low scored results will be marked also.

Verification and validation were conducted by the NSC experts, and found to be applicable to the Korean NPPs.

Detailed information is confidential and cannot be disclosed, but a summary of the project can be found here. [11]

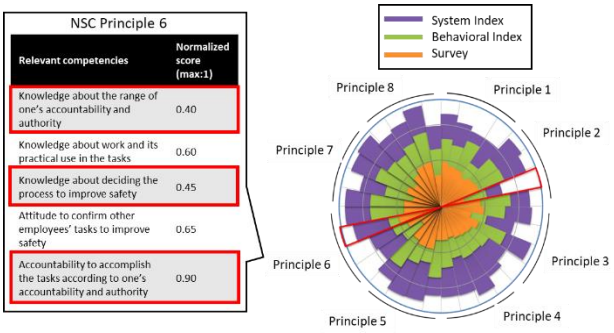

Fig. 3 Example of individual NSC competency result.

2.2 Operation team NSC

NSC of operation teams is one of the important aspect, because the core organization of the operating NPP is the operation team. Operation team NSC evaluation method has been developed for a master's thesis in NICIE Lab.

The main idea for operation team NSC competency evaluation is a probabilistic approach. Probabilistic Safety Culture Healthiness Evaluation Method (Pro-SCHEMe) was modeled with event trees and fault trees in the context of desirable safety culture.

NSC integrity and completeness of operation teams can be enhanced by achieving the following 3 sub-goals:

1) Reducing occurrence frequency of incidents and accidents by building a safety conscious working environment (SCWE) [12]
2) Managing and mitigating occurred incidents and accidents appropriately [1]
3) Re-examining so that preventing the recurrence of incidents or accidents [13]

If any one or more of these 3 sub-goals is not achieved, NSC is not in a desirable state. [14] Figure 4 shows the flow of sub-goals in the desirable NSC state.

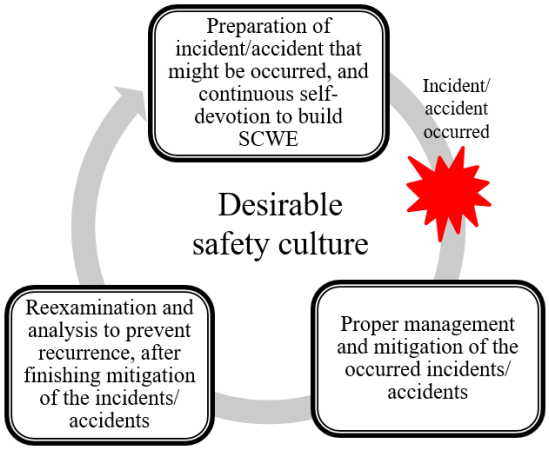

Fig. 4 Desirable NSC of an operation team.

For the first stage, safety culture assessment items from various organizations were re-classified and sorted out for the purpose of this research, namely operation team, because the definition, structure and contents of the assessment items in one nuclear related organization differ from those of others. Eight reports published by 4 major nuclear-related organizations were reviewed. [1-8] Total 36 assessment items, which are suitable for assessing NSC of the operation team, were selected and divided into 8 categories. Table 1 shows the 8 categories of assessment item and their acronyms. Detailed descriptions about assessment items can be found here. [15]

Table 1. Abbreviations of categories

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

The general NSC model is stemmed from 3 sub-goals of NSC, which can be evaluated by assessing the assigned assessment items, mentioned with Fig. 4. The relationship between a desirable NSC states and assessment items which belong to each sub-goal categories are shown in Fig. 5.

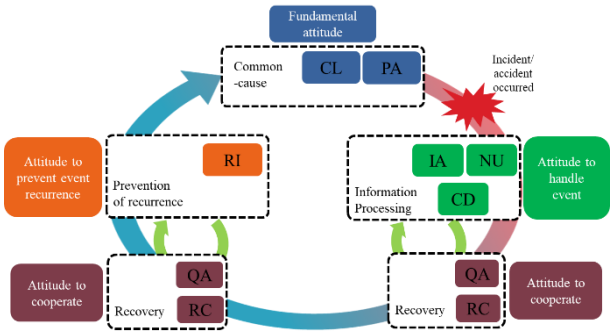

Fig. 5 Categories of assessment items in desirable safety culture context.

Then the assessment items were converted into event trees and fault trees. Figures 6, 7, and 8 show event tree of operation team NSC and success trees of each top event, respectively. The relationship between assessment items is expressed in success trees, which is more appropriate representation since the NSC aims for the success state to be, instead of fault trees.

In Fig. 7 and 8, the assessment items with subscript 'F' are final success probabilities considering CCF and recoveries, the assessment items without subscript 'F' are the nominal success probabilities, and the assessment items with small circle are the nominal failure probabilities. Literature survey and expert opinion were used to justify the credibility of the suggested success trees. [16][17][18][19]

Nominal success probabilities of basic events can be calculated by observing the operation team with following equation.

Nominal Success Prob. of an Assessment Item = Total # of success cases/Total # of all cases (1)

NPP operation team behaviors during emergency response training using a full scope simulator are recorded for this case study. Training scenarios for audio-visual data are a loss-of-coolant accident (LOCA), a steam generator tube rupture (SGTR), and anticipated transient without scram (ATWS) in a PWR type NPP in Korea. Observation guidelines which contains the criteria to decide success cases and failed cases and their description can be also found in here. Case studies showed that there is a positive relationship between the 'success' states of NSC and human performance, each team shows a unique ratio of safety success probability to that of an unsafe probability regardless of the scenarios, and the cut-set analysis by the proposed method provides not only root causes but also the latent causes of failures.

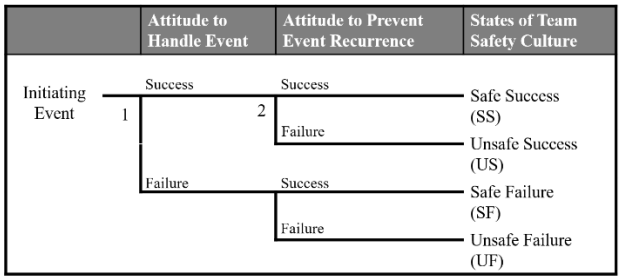

Fig. 6 Event tree of team safety culture and its probable states.

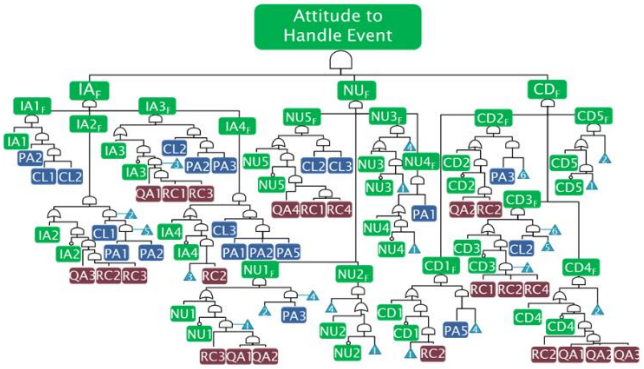

Fig. 7 Success tree of 'attitude to handle events'.

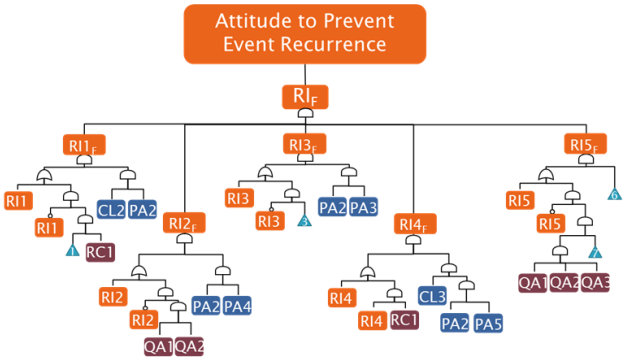

Fig. 8 Success tree of 'attitude to prevent event recurrence'.

2.3 Organization NSC

The ultimate quantitative NSC assessment should be conducted at the organizational scale, but it has difficulties due to the large scale and complexity to simulate the organization. Kim from NICIE Lab. has developed a quantitative assessment method, called Korean Safety Culture Assessment (KOSCA) model for organization NSC for his Ph.D. thesis with Bayesian network model.

Kim claimed the NSC aspect of organization consists of four parts: Norm system, Safety management system (SMS), Safety culture awareness of workers,

and worker's behavior, based on the literature review. [20-24]

Norm system includes all norms and values related to safety in NPPs. Norm system includes vision, policy, principle, and rules of organization which are essential to control worker awareness for safe operation at NPPs. Therefore, the existence of such norms is a starting point of safety culture within the organization. While the norm system defines the value of an organizational NSC, SMS represents the direct affect to the worker's behavior. The elements of SMS were determined based on the 19 common problems weakening safety culture. Resources, environment, training, procedure, and assessment level was chosen as the elements in SMS.

The mental model, NSC awareness of workers forms from their norm system, by which the value of an organization is defined, and the model is the beginning for a strong safety culture awareness. Norm system has an impact on operational procedure as well as the formation of new SMS. Safety culture awareness of workers is strengthened when their efforts to create and apply norm system are accumulated over a long period of time. In addition, safety culture awareness of workers can be positively or negatively affected while interacting with SMS. Conditions under which the SMS and norm system are incompatible can change safety culture awareness of workers in negative ways. Safety culture awareness of workers is exhibited through their behavior. The unconscious action of workers might lead to safe or unsafe conditions at NPPs.

To investigate the relationship among elements in NSC awareness workers, NSC traits in NRC, INPO, and IAEA reports were reviewed in the first place, and total 30 traits were selected. [2][6][7]

Then by the assumption that that the safety culture awareness of workers has three levels: artifacts, shared value, basic assumption, according to Schein's model of organizational culture. Schein divided organizational cultures into three levels. Artifacts are at the surface and include the visible products of the group, such as the architecture of its physical environment, its language, its technology and its products. Beneath artifacts are espoused values, such as conscious strategies, goals and philosophies. Basic assumptions and values represent the core, or essence, of the organizational culture. These basic assumptions form around deeper dimensions of human existence, such as the nature of humans and human relationships, as well as their activity, reality and truth. Factor analysis was conducted to confirm the classification of NSC traits. The relationship among categorized NSC traits is shown in Fig. 9.

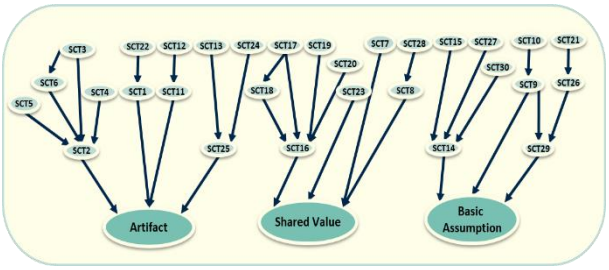

Fig. 9 Organizational NSC Traits and their relationship within 'NSC awareness of workers'.

Entire model includes norm system and SMS can be shown in Fig. 10.

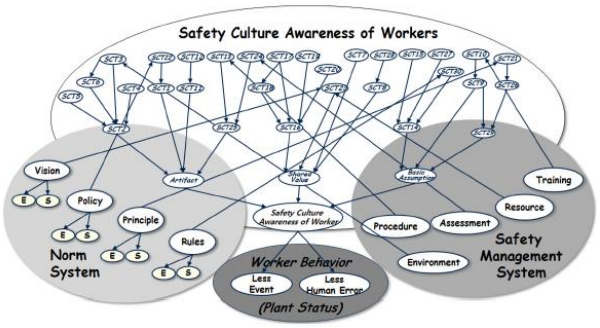

Fig. 10 KOSCA model.

Through sensitivity analysis of KOSCA model, 'principle' in norm system and 'training' in SMS affect to the plant safety the most, and 'rules' in norm system and 'procedure' in SMS affect to the plant safety the least. Thus, training is the element which can change the safety culture awareness of workers most positively when training for workers at a nuclear power plant is implemented periodically. Training and education are important to achieve strong safety culture awareness in workers. The level of safety culture at NPPs may increase when training for workers is implemented constantly and effectively. In addition, we verified that the procedure of SMS cannot easily change the safety culture awareness of workers positively even if the procedural quality at NPPs is highly advanced. In additional to norm system and

SMS, when NSC awareness of workers are associated, the combination of principle and training are the most affecting one that should be enhanced and constantly emphasized to improve the level of safety culture at NPPs. Detailed quantitative analysis results can be found in here. [24]

3 Conclusion

Until the quantitative NSC assessment methods have been introduced. NICIE Lab. have been endeavored several years to develop quantitative NSC evaluation methods in individual, operation team, and organization perspectives.

The developed methods resolved the limitations of current assessment methods, such as the results are qualitative and subjective, the reliability of results is often dependent on respondents, and the analysis process takes several days to weeks to provide results including preparation and schedule arrangement. The methods have an accent on the first attempt to assess NSC of individual, operation team, and organization with quantitative manner. In addition to that, the methods showed the validity through Korean NPPs, and the possibility to be further applied to any NPPs in any culture with various perspectives.

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