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Psychometric model for safety culture assessment in nuclear research facilities

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HIGHLIGHTS

- A psychometric model to evaluate 'safety climate' at nuclear research facilities.
- The model presented evidences of good psychometric qualities.
- The model was applied to nuclear research facilities in Brazil.
- Some 'safety culture' weaknesses were detected in the assessed organization.
- A potential tool to develop safety management programs in nuclear facilities.

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ABSTRACT

A safe and reliable operation of nuclear power plants depends not only on technical performance, but also on the people and on the organization. Organizational factors have been recognized as the main causal mechanisms of accidents by research organizations through USA, Europe and Japan. Deficiencies related with these factors reveal weaknesses in the organization's safety culture. A significant number of instruments to assess the safety culture based on psychometric models that evaluate safety climate through questionnaires, and which are based on reliability and validity evidences, have been published in health and 'safety at work' areas. However, there are few safety culture assessment instruments with these characteristics (reliability and validity) available on nuclear literature. Therefore, this work proposes an instrument to evaluate, with valid and reliable measures, the safety climate of nuclear research facilities. The instrument was developed based on methodological principles applied to research modeling and its psychometric properties were evaluated by a reliability analysis and validation of content, face and construct. The instrument was applied to an important nuclear research organization in Brazil. This organization comprises 4 research reactors and many nuclear laboratories. The survey results made possible a demographic characterization and the identification of some possible safety culture weaknesses and pointing out potential areas to be improved in the assessed organization. Good evidence of reliability with Cronbach's alpha coefficient of 0.951 was obtained. Validation method was based on Exploratory Factor Analysis (EFA), using Principal Components Analysis (PCA) and Varimax orthogonal factor rotation. The results confirmed the unidimensionality of the items and, almost entirely, the conceptual framework of the safety culture proposed for the instrument. However, the results also suggested that some adjustments to the conceptual framework of the instrument must be performed in case of a new application.

1. Introduction

A special attention has been dedicated in the last years to industrial plants safety concerns. Most studies are based on the relatively recent catastrophic accidents in nuclear, chemical and petrochemical plants such as the nuclear accident at Three Mile Island, in 1979; the toxic spill in Bhopal chemical plant, in 1984 and the Chernobyl nuclear accident in 1986. Other important related events are the fire and explosion of the offshore platform Piper Alpha, UK, in 1988; the nuclear accident at Tokaimura, in 1999, and the Fukushima nuclear disaster, in 2011.

The contribution of organizational factors and vulnerabilities of the safety culture at these facilities was significant to the sequence of these events as is pointed out in many reports. Some of the main

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reports on this matter are USNRC (1980) and NUREG-0585 (1979) on Three Mile Island case; Willey (2006) and ICFTU (1985) on Bhopal event; INSAG-7 (1992) describing Chernobyl disaster; AIChE (2005) describes Piper Alpha event; IAEA (1999) reports Tokaimura event and finally INPO (2011) and NAS (2014) on Fukushima accident.

There is a growing recognition that the safe and reliable operation of nuclear power plants depends not only on the technical excellence, but also on the people and on the organization (Wilpert and Itoigawa, 2001). Deeper analysis suggests that a large proportion of accidents could have been avoided if the organization had taken appropriate precautions before they occurred (IAEA, 1998, 2009; Hollnagel, 2002).

Wilpert and Itoigawa (2001) also affirm that although several research organizations in the USA, Europe and Japan have recognized the importance of organizational factors as the causal mechanisms of accidents, research efforts in this area have been modest.

In the same direction, Reason (1998) and Sorenson (2002) draw attention to the fact that deficiencies in organizational factors reveal weakness in the organization's safety culture. In addition, they say that these factors correspond to the attributes that determine and characterize this safety culture in the organization.

The 'safety culture' term was consistently first used in nuclear literature, in an initial report on Chernobyl's accident produced by the International Atomic Energy Agency (IAEA) in its "Safety Series No 75-INSAG-4". In that document, INSAG-4 (1991), 'safety culture' definition was "Safety Culture is that assembly of characteristics and attitudes in organizations and individuals establishing that, as an overriding priority, nuclear plants safety issues should receive the attention warranted by their significance".

Cooper (2000) suggests that 'safety culture' model evolution should surpass both the interpretative and functionalist views. He includes most of IAEA definitions as part of this interpretative view, where 'safety culture' is seen as an "emergent property of social groupings" and also seen as what the organization 'is'. According to Cooper, the antagonist view (functionalist) sees culture as a "pre-determined function favored by managers and practitioners" and considers 'safety culture' as something that the organization 'has'. Cooper (2000) still argues that the 'product' of the safety culture construct was being overlooked and that this was inducing "an overly narrow emphasis" on safety climate via questionnaires surveys "being used as a surrogate measure of safety culture, at expense of the holistic, multi-faceted nature of the concept of safety culture itself."

In our view, HSG65 (2008) uses a 'safety culture' definition which considers possible performance measures, which is in accordance with the proposed 'product-oriented' safety culture construct suggested by Cooper. Citing HSHG65 definition: "The safety culture of an organization is the 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 health and safety management. Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the safety importance and by confidence in the efficacy of preventive measures". In this context, the application of questionnaires can be seen, at least, as part of performance measurement tasks (HSG65, 2008, chapter 5), which could indicate the implementation of safety management actions (active monitoring for instance).

In a much broader safety investigation, Zohar (1980) applies questionnaires in a stratified sample of 20 industrial organizations in Israel. In this work, a type of organizational climate is proposed, examining its implications. However, he recognizes that attempting to improve safety levels with new safety regulation and similar campaigns is not enough. He arguments that is necessary a change in management attitudes and increased commitment.

It can be observed some conflicts and inconsistencies about the 'safety culture' and 'safety climate' terms, although they are very intimately related. Usually 'safety culture' is used to personal behavior aspects ('what people do') and company situational aspects ('what organization has'). The 'safety climate' is more applied to employee psychological characteristics ('how people feel'), corresponding to values, attitudes and perceptions that employees have about safety in their organization.

Guldenmund (2000) points some main differences in those definitions. In Guldenmund work it is affirmed that 'safety culture' is characterized by shared beliefs, values and attitudes which are related to the work and to the organization as a whole. The 'safety climate' is nearer of operational tasks and is characterized by the diary perception of working environment, working practices, organizational politics and management. We can say that each term applies to different levels of evaluation. It could be concluded that 'safety culture' is a whole set of values and beliefs that guide the action while 'safety climate' reflects the actual attitude related to safety. The culture is more stable while climate is subject to fluctuations in response to local variable changes.

Wilpert and Itoigawa (2001) point out that the prevailing consensus in the nuclear energy international community is that a strong nuclear safety culture should be universally adopted by: (a) the top management of organizations that operate nuclear power plants; (b) by the individuals working in these plants; (c) by the regulatory agencies and (d) by other organizations that establish nuclear energy policies. In fact, safety commitment is an international priority, as has been evidenced by some treaties on nuclear safety.

In an attempt to reduce accidents and their related costs, many organizations have made efforts to assess and promote a positive safety culture. Many studies have proposed models to evaluate the safety culture or to verify whether safety measures have changed in an organization over time (Sorenson, 2002).

According Mkrtchyan and Turcanu (2012) and Williams (2008), a primary concern in a safety-culture evaluation is to ensure that research instruments can be valid and reliable, that is, that they can measure what they intend to measure, producing similar results in repeated measures. For this reason, it is very important that the research instruments show reliability and validity evidences (psychometric properties).

The academic and scientific interest in safety-culture measurement methods has resulted in a proliferation of assessment instruments, most of them based on self-assessment questionnaires, applied in different sectors, mainly in health and production areas. Most of these instruments have their psychometric properties evaluated. However, there are few instruments in the nuclear area with evidences of reliability and validity. Some of these works were analyzed, among which Lee (1998), Lee and Harrison (2000), Morrow (2012) and De Castro et al. (2013) stand out.

There is no such instrument using psychometric qualities applied to a nuclear-area case in Brazil. It is important to highlight that safety culture assessment tools with evidence of reliability and validity arising from the application in another country, could not be directly employed in Brazil due to cultural differences (TECDOC-1321, 2002; TECDOC-1329, 2002). In order to apply those tools, according Weidmer (1994) and Cha et al. (2007), it would be necessary to undertake a translation and cross-cultural adaptation process that would imply in a new instrument validation.

Therefore, this work aimed to develop an instrument to evaluate, with valid and reliable measures, the safety climate at nuclear research facilities in Brazil and consequently enable assessment of safety culture at these organizations. Two specific objectives were established as a basis. The first one was to develop a data collection instrument to be applied to the CNEN's staff, an important nuclear organization in Brazil which comprises 4 research reactors and