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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 many nuclear laboratories. The National Nuclear Energy Commission (CNEN) is also responsible for establishing standards, conducting research and controlling nuclear activities in Brazil. The second objective was to evaluate the psychometric properties of this instrument through a reliability analysis and content, face and construct validations.

2. Methods

2.1. Development of the survey instrument (questionnaire)

The foreseen modeling of the survey instrument was based on summed scale concept. This approach consists on combining many variables that measure the same concept into a unique variable, in an attempt to increase the measurement reliability, according to Hair et al. (2010).

A summed scale provides two main advantages: it reduces the measurement error by using multiple indicators, diminishing the reliance on a single response; and it has the ability to represent the multiple aspects of a concept in a single measure.

The quality of the measurements obtained by a survey instrument is determined by the analysis of its psychometric properties. These analyses aim to obtain reliability and validity evidences for the instrument (DeVellis, 2003; Sekaran, 2003; Netemeyer et al., 2003; Hinkin, 2011).

Regarding validation, three approaches have been implemented in this work: content, face and construct validity.

2.1.1. Conceptual definition of the construct safety culture

In the words of Hair et al. (2010), "conceptual definition" is the starting point for creating any summated scale. The conceptual definition specifies the theoretical basis for the summated scale by defining the concept (construct) in terms applicable to the research context. A thorough comparative literature review was conducted to identify the dimensions that constitute the safety culture construct, i.e., its dimensionality.

The innovative work of identifying the dimensions that characterize a safety culture for the industrial segment was proposed by Zohar (1980). After this work, there were numerous publications dealing with safety culture dimensionality, among which stand out the works of Reason (1997), Guldenmund (2000), Cooper (2000), Sorenson (2002), Diaz-Cabrera et al. (2007) and Zohar (2010).

The main studies which address the safety culture dimensionality of nuclear facilities were presented by Wilpert and Itoigawa (2001), NUREG-1756 (2002), Alexander (2004), NUREG-2165 (2014). Presenting the same focus there are also the important works published by the IAEA, from which three stand out and are following commented. In TECDOC-1321 (2002), seven organizational factors (dimensions) were chosen to be considered in the solutions for safety culture issues. Subsequently, based on lessons learned from organizational failures and international safety experts' cooperation, TECDOC-1329 (2002) was published, identifying 24 safety culture characteristics (dimensions) to be considered in evaluation processes. In order to consolidate the previously mentioned organizational factors and safety culture characteristics into a single document, SCART (2008) was proposed by IAEA. This document identifies five key features of safety culture specified by a set of 37 attributes.

There is no consensus about the dimensions that make up the concept of safety culture among these different authors and researchers. In this work, the conceptual definition of the construct was chosen based on the most cited dimensions on previously mentioned works. The preliminary conceptual framework of the safety culture construct was defined through the 12 dimensions described below:

- D1. Priority given to safety;
- D2. Allocation of resources;
- D3. Roles and responsibilities;
- D4. Safety commitment;
- D5. Qualification and personnel size;
- D6. Communication;
- D7. Relationship with superiors and regulators;
- D8. Feasibility of processes;
- D9. Documentation and procedures;
- D10. Work conditions;
- D11. Organizational learning;
- D12. Internal and external evaluations.

Table 1
Conceptual framework of the safety culture.

Dimensions (Constructs)	Measurement indicators	Questions
D1. Priority given to safety	Safety policy knowledge Safety policy priority Safety policy content Safety approach in the meetings Safety versus production Deviations and shortcuts in the process	Q1 to Q6
D2. Allocation of resources	Resources for safety equipment Resources for training Resources for maintenance Review of resources	Q7 to Q10
D3. Roles and responsibilities	Responsibilities definition Responsibilities knowledge	Q11 and Q12
D4. Safety commitment	Senior management commitment Management commitment Safety current status	Q13 to Q15
D5. Communication and relationship	Communication between the management and employees Communication between shifts Communication check-up Relationship with seniors Relationship with regulators	Q16 to Q20
D6. Qualification and personnel size	Training adequacy Training Review Work team Qualification	Q21 to Q24
D7. Documentation and procedures	Documentation content Documentation availability Documentation understanding Documentation problems Documentation update Process feasibility	Q25 to Q30
D8. Work conditions	Workload Environment temperature Environment lightness Air quality Environment noise Time pressure Work ergonomics Housekeeping Safety systems status Work stress Overtime demand Satisfaction at work	Q31 to Q42
D9. Organizational learning	Lessons learned Accidents analysis Corrective actions Publication of accidents cause	Q43 to Q46
D10. Internal and external evaluations	External evaluations (receptivity) Internal evaluations (frequency) Publication of evaluation results	Q47 to Q49

These 12 dimensions were operationalized through 62 measurement indicators based on INSAG-4 (1991), TECDOC-943 (1995), NEA (1999), TECDOC-1125 (1999), TECDOC-1321 (2002), INSAG-15 (2002), O'Brien and Charlton (2002), Stanton et al. (2005), AIChE (2007), SCART (2008), IAEA (2009) and IAEA (2010).

Based on this structure, a preliminary version of the data collection instrument was constructed, consisting of a 75 questions' questionnaire to make evident the measurement indicators. This defined initial number of questions and indicators followed Devellis (2003) recommendation to begin to develop a scale using a superior number of items than that number of items of the intended definite scale. Through this procedure, the reduction of the number of items could occur if content validation and face validation processes would indicate so.

2.1.2. Content validity

According to Hair et al. (2010), content validity is the evaluation of the correspondence of the variables (items or indicators) to be included in the summated scale and its conceptual definition. DeVellis (2003) adds that the content validity should be performed by expert judges in the related research area, which assess the degree of agreement of the items in relation to the construct.

The content validity appraisal of the organizational factors and safety culture in the nuclear area, was performed by a team of experts composed of 11 researchers who currently work in Brazil. Experts were asked to assign a degree of relevance (1, 2, 3 or 4) to each item intended to measure the related construct, indicating which items could be removed and checking general syntax and semantics' problems.

The main actions taken as result of the expert's judgment were: questions with degree of relevance judged as 1 or 2 were removed; questions considered as redundant have also been removed and those presenting writing inconsistencies were accordingly changed. As a result of these actions, 26 questions were excluded and some writing changes were realized, causing a dimension reduction from 12 to 10.

2.1.3. Face validity

According to Netemeyer et al. (2003) and Trochim (2006), the face validity should be performed by individuals representing the target population to verify whether the items would generate misunderstandings for the respondents.

The face validation was carried out with a target population sample composed of 7 researchers from CNEN. The group was asked to identify questions (items) that were difficult to understand or those with ambiguous interpretation. As result, 17 questions were re-edited.

The content and face validation processes allowed the conceptual framework definition of the safety culture, consisting of 10 dimensions, 49 measurement indicators and 49 questions, as presented in Table 1.

2.2. Survey administration

The definitive research instrument was composed of seven demographic questions and 49 resultant questions (measurement indicators) based on the conceptual framework presented in Table 1.

Each question was composed of six possible answers that were labelled with natural language. The first five first options had different grades of truth or emphasis through which the replier could chose to express his perception or opinion about the characteristic being assessed. The last option "Not applicable" was included as option in case the respondent would judge that such question was not related to his kind of activity or workplace.

The first five options were disposed in ordered gradual intensity. The first two were related to a more favorable or important situation. The last two were intended to represent a less favorable or important situation. The third was intended to represent an intermediate answer.

A numeric codification (0–5) of these options was done to reflect the opinion or perception intensity of each question, where 0 was related to "Not applicable" (last ordered possible answer) and 5 (first possible answer) to the 'more intense' option.

Q1. Evaluate the knowledge level you have about the stablished safety policy for your nuclear installation.

O Excellent
O Very good
O Good
O Fair
O Poor
O Not applicable

Q15. What is your satisfaction level with the current safety state of the installation?

O Extremely satisfied
O Very satisfied

O Moderately satisfied
O Slightly satisfied
O Not at all satisfied
O Not applicable

Q26. How frequent the necessary documentation to carry out your activities is available at your workplace?

O Always
O Most of the time
O Some-times
O Rarely
O Never
O Not applicable

Fig. 1. Examples of questionnaire questions.

Fig. 1 shows a typical set of questions used in this work.

The questionnaire's target population was constituted of National Nuclear Energy Commission's staff members as mentioned in Section 1.

The questionnaire was available to respondents through an access link for 45 days during June and July of 2014. A satisfactory return rate of near 11% (226 units) was obtained to these questionnaires, considering the approximate overall number of 2000 CNEN's employees.

3. Results and discussion

Out of these 226 responses, 28 had a significant amount of missing data. These 28 questionnaires were discarded, in compliance with the guidance given by Hair et al. (2010).

All analyses and calculations with the remaining 198 questionnaires were performed using the Statistical Package for Social Sciences software (SPSS), version 19.0, which is a specialized statistical program to perform univariate and multivariate analysis of data (SPSS, 2010).

3.1. Statistical analysis of demographic variables

The demographic results showed the following CNEN's staff characteristics: 44.9% had been working in the institution for over 30 years; 56.6% of respondents worked in research and development area; 44.4% of respondents had more than 30 years of nuclear area professional experience; 46% were over 56 years old; 52% had doctorate instruction level and 52% had the function of researcher.

3.2. Statistical analysis of result variables (indicators)

Table 2 presents the obtained ratings and mean values using the measurement indicators of the constructs.

The positive rating corresponds to the accumulated percentage of the two higher values (5 and 4) attributed to the question. The negative rating corresponds to the lowest concepts (2 and 1) worst options of responses. The intermediate values correspond to the central position responses (3).

The obtained positive ratings and average values close to 3 and 4 presented in Table 2 for most indicators, show respondents' positive perceptions and opinions about CNEN's safety and suggest that there are stable areas and safety culture strength throughout the institution.

However, some indicators presented negative ratings that require special attention. These indicators address important areas such as: the allocation of resources for training (Q8) and maintenance (Q9), results disclosure, both about the causes of accidents (Q46) and about the internal and external evaluations (Q49). The negative ratings and the lower-than-3 mean values, obtained by these indicators, reveal weaknesses and vulnerabilities in the safety culture at CNEN.

Other indicators that also required attention, although at lower levels, were the Q7, Q10, Q14, Q16, Q23, Q36, Q45 and Q48 items, which showed intermediate classification as result. They are related to important areas such as: resources for safety equipment, management commitment to safety, time pressure to carry out the activities, corrective actions and internal evaluations. These results indicated some fragility and vulnerability in the safety culture of the organization. Therefore, the indicators which have not received a positive rating should represent warning signals and to be considered as potential areas for improvement actions in the organization culture.

Table 2
Statistical analysis of result variables (Indicators).

Indicators	Rating	Mean
Q1. Safety policy knowledge	Positive 63.1%	3.68
Q2. Safety policy priority	Positive 61.6%	3.73
Q3. Safety policy content	Positive 51.0%	3.47
Q4. Safety approach in the meetings	Positive 49.0%	3.50
Q5. Safety versus production	Positive 65.2%	4.07
Q6. Deviations and shortcuts in the process.	Positive 44.4%	4.20
Q7. Resources for safety equipment	Intermed 32.8%	2.97
Q8. Resources for training	Negative 36.9%	2.80
Q9. Resources for maintenance	Negative 34.4%	2.76
Q10. Review of resources	Intermed 39.9%	3.08
Q11. Responsibilities definition	Positive 48.5%	3.26
Q12. Responsibilities knowledge	Positive 43.9%	3.36
Q13. Senior management commitment	Positive 39.9%	3.25
Q14. Management commitment	Intermed 43.4%	3.17
Q15. Safety current status	Positive 50.5%	3.42
Q16. Communication between the management and employees	Intermed 43.9%	2.91
Q17. Communication between shifts	Positive 18.2%	3.28
Q18. Communication check-up	Negative 24.2%	2.89
Q19. Relationship with seniors	Positive 79.8%	4.18
Q20. Relationship with regulators	Positive 36.9%	3.41
Q21. Training adequacy	Positive 40.9%	3.23
Q22. Training Review	Positive 37.4%	3.24
Q23. Work team	Intermed 39.4%	3.18
Q24. Qualification	Positive 75.8%	4.01
Q25. Documentation content	Positive 57.0%	3.60
Q26. Documentation availability	Positive 68.7%	3.90
Q27. Documentation understanding	Positive 71.2%	3.90
Q28. Documentation problems	Positive 61.6%	3.73
Q29. Documentation update	Positive 52.0%	3.49
Q30. Process feasibility	Positive 42.6%	3.42
Q31. Workload	Positive 50.5%	3.36
Q32. Environment temperature	Positive 76.5%	3.82
Q33. Environment lightness	Positive 82.4%	4.02
Q34. Air quality	Positive 73.3%	3.93
Q35. Environment noise	Positive 60.4%	3.59
Q36. Time pressure	Intermed 63.6%	3.03
Q37. Work ergonomics	Positive 57.2%	3.59
Q38. Housekeeping	Positive 75.3%	3.91
Q39. Safety systems status	Positive 43.0%	3.30
Q40. Work stress	Positive 44.6%	3.45
Q41. Overtime demand	Positive 30.6%	3.33
Q42. Satisfaction at work	Positive 40.0%	3.17
Q43. Lessons learned	Positive 41.6%	3.22
Q44. Accidents analysis	Positive 54.6%	3.66
Q45. Corrective actions	Intermed 44.9%	3.12
Q46. Publication of accidents cause	Negative 31.4%	3.00
Q47. External evaluations (receptivity)	Positive 37.0%	3.29
Q48. Internal evaluations (frequency)	Intermed 33.7%	3.02
Q49. Publication of evaluation results	Negative 25.4%	2.77

3.3. Evaluation of the psychometric properties of the model

3.3.1. Data preparation and treatment

Among the remaining 198 questionnaires, 17 still had some missing data which could compromise the reliability calculations and consequently further analyses was necessary to the instrument's construct validation.

Table 3
Cronbach's alpha coefficient for each dimension.

Dimensions (Constructs)	N of items	Cronbach's alpha
D1. Priority given to safety	5	0.722
D2. Allocation of resources	3	0.828
D3. Roles and responsibilities	2	0.719
D4. Safety commitment	3	0.875
D5. Communication and relationship	2	0.437
D6. Qualification and personnel size	4	0.717
D7. Documentation and procedures	6	0.793
D8. Work conditions	11	0.773
D9. Organizational learning	5	0.860

Table 4
Item-total correlations.

Dimensions (Constructs)	Indicators	Item-total Correlations
D1. Priority given to safety	Q1. Safety policy knowledge	0.414
	Q2. Safety policy priority	0.712
	Q3. Safety policy content	0.698
	Q4. Safety approach in the meetings	0.476
	Q5. Safety versus production	0.397
D2. Allocation of resources	Q7. Resources for safety equipment	0.692
	Q8. Resources for training	0.775
	Q10. Review of resources	0.599
D3. Roles and responsibilities	Q11. Responsibilities definition	0.561
	Q12. Responsibilities knowledge	0.561
D4. Safety commitment	Q13. Senior management commitment	0.759
	Q14. Management commitment	0.791
	Q15. Safety current status	0.743
D5. Communication and relationship	Q16. Communication between the management and employees	0.284
	Q19. Relationship with seniors	0.284
D6. Qualification and personnel size	Q21. Training adequacy	0.516
	Q22. Training Review	0.599
	Q23. Work team	0.516
	Q24. Qualification	0.401
D7. Documentation and procedures	Q25. Documentation content	0.666
	Q26. Documentation availability	0.595
	Q27. Documentation understanding	0.550
	Q28. Documentation problems	0.657
	Q29. Documentation update	0.542
	Q30. Process feasibility	0.374
D8. Work conditions	Q31. Workload	0.386
	Q32. Environment temperature	0.482
	Q33. Environment lightness	0.505
	Q34. Air quality	0.490
	Q35. Environment noise	0.547
	Q36. Time pressure	0.337
	Q37. Work ergonomics	0.508
	Q38. Housekeeping	0.579
	Q39. Safety systems status	0.517
	Q40. Work stress	0.300
	Q42. Satisfaction at work	0.358
D9. Organizational learning	Q43. Lessons learned	0.663
	Q44. Accidents analysis	0.756
	Q45. Corrective actions	0.685
	Q46. Publication of accidents cause	0.656
	Q48. Internal evaluations (frequency)	0.654

The ‘‘Mean substitution” method was adopted for the missing data treatment. Sekaran (2003) and Hair et al. (2010) judge that this is the most representative value for missing data. Based on this treatment it was possible to rely upon a sample of 198 valid cases.

Eight variables assigned with ‘‘Not applicable” option (more than 10% of the responses) were identified. According to Sekaran (2003) and Hair et al. (2010) this result could also compromise the reliability calculations and analyses and the construct validation. Therefore, items Q6, Q9, Q17, Q18, Q20, Q41, Q47 and Q49 were not considered in this analysis.

According to the Hair et al. (2010) suggested criteria for sample size adequacy, the obtained sample consisting of 198 cases and 41 variables (49 – 8 not considered), might be considered suitable for multivariate data analysis.

3.3.2. Instrument reliability analysis

According to DeVellis (2003), reliability is the extent to which one variable or a set of variables is consistent in what it is intended to measure. If multiple measurements are taken, all reliable measures will be consistent in their values. Highly reliable construct indicators are highly inter-correlated indicating that they all seem to be measuring the same object.

The calculations of Cronbach’s alpha coefficient were carried out considering the instrument as a whole, for each dimension and additionally, the calculation of the item-total correlation was also done. The obtained value for Cronbach’s alpha coefficient considering the instrument as a whole (41 items) was 0.951. This value may be considered as very good and indicates that there is a strong correlation among these items. According to DeVellis (2003), Cronbach’s Alpha lowest limit of acceptability is considered to be between 0.60 and 0.70. The obtained values for Cronbach’s alpha coefficient for each dimension are presented in Table 3.

It is worth noting that as Q6, Q9, Q17, Q18, Q20, Q41, Q47 and Q49 items were not considered (see Section 3.3.1), D10 dimension would be consisted of a unique item: Q48. Therefore, this item was relocated to D9 dimension.

Obtained alpha values in the 0.717–0.875 range are shown in Table 3, suggesting very good internal consistency reliability. However, only D5 has the recommended below 0.70 reliability level.

The item-total correlations were evaluated and are presented on Table 4.

According to Devellis (2003), an item-total correlation with a ‘less than 0,3’ value indicate that such item is measuring some factor which is outside of the whole scale. This occurrence turns the item a strong candidate to be eliminated.

From Table 4 is possible to observe that D5 dimension have presented a weak correlation. Considering also the presented low Cronbach's alpha coefficient, D5 dimension was kept following Hair et al. (2010) recommendations. This decision was taken despite the caveat of a somewhat possible lower reliability and a consequent need for future additional indicators development to better represent this concept.

Therefore, despite the D5 problem, the obtained results indicate that the instrument can provide satisfactory reliability evidence, i.e., it is expected that similar results could be obtained if this questionnaire would be applied to the same facilities, provided that measured conditions would not undergo important changes.

3.3.3. Construct validity

Hair et al. (2010) defines that construct validity is the extent to which the set of measured items actually reflects the theoretical latent construct that those items are designed to measure. Evidence of construct validity provides confidence that the item measurements, taken from the sample, represent the current true score existing in the population.

In a construct validation process, an underlying assumption and essential requirement is that items are unidimensional, i.e. that they are strongly associated with each other and that represent a single concept, with high loads on a single factor. Factor analysis plays a pivotal role in making an empirical evaluation of the dimensionality of a set of items by determining the number of factors and the loadings of each variable on the factors (Hair et al., 2010).

According to Conway and Huffcutt (2003) and Hinkin (2011), the factor analysis is an important tool to the development and validation of a search instrument. They also mention that factor analysis may be useful to verify the construct validity, which analysis results will confirm or not, whether the theorized dimensions appear.

Preceding factor analysis, two sampling adequacy tests were performed, the Kaiser-Meyer-Olkin (KMO) and the Bartlett sphericity test. KMO test resulted in a 0.838 value and the Bartlett test in a sign = 0.000. According to Hair et al. (2010), these results indicate that factor analysis can be considered an appropriate technique to be applied in this instrument's construct validation.

The data were, then, submitted to the Exploratory Factor Analysis (EFA), using Principal Components Analysis (PCA) without establishing, a priori, the number of factors, and considering eigenvalues greater than 1. As a result, a nonrotated component matrix was obtained, consisting of 10 components, as shown in Table 5.

Table 5
Nonrotated component matrix.

Items	Components									
	1	2	3	4	5	6	7	8	9	10
Q1	0.607	−0.099	−0.387	0.005	0.009	0.189	0.061	−0.080	−0.410	−0.024
Q2	0.683	−0.187	−0.276	0.172	0.029	0.004	0.298	−0.016	0.006	−0.141
Q3	0.712	−0.124	−0.250	−0.088	0.181	−0.052	0.333	−0.208	−0.133	−0.017
Q4	0.706	−0.170	−0.073	−0.087	0.097	−0.217	0.193	0.116	0.263	−0.146
Q5	0.225	−0.238	0.265	0.425	−0.064	0.154	0.404	−0.212	0.090	0.454
Q7	0.685	−0.251	−0.135	−0.081	0.197	−0.317	−0.233	−0.084	0.184	−0.121
Q8	0.732	−0.269	−0.114	−0.142	0.047	−0.263	−0.270	−0.134	0.082	0.080
Q10	0.614	−0.310	0.032	−0.005	0.086	0.002	−0.265	−0.188	0.143	0.258
Q11	0.659	−0.164	−0.335	−0.189	0.205	0.128	−0.007	0.117	−0.085	−0.083
Q12	0.547	0.040	−0.405	−0.005	0.210	0.270	−0.125	0.222	−0.227	0.174
Q13	0.776	−0.219	−0.115	−0.031	0.175	−0.049	0.094	0.029	0.176	0.001
Q14	0.764	−0.101	−0.196	−0.150	0.044	−0.017	0.144	−0.032	0.248	0.024
Q15	0.846	−0.034	−0.066	−0.208	0.081	0.009	−0.068	−0.111	0.069	0.126
Q16	0.725	−0.092	0.005	−0.081	0.312	−0.051	0.081	0.074	−0.047	0.193
Q19	0.467	0.059	0.143	−0.108	−0.079	−0.430	0.125	0.555	0.073	−0.017
Q21	0.650	−0.070	0.105	−0.067	−0.163	0.210	0.066	0.172	0.011	−0.107
Q22	0.594	−0.150	0.204	−0.067	−0.254	0.326	−0.299	0.189	0.221	−0.122
Q23	0.478	0.367	−0.069	−0.289	−0.356	0.114	−0.178	−0.187	0.124	0.100
Q24	0.434	0.248	−0.062	−0.134	−0.212	0.246	−0.352	0.249	−0.116	0.078
Q25	0.728	0.086	0.044	−0.136	−0.299	−0.265	−0.025	0.040	−0.072	0.261
Q26	0.629	0.229	−0.074	0.090	−0.395	0.005	0.236	0.068	−0.210	−0.118
Q27	0.555	0.383	−0.210	0.070	−0.425	−0.099	0.245	0.095	0.041	0.038
Q28	0.648	0.156	0.029	0.012	−0.423	−0.288	0.059	−0.152	0.088	0.032
Q29	0.632	−0.007	0.287	0.049	−0.322	0.032	−0.048	−0.180	0.004	0.062
Q30	0.401	0.224	0.095	−0.403	0.087	0.190	0.125	0.205	0.073	0.180
Q31	0.267	0.602	0.110	−0.302	0.136	0.113	0.317	−0.220	0.197	−0.087
Q32	0.468	0.191	−0.171	0.506	0.085	0.192	−0.117	0.232	0.334	0.080
Q33	0.452	0.404	−0.304	0.403	0.134	0.107	−0.192	−0.034	0.179	0.106
Q34	0.498	0.127	0.346	0.506	0.122	0.031	−0.111	−0.075	0.105	−0.032
Q35	0.480	0.334	0.026	0.498	0.215	−0.077	0.049	0.004	0.013	−0.220
Q36	0.181	0.561	0.334	−0.269	0.354	0.032	0.011	−0.070	0.083	−0.203
Q37	0.475	0.388	−0.099	0.179	0.114	−0.379	−0.141	0.086	−0.289	−0.039
Q38	0.586	0.343	0.031	0.169	0.105	−0.097	−0.083	−0.154	−0.300	0.189
Q39	0.650	0.210	0.133	−0.014	0.148	−0.152	−0.252	−0.259	−0.074	−0.212
Q40	0.210	0.277	0.331	−0.281	0.427	0.172	0.100	0.076	−0.025	0.265
Q42	0.312	−0.183	0.533	0.128	0.150	−0.270	0.041	0.322	−0.153	0.158
Q43	0.662	−0.170	0.408	−0.067	0.045	0.087	−0.035	−0.090	−0.325	−0.100
Q44	0.759	−0.146	0.218	0.139	−0.056	0.145	−0.040	0.044	−0.110	−0.013
Q45	0.736	−0.248	0.256	−0.094	−0.139	−0.017	−0.081	−0.137	−0.058	−0.158
Q46	0.731	−0.123	0.089	−0.025	−0.094	0.298	0.115	−0.051	−0.024	−0.127
Q48	0.673	−0.192	0.208	0.173	0.042	0.292	0.082	0.104	−0.012	−0.287

Table 6
Rotated component matrix.

Items	Components									Communal
	1	2	3	4	5	6	7	8	9	
Q8	0.820									0.816
Q7	0.740									0.806
Q15	0.672									0.808
Q10	0.613									0.674
Q11	0.559									0.695
Q13	0.536									0.739
Q39	0.465									0.710
Q44		0.700								0.704
Q46		0.692								0.688
Q48		0.648								0.751
Q45		0.595								0.751
Q43		0.584								0.774
Q21		0.462								0.559
Q1		0.451								0.743
Q28			0.769							0.742
Q27			0.672							0.766
Q25			0.671							0.794
Q26			0.649							0.737
Q29			0.610							0.628
Q24			0.439							0.583
Q2				0.764						0.717
Q3				0.741						0.800
Q14				0.497						0.742
Q4				0.496						0.738
Q16				0.488						0.691
Q33					0.765					0.733
Q32					0.729					0.771
Q35					0.702					0.694
Q34					0.662					0.685
Q37					0.485					0.687
Q38					0.439					0.668
Q31						0.744				0.764
Q36						0.697				0.711
Q40						0.611				0.608
Q30						0.445				0.521
Q22							0.579			0.781
Q23							0.435			0.683
Q42								0.662		0.681
Q19								0.659		0.773
Q5									−0.740	0.808
Q12									0.409	0.729

The component matrix showed in Table 5 is not conclusive due to excessive cross loadings, presenting some low factor loadings and factors that are correlated with many variables.

Therefore, a factor rotation by orthogonal methods was realized using Varimax option and adjusting the cutting loading factor to 0.4. Several factor rotations were done in order to achieve a simplified factor structure. The rotation convergence was obtained on 29 iterations, as shown in Table 6.

The analysis results revealed 9 components with eigenvalues greater than 1.

Comparing the Table 6 component matrix with the conceptual framework that gave rise to the research instrument represented in Table 1, it is observed that items were derived from the same dimension of the correspondent conceptual framework for each of the first seven components. The dimensionality of the items was assured by the clean interpretation for each factor, presenting high factor loadings for each variable on only one factor.

Items from four distinct dimensions were grouped in 8th and 9th components. The need to group some items coming from different dimensions was an imbalance in the conceptual framework of the instrument, caused by the non-consideration of Q6, Q9, Q17, Q18, Q20, Q41, Q47 and Q49 items in factor analysis.

The commonalities observed in Table 6 are high (>0.5), indicating that all variables are properly explained by the factor solution (Conway and Huffcutt, 2003).

The Total Variance Explained is shown in Table 7.

It is possible to observe, on Table 7, that only the first nine components have eigenvalues greater than 1. This fact is equivalent to say that these nine components represent 61.3% of variance as can be observed on 'Cumulative %' column of Table 7.

A scree plot showing the eigenvalues from the 41 questionnaire items is shown in Fig. 2.

The 41 components are plotted with their correspondent eigenvalues which concentrate 61.3% of total variance. Therefore, the factor analysis' results have indicated that the proposed research instrument had good evidence of the construct validity. The unidimensionality of the items was assured and the conceptual framework of the safety culture proposed for the model was almost totally confirmed by EFA.

4. Conclusions

In order to develop an adequate psychometric model to evaluate safety climate in nuclear facilities, a preliminary survey instrument was designed and submitted to content and face validation processes. The validations processes results were satisfactory because have led to a reorganization of the conceptual framework and therefore, have provided a basis for the definitive research instrument development. The activities carried out during the

Table 7
Total variance explained.

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	12.057	29.408	29.408	12.057	29.408	29.408	4.694	11.450	11.450
2	2.530	6.170	35.578	2.530	6.170	35.578	3.820	9.316	20.766
3	2.030	4.951	40.529	2.030	4.951	40.529	3.518	8.581	29.347
4	1.890	4.609	45.138	1.890	4.609	45.138	3.237	7.894	37.241
5	1.495	3.647	48.785	1.495	3.647	48.785	3.173	7.740	44.981
6	1.412	3.443	52.228	1.412	3.443	52.228	2.242	5.469	50.450
7	1.314	3.205	55.432	1.314	3.205	55.432	1.606	3.917	54.367
8	1.207	2.945	58.377	1.207	2.945	58.377	1.493	3.641	58.008
9	1.203	2.933	61.310	1.203	2.933	61.310	1.354	3.303	61.310
10	.980	2.536	63.847						
11	.935	2.403	66.249						
12	.909	2.216	68.466						
13	.856	2.089	70.555						
14	.843	2.057	72.612						
15	.766	1.868	74.479						
16	.733	1.787	76.267						
17	.711	1.734	78.001						
18	.705	1.718	79.719						
19	.670	1.633	81.353						
20	.647	1.577	82.930						
21	.581	1.417	84.347						
22	.545	1.330	85.677						
23	.507	1.236	86.914						
24	.497	1.213	88.127						
25	.461	1.124	89.250						
26	.446	1.089	90.339						
27	.426	1.038	91.377						
28	.394	.962	92.339						
29	.369	.899	93.238						
30	.332	.809	94.048						
31	.316	.771	94.819						
32	.298	.727	95.546						
33	.274	.668	96.214						
34	.254	.620	96.834						
35	.242	.591	97.424						
36	.220	.536	97.960						
37	.192	.469	98.429						
38	.185	.452	98.881						
39	.167	.408	99.289						
40	.159	.388	99.677						
41	.132	.323	100.000						

Extraction method: principal component analysis.

model development comply with all methodological principles that are recommended to be applied to research-instruments' modeling

The research instrument (questionnaire) was applied to an important nuclear research organization in Brazil – National Nuclear Energy Commission (CNEN). The application results provided a demographic characterization of the respondents, the identification of the actual CNEN's safety climate conditions and provided the necessary data for the psychometric-properties' evaluation of the instrument.

Some obtained indicators' results pointed to safety culture weaknesses and represent a warning signal to organization potential areas in CNEN that should be improved.

The obtained results of psychometric properties showed evidences that the research instrument is able to provide valid and reliable measures in evaluating the safety climate in nuclear research institutions that can enable safety culture assessment.

This developed instrument has proved to be an adequate tool to be used to measure safety climate at nuclear installations enabling enough safety culture insights that may induce more appropriate management actions and strategy definitions that search for improvements of the organization safety.

This research represents a first step on exploring safety culture and safety performance at nuclear installations in Brazil. It also contributes, in a broader sense, to a refinement of safety measures to be implemented in organizations that deal with dangerous technologies.

The proposed psychometric model contributes with a research tool to evaluate safety climate in nuclear facilities, and through its usage of original psychometric qualities evaluation, allows good inference of safety culture scenery.

Although the model was applied to a nuclear research organization, the obtained results showed very good consistency with previous work on power plants used as reference for its construction (see Section 2).

However, the model presented some limitations that should be addressed:

a) It is recommended that for a new application of the instrument: first, a specific area inside CNEN's organization should be selected to proceed a new content validation to assess the indicators' applicability and to avoid significant amounts of "Not applicable" rating in the search, and second, additional indicators to represent the D5 dimension should be developed;

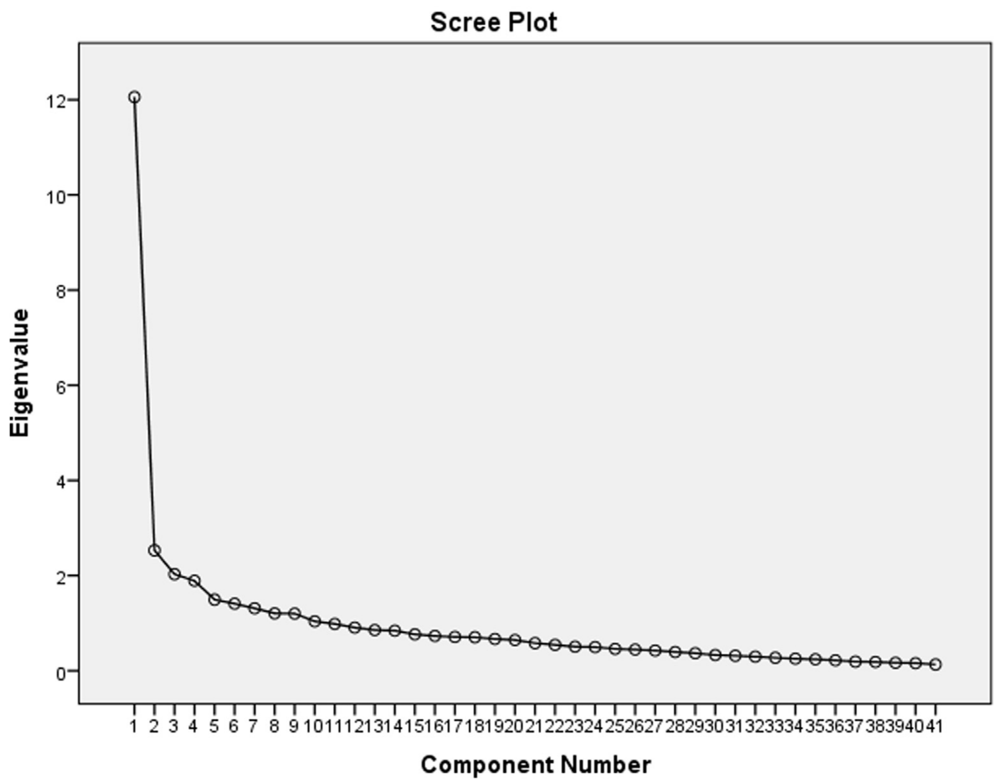

Fig. 2. Scree plot of eigenvalues.

b) Although the proposed questionnaire may be used as a tool to infer safety culture evaluations, the obtained results cannot be taken separately. A more detailed organization safety culture diagnostic should take into consideration more complex and profound factors that could be researched through complementary resources such as a written questionnaire, or personal interviews with respondents;
c) This analysis can also be included in more complex organization management programs that could measure performance of implemented changes and correlate them with previous culture climate analysis results.

New research should be realized to determine the time evolution of observed relations. Thus, would be possible to observe if the same factors would emerge from subsequent applications of this tool inside CNEN over time.

In future work developments, it should be emphasized that, despite having been validated to a research organization, the model can be applied to other scenarios:

a) Through an appropriate content validation, it may be applied, for example, to a nuclear power plant;
b) Likewise, through a process of translation and cross-cultural adaptation, the instrument can be applied in other countries' nuclear facilities;
c) With appropriate adaptations, the model could be also applied to other organizations that handle with dangerous technologies as chemical, petrochemical and aviation industries.

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