



## Exploring the relationship between safety culture and safety performance in U.S. nuclear power operations



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### ABSTRACT

How do nuclear power plant workers, within a single national culture, perceive safety culture within their organizations? What is the relationship between safety culture and other indicators of safety? Is the construct of safety culture useful for predicting future plant performance? These questions were addressed in the current study using a survey administered to a sample of personnel at 97% of the nuclear power plants in the United States, resulting in 2876 responses from 63 nuclear power plant sites. Exploratory and confirmatory factor analysis revealed a multi-factor structure to the safety culture survey. For each nuclear power plant, the mean score for the total survey results and the factor means were correlated with organization-level performance indicators both concurrently and one year following the survey administration. Correlations suggested meaningful, statistically significant relationships between safety culture, as measured by the survey, and multiple nuclear power plant performance indicators. This study presents a unique look at safety culture across the United States nuclear power industry and takes a critical step toward establishing that safety culture is empirically related to safety performance.

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### 1. Introduction

The term “safety culture” was first introduced to the nuclear industry as part of the International Atomic Energy Agency (IAEA) assessment of the causes of the 1986 Chernobyl accident. The International Nuclear Safety Advisory Group (INSAG), an advisory group reporting to the Director General of the IAEA, concluded that “Formal procedures, properly reviewed and approved, must be supplemented by the creation and maintenance of a nuclear safety culture” (INSAG, 1986). Although not labeled “safety culture” at the time, the U.S. Nuclear Regulatory Commission (NRC) also recognized the contribution of organizational factors to accidents in their investigation of the Three Mile Island (TMI) accident in 1979. The NRC’s investigation report stated that “The one theme that runs through the conclusions we have reached is that the principal deficiencies in commercial reactor safety today are not hardware problems, they are management problems” (Rogovin, 1980). These accident investigations helped spur research in the area of safety culture to understand how shared, underlying beliefs and values in an organization may help or hinder safe performance.

In 2002, Sorensen published a critical review of the state-of-the-art of safety culture research as applied to the nuclear industry. Sorensen asserted that safety culture research cannot progress until safety culture has been defined, the characteristics or attributes of safety culture have been delineated, and a link between safety culture and safe operations has been established. It is only in the last 10 years that researchers have begun to publish more rigorous studies explicitly testing for relationships between safety culture and safety performance and reviews of the safety culture literature have begun to reach agreement around common themes in safety culture definitions and dimensions.

The primary purposes of the current study were to investigate the factors that comprise the concept of safety culture in the nuclear power industry and evaluate the relationships between these safety culture factors and other measures of organizational and safety performance. The nuclear industry collects and trends vast amounts of data gauging equipment reliability and operating performance. However, to our knowledge this study is the first comprehensive look at potential linkages between a measure of safety culture in nuclear power organizations and these other types of data. The administration of this survey provided a unique opportunity to explore how perceptions of safety culture are related to organizational-level performance measures across nearly all operating plants in the U.S. nuclear power industry.

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### 1.1. The underlying theory of organizational safety culture

Schein's (1992, 2010) model of organizational culture is perhaps the most widely-adopted model in both nuclear and non-nuclear domains. Schein defines organizational culture as "a pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid, and, therefore to be taught to new members as the correct way to perceive, think, and feel in relation to those problems" (1992, p. 12). Safety culture is generally considered to be a specific aspect of organizational culture regarding the organization's shared beliefs, values, and attitudes that contribute to ensuring safe operations.

The practical utility of assessing an organization's safety culture is that the assessment may be used as a performance indicator, in addition to more established indicators like safety management audits or analyses of events and near-misses (Guldenmund, 2000). Further, it is possible that safety culture assessments may serve as leading indicators of performance, and provide opportunities for intervention before significant events occur. Post-event investigations, like TMI and Chernobyl, have repeatedly shown that weaknesses in an organization's safety culture can create opportunities for significant adverse events.

At an individual level, the relationship between safety culture and safety performance may be best described using the Theory of Planned Behavior (Ajzen and Fishbein, 1977). Employees' beliefs about the importance of safety are shaped by the safety culture of the organization, which then influences their attitudes toward safety, perceived norms for working safely, and perceptions of control over safe working behaviors. For example, an employee working in a strong, positive safety culture is more likely to have positive attitudes toward the importance of safety, perceive that performing a job safely (e.g., by following procedures or wearing personal protective equipment) is the accepted norm, and perceive that they have more control over safety because the organization promotes and prioritizes doing the job safely over competing demands. This logic is also consistent with Neal and Griffin's (2006) exploration of safety motivation and compliance as mediators of the relationship between safety climate and safety behaviors. The organizational safety culture provides the contextual cues that the employee uses to determine whether to behave in a safe or unsafe manner while performing work. The more employees engage in unsafe behaviors the more likely an adverse event will occur because each unsafe behavior creates holes in the organization's defenses and barriers, as described by Reason's (1997) Swiss Cheese Model. The aggregated behaviors then influence or directly determine the overall performance of the organization. A weak or negative safety culture shapes employee beliefs that it is acceptable to take shortcuts or become complacent, which may degrade the safety performance of the organization over time and lead to a significant adverse event.

### 1.2. Relationships between safety culture and safety performance

A series of meta-analytic studies published between 2006 and 2010 significantly advanced the state of safety culture research by providing comprehensive analyses of past safety culture studies (Christian et al., 2009; Clarke, 2006; Beus et al., 2010). The studies included in these meta-analyses measured safety culture using surveys where employees were asked various questions regarding their perceptions of the extent to which their organization valued safety.

Safety performance is used as an umbrella term to refer to the various types of safety outcomes that have been used as dependent variables in safety culture studies, ranging from observed or self-reported employee safety behaviors (e.g., following procedures,

wearing personal protective equipment, participating in safety meetings) to organization-level safety outcomes like accident and injury rates. The studies hypothesized that there should be a relationship between measures of safety culture and other indicators of safety performance.

The results from the meta-analytic studies found consistent evidence of a statistically significant linear relationship between safety culture and accidents/injuries, ranging from a correlation of  $-.22$  to  $-.39$  ( $p < .05$ ), and even larger statistically significant correlations between safety culture and employees' self-reported safety behaviors, ranging from  $.43$  to  $.61$  ( $p < .05$ ). Using Cohen's (1988) labels, the relationship between safety culture and safety performance appears to be a medium effect, and the relationship between safety culture and safety behaviors appears to be a large effect. Effect sizes can also be interpreted in terms of the percent of variance shared by two variables. In the case of correlation analyses, the square of the correlation coefficient represents the percent of shared variance. The results of the meta-analyses suggest that, overall, safety culture may account for 5–15% of the variance in an organization's accident and injury rates, and 18–37% of the variance in employees' safety behaviors.

Longitudinal studies have reached mixed conclusions about the relationship between safety culture and safety performance. Mearns et al. (2003) found some support for a relationship between safety climate at the organizational level and safety performance in offshore oil and gas installations. However, the study suffered from a lack of statistical power when the data were analyzed at the organization level because only 13 installations were included in the study. Correlations between the organizations' safety climate survey results and measures of accident and incident rates were in the expected directions, but were not statistically significant, and the effects were much stronger in time one as compared to time two.

Neal and Griffin (2006) found support for group-level safety climate as a predictor of safety motivation, which subsequently influenced safety behaviors. The study tested these relationships over a five-year time period, focusing on the causal chain linking safety climate to safety performance. Safety behaviors were also a significant predictor of accident rates in the following year, but safety climate did not predict accident rates in the following year. Neal and Griffin argue that this is because safety climate is a distal predictor of safety performance, whereas safety behavior is a more proximal predictor. Zohar (2000) tested a group-level model of safety climate within a single manufacturing organization and found support for safety climate as a predictor of microaccidents (i.e., minor on-the-job injuries requiring medical attention) over a five-month period. Zohar's use of microaccidents as an objective measure of safety was an important contribution to the literature, but the examination of group-level climate makes it difficult to generalize these findings to organizational safety culture. The current study expands on previous longitudinal research by examining safety culture at the organizational level across a large number of organizations in a single industry, and using a diverse set of objective safety performance measures.

### 1.3. Safety performance in the nuclear industry

In high reliability industries, like nuclear power, accidents are extremely rare occurrences. As a result, less significant events that occur more frequently are relied upon as indicators of potentially degrading performance. These more frequent events are also more conducive to quantitative data analysis because there are more data points and more variability across organizations. Although there are many reasons a plant could see declines in their safety performance measures, some of those reasons could theoretically relate to safety culture. For instance, it is possible that declines

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