A methodology for a quantitative assessment of safety culture in NPPs based on Bayesian networks

Young Gab Kim [a,b], Seung Min Lee [a,c], Poong Hyun Seong [a,*]

[a] Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 291, Gwahak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea
[b] Korea Hydro & Nuclear Power Co., Central Research Institute, 70, 1312-gil Yuseong-daero, Yuseong-gu, Daejeon 34101, Republic of Korea
[c] Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, 34057, Republic of Korea

ARTICLE INFO

ABSTRACT

For a long time, safety has been recognized as a top priority in high-reliability industries such as aviation and nuclear power plants (NPPs). Establishing a safety culture requires a number of actions to enhance safety, one of which is changing the safety culture awareness of workers. The concept of safety culture in the nuclear power domain was established in the International Atomic Energy Agency (IAEA) safety series, wherein the importance of employee attitudes for maintaining organizational safety was emphasized. Safety culture assessment is a critical step in the process of enhancing safety culture. In this respect, assessment is focused on measuring the level of safety culture in an organization, and improving any weakness in the organization. However, many continue to think that the concept of safety culture is abstract and unclear. In addition, the results of safety culture assessments are mostly subjective and qualitative. Given the current situation, this paper suggests a quantitative methodology for safety culture assessments based on a Bayesian network. A proposed safety culture framework for NPPs would include the following: (1) a norm system, (2) a safety management system, (3) safety culture awareness of worker, and (4) Worker behavior. The level of safety culture awareness of workers at NPPs was reasoned through the proposed methodology. Then, areas of the organization that were vulnerable in terms of safety culture were derived by analyzing observational evidence. We also confirmed that the frequency of events involving human error decreases when the level of safety culture is high. It is anticipated that the causality between the safety culture awareness of worker and the state of safety at NPPs can be verified using the proposed methodology.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Accidents affecting systems that require high reliability, such as airplanes and nuclear power plants (NPPs), can result in significant damage to the public as well as loss of life. Therefore, significant safety-related research that may improve safety in these high reliability industries has long been prioritized. The variety of efforts intended to make safety the top priority in organizations have also created safety cultures. Typically, this safety culture process requires the changing of worker awareness. Safety culture terminology was introduced for the first time in the nuclear power plant domain after the Chernobyl accident in 1986 (INSAG, 1991). The concept of safety culture was then established to emphasize the

importance of cultivating attitudes, among employees and within organizations, which promote safety. The more recent Fukushima accident (2011) further highlighted the importance of safety culture in NPPs, and strengthened the need to create activities to enhance the safety culture awareness of workers. A good starting point for enhancing safety culture is to define exactly what safety culture means.

Uttal (1983) defined safety culture as "shared values and beliefs that interact with an organization's structures and control systems to produce behavioral norms". Later, Turner (1989) defined it as, "the set of beliefs, norms, attitudes, roles, and social and technical practices that are concerned with minimizing the exposure of employees, managers, customers and members of the public to conditions considered dangerous or injurious". The term 'Safety Culture' is more loosely used to describe the atmosphere or culture of corporations, in which safety is considered and accepted as the number one priority (Cullen, 1990). At 1991, the IAEA redefined safety culture as the assembly of characteristics and attitudes in

organizations and individuals that establishes, as an overriding priority, that nuclear plant safety issues receive the attention warranted by their significance.

There are several other common features of safety culture mentioned in other studies. First, it is a concept defined at the group level or higher that refers to shared values among all of the members of a group or organization. Second, it is concerned with formal safety issues in an organization, which are closely related to, but not restricted to, the management and supervisory systems of the organization. Third, it emphasizes the contributions of all members in their own positions in an organization. Fourth, it has an impact on the behavior of members at work. Fifth, it is reflected in an organization's willingness to improve safety by learning from errors, incidents, and accidents. Sixth, it is relatively enduring, stable, and resistant to change (Zhang et al., 2002). Many organizations have struggled to establish a healthy safety culture based on these common features. One action that is commonly taken among various efforts is to assess the existing safety culture in the organization. The purpose of safety culture assessment is to diagnose the level of safety culture in an organization and to improve any weaknesses that may be found. A safety culture assessment is generally performed by means of interviews or surveys. The IAEA (1996, 2008) has provided tools for safety culture assessment (e.g., Assessment of Safety Culture in Organization Team (ASCOT), Safety Culture Assessment Review Team (SCART), and the Independent Safety Culture Assessment Review (ISCA)) to member nations since 1994. IAEA's tools represent a comprehensive approach to assess the safety culture at nuclear facilities. However, the interviews focus mainly on management and the overall procedure is very time-consuming and costly. The Institute of Nuclear Power Operations (INPO) has also performed safety culture assessments of NPPs using an improved method (Nuclear Safety Culture Assessment). The NSCA approach, developed by the US Nuclear Energy Institute (INPO, 2009b,c), involves self-assessments (or independent assessments) with relatively increased sample sizes of both the interviews and observations. Data gathering methods include questionnaires, interviews and observations, and the results are analyzed based on INPO safety culture principles and attributes. Safety culture assessments in Korea are also performed by interview and survey methods. The assessment method was improved based on the INPO methodology in 2012. However, this approach is limited in that numerous workers should attend interviews. Moreover, the scoring rules are inconsistent (Mkrtchyan, 2012). The Safety Culture Oversight Process (SCOP, 2010), initiated in Romania, is a supplementary tool for inspectors to conduct safety culture assessments at licensees' organizations. This assessment was designed with support from the IAEA based on IAEA safety culture characteristics. Therefore, it is also limited in that it is time-consuming with an unclear data analysis process, similar to SCART.

Various methodologies for safety culture assessment have been suggested and applied by many institutes or researchers. However, the methodologies have the common limitation of time-consuming or subjective (qualitative) results which can be changed depending on the assessors. Even if a survey in the assessment process shows a quantitative result, it is only the statistical average value of measurement attributes. In addition, when safety culture assessment interviews have been executed, it is often found that many interviewees tend to think that the safety culture concept is abstract and unclear. Therefore, there has been little effort to establish a quantitative assessment method, as it is controversial and difficult to quantify a culture. However, Susana Garcia-Herrero et al. (2013) analyzed quantitatively the relationship between safety culture and organizational culture in nuclear power plants. In this methodology, it was established that probabilistic relationships among organizational culture factors can influence the safety culture based on a Bayesian network. This analysis procedure is very complex and the assessment scope is limited only to the relationship between the safety culture and the organizational culture. Therefore, a quantitative methodology for safety culture assessment is proposed in this paper because it has the potential to help measure the safety culture level of NPPs and to improve vulnerable areas in NPPs. The time and cost to assess the safety culture can be reduced through this methodology, and consistent results could be provided regardless of who performs the assessment. In addition, symptoms weakening safety culture can be revealed by observations of the resulting trends, and unwanted events at NPPs can be reduced. The quantitative safety culture assessment result can be used as an indicator for intervention before significant events occur. The safety culture assessment method was developed based on a Bayesian network (BN). It is a probabilistic graphical model which intuitively represents a set of random variables and their conditional dependencies. It utilizes causal knowledge when constructing models and provides a way to represent knowledge in an uncertain domain as well as a means by which to consider this knowledge. Therefore, Bayesian networks are selected to consider safety culture awareness and construct a safety culture model. BNs have been applied in different research as well related to safety. For instance, Zhou et al. (2008) proposed a BN model to establish a probabilistic relational network among causal factors, including safety climate factors and personal experience factors, which exert influence on human safety behavior. Martin et al. (2009) used BNs to analyze the factors affecting the performance of tasks that involve a high risk of falls from ladders or from other auxiliary equipment. Through the suggested safety culture assessment method, it is expected that the level of safety culture among members of NPP organizations can be measured quantitatively. This would allow the safety culture of NPPs to be enhanced by improving those areas where weaknesses have been verified by the proposed methodology.

2. Development of quantitative assessment method of safety culture

2.1. A framework of safety culture in NPPs

A framework of safety culture in NPPs is proposed. It consists of four elements based on literature surveys and expert opinions. There are the norm system, the safety management system, the safety culture awareness of worker, and worker behavior. Several researchers identified an interactive relationship between personal (psychological), situational and behavior factors in a model of safety culture (Reason, 1993; Heinrich, 1980; Cohen, 1977; Smith et al., 1978). Cooper also (2000a,b) found that this interactive relationship between psychological, situational and behavioral factors is applicable to the accident causation chain at all levels of an organization. Therefore, these three factors (person, situation, and behavior) were considered as the elements for a safety culture framework and were determined as the safety culture awareness of worker (personal), the safety management system (situational) and worker behavior (behavioral). The norm system was added to the safety culture framework for the following reasons. Norms in an organization influence the behavior of workers, and the importance of norms has been emphasized in numerous studies (Schein, 2004; Deal and Kennedy, 1999; Hofmann and Stetzer, 1996). Schwartz also stated that personal norms are determined by two factors: the awareness that performing (or not performing) a particular behavior has certain consequences, and the feeling of responsibility for performing a specific behavior (Schwartz, 1977). The safety culture level in NPPs is determined based on worker awareness level. The formation of worker awareness depends on the organization, specifically in how it provides direc-