Annals of Nuclear Energy 121 (2018) 305–315

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Approach for safety culture evaluation under accident situation at NPPs; an exploratory study using case studies

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ARTICLE INFO

Article history:
Received 24 April 2018
Received in revised form 10 July 2018
Accepted 12 July 2018

Keywords:
Safety culture
Severe accident
Quantitative assessment
Safety culture traits
Bayesian networks
Case study
Conditional probabilities

ABSTRACT

As advanced technology develops, it has been demonstrated by many accidents in the past that software (human) has a greater influence on safety than does hardware (equipment). Therefore, the software (human) of an organization should be focused on in order to enhance the safety in complex system industries. Safety culture plays an important role in the software of such organizations. Attempts to measure the worker safety culture awareness and to capture signs of their degradation are very difficult and highly uncertain. However, safety failures in the nuclear industry can lead to irreparable performance failures. Therefore, the industry has been continuing its efforts to measure the worker safety culture awareness and to improve weaknesses in organizations. It was confirmed in several studies that the probability of an accident is high at an organization with a low level of worker safety culture awareness (Vinodkumar and Bhasi, 2009; Morrow et al., 2014; Shirali et al., 2016). The previous paper suggested the method to quantitatively assess safety level of nuclear power plants. In this paper, the purpose is perform case studies in order to apply the suggested method to real nuclear power plant accidents. Weak safety culture traits through case studies assuming accident situation were analyzed and how the barriers of a nuclear power plant became vulnerable and how they contributed to the accident was identified. If this method proposed is applied to the real accident situation and extends to minor accidents at a nuclear power plant, workers can learn and understand how to behave in an accident situation and severe accidents can be proactively prevented. In addition to, the high frequency of weak safety culture traits analyzed, as a lagging indicator, could show which areas of a nuclear power plant are vulnerable, and their improvement will contribute to strengthen the safety of the nuclear power plant.

1. Introduction

Safety culture has not received much attention in high-reliability industries, which often put a high value on hardware systems. In such industries, it was a major concern and the best value to strengthen the safety equipment and to adopt multiple protective designs in order to enhance the system safety. However, researchers began to recognize that humans are an important part of the system after the occurrence of the Three Mile Island (TMI) accident. As advanced technology has developed, it has been demonstrated that software (human) has a greater influence on safety than does hardware (equipment). Safety culture plays an important role in the software of an organization. Safety culture is related with attitudes and behaviors shared for safety in an organization, as can be seen in numerous definitions of safety culture in literatures (INSAG, 1991; Uttal, 1983; Turner et al., 1989). It was identified that these attitudes and behaviors shared for safety have an interactive relationship in safety culture models proposed by many researchers (Reason, 1993; Heinrich et al., 1980; Cohen, 1977; Smith et al., 1978). Also, Cooper (2000) mentioned that this interactive relationship between these factors is applicable to the accident causation chain at all levels of an organization and this relationship was recognized in the work conducted to identify the organizational characteristics of high versus low accident plants (Cohen, 1977; Smith et al., 1978). Individual and group values and attitudes refer to members' perceptions about, and attitudes towards, safety goals. Patterns of behavior refer to members' day-to-day goal-directed safety behavior (Health and S. Commission, 1993). Therefore, the safety culture of an organization is controlled by the workers behaviors with the consciousness

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https://doi.org/10.1016/j.anucene.2018.07.028
0306-4549/

who attempt to operate complex systems safely and carefully. A higher level of safety is the result of a complex interaction between good design, operational safety and human performance. Nuclear power plants (NPPs) with excellent safety records also tend to be good performers (IAEA, 2000). Therefore, the strength of the safety culture can be inferred from the results shown by operational safety performance indicators (IAEA, 2001). However, workers in the nuclear industry still regard safety and production as conflicting objectives. When safety performance indicators are tampered with or are developed ambiguously without regard to workers' attitudes, it is difficult to say that excellent safety performance indicators indicate a strong safety culture of an organization. We know through operating experience over the past decades that the main causes of safety accidents were related to time pressure, because workers must follow a policy that emphasizes performance (i.e., production) in order to achieve the organization's goal. A negative correlation between workers' attitudes and accidents was confirmed in several studies (Vinodkumar and Bhasi, 2009; Morrow et al., 2014). The safety culture awareness of worker represents the knowledge level, beliefs, and unconscious mindsets that could affect the safety of NPPs (Kim et al., 2017). While measuring the safety culture awareness of workers is crucial in order to capture the signs of degradation, this is very difficult and includes significant levels of uncertainty. Therefore, the nuclear industry are trying to improve their weakness by making their efforts to measure the safety culture awareness of workers over several decades. Most studies of the safety culture of an organization begin with a clear definition of safety culture. Since the safety culture concept was introduced in INSAG (1991), it has been defined by several researchers and institutes (Turner et al., 1989; Cullen, 1990; IAEA, 2007; INPO, 2012). The International Atomic Energy Agency (2007) defined safety culture as an assembly of characteristics and attitudes in organizations and individuals that establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance. The Advisory Committee on the Safety of Nuclear Installations defined safety culture as a product of individual and group values, attitudes, perceptions, competencies and patterns of behavior that determine the commitment to and the style and proficiency of an organization's health and safety management (Health and S. Commission, 1993). The INPO (2012) also defined safety culture, calling it the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure the protection of people and the environment. Safety culture has also attracted attention as a safety management method in other safety-critical industries. Therefore, it is necessary to achieve a mutual understanding of safety culture by stakeholders in order to achieve safety goals. Safety culture does not generally change, and it includes attributes and behaviors reflecting all employees' basic assumptions, which do not easily emerge (Schein, 2004).

Safety culture is mostly evaluated in a qualitative manner. Safety culture assessment methods that are commonly used internationally include interviews, surveys, observations and document reviews. The IAEA (2002) recommended that they should be used in combination with several assessment methods although these methods have advantages and disadvantages at the same time. It is described that information on employee attitudes, opinions or perceptions can be collected by means of both a written questionnaire and an oral interview because there is not a single approach that can measure intangible safety culture. However, these methods are time-consuming and expensive (Mkrtchyan and Turcanu, 2012). Moreover, the evaluation results are limited because they are qualitative and subjective, depending on the evaluators. Intervention by the factor of personal subjectivity can degrade the consistency of evaluation results. In addition, evaluation results are likely to be affected by an organization's internal and external environment at the time of the evaluation. Even when evaluation results are presented in a quantitative manner, they simply show statistical values pertaining to safety culture elements and do not indicate connectivity with the overall safety culture result. Further, there are likely to be weak areas that can only be found in some parts of an organization because identified weak areas are derived only by fragmentary interviews or observations. In order to resolve those problems, a quantitative safety culture assessment methodology (KOSCA) was proposed (Kim et al., 2017). The time and cost required to assess the safety culture in an organization might be reduced through KOSCA model and consistent results could be expected regardless of who evaluates. The evaluation result, as a leading indicator, can contribute to the safety improvement in NPP. However, there has been rare to quantitatively evaluate the workers' safety culture awareness and weakness of the NPP when a real accident happens at a NPP. Safety culture awareness of workers at the time of the accident has important meaning for the safety improvement of NPP. The purpose of this paper is to evaluate the safety culture awareness of workers under nuclear accident situation. Literatures related to quantitative evaluation methodology about safety culture were reviewed and KOSCA model suggested in the previous paper was briefly introduced. Then weak safety culture traits were analyzed through case studies, TMI (Three Mile Island) accident and Fukushima accident. Here, weak safety culture is defined as safety culture traits which become weaken or less strong by the degradation of arbitrary barrier in a NPP. As a result, how the barriers of the NPP became vulnerable and how they contributed to the accident were identified. It is expected that this result contributes to preventing the recurrence of accidents and improving the safety at NPPs.

2. Safety culture assessment

2.1. Quantitative assessment methodology

Recently there have been many attempts to assess safety culture quantitatively. Mariscal et al. (2012) constructed the evaluation tool using the EFQM (European Foundation for Quality Management) model and assessed the safety culture of Spanish NPP quantitatively with a working group of experts. Morrow et al., (2014) performed the factor analysis to establish the factor structure of the survey. The overall measure of safety culture demonstrated statistically significant correlations with the safety performance measures of unplanned scrams, total ROP (Reactor Oversight Process) cross-cutting aspects and human performance error rate. Shirali et al. (2016) evaluated resilience safety culture quantitatively by utilizing the principal components analysis (PCA). Here, a safety culture with resilience, learning, continuous improvements and cost-effectiveness as its focus is referred to as resilience safety culture. Using data obtained with a questionnaire, PCA and numerical taxonomy (NT) assessment were performed to quantitatively evaluate the resilience safety culture of a petrochemical plant. This analysis led to the determination of a score for the resilience safety culture and its weakness in petrochemical units. Warszawska and Kraslawski (2016) introduced a new method, referred to as the assessment tree method (ATM), to quantitatively estimate the level of safety culture in an organization. The tree structure of the ATM is similar to that of a fault tree, a tool commonly used to analyze accidents. The assessment process was based on guided interviews and the results provided deeper insight and an effective means of identification of weak points in a specific safety culture. Especially using Bayesian network, various quantitative assessment methodologies were introduced and these methodologies are useful to make an inference about the value