

Development of a safety culture model and measure for Great Britain's nuclear industry

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The Office for Nuclear Regulation (ONR) commissioned Alliance Manchester Business (AMBS) school to develop a model and measure of safety culture to enable Great Britain's (GB's) nuclear industry to accurately measure safety culture, benchmark results, and learn from good practices, with the goal of further improving safety outcomes. This work completed in July 2023 and the model and measure is now available to use by GB's nuclear industry. This paper provides an overview of the research undertaken by the academic team at AMBS to develop the model and measure, describes each of its six dimensions and 15 sub-dimensions, provides an overview of industry level safety culture results from a survey undertaken to validate the model and measure, and discusses the next steps for this work and its potential adoption by other high hazard industries.

Acknowledgements

This paper outlines research carried out by an academic team from AMBS, comprising of Professor Sharon Clarke, Professor David Holman, Dr David Hughes, and Ms Lina Siegl. I am incredibly grateful to the team for allowing me to present this work on their behalf at Hazards 33. Having commissioned this research on behalf of ONR, I have been immensely impressed by the quality of the research carried out by the team in a challenging timescale. A project involving all 17 organisations that operate, or conduct operations on GB's 35 nuclear licensed sites, involved a great deal of stakeholder engagement and this would not have been possible without the academic team making themselves available for many meetings with me and industry stakeholders over the research period. I would also like to thank the staff at the Thomas Ashton Institute for Risk and Regulatory Research who project managed this research on behalf of AMBS for accommodating my several requests for meeting rooms at the university so that we could engage with stakeholders on this project. I also thank the safety directors and safety culture leads of each organisation that participated in the research for enabling the academic team to conduct interviews with staff and administer the survey within their organisations. I consider this to be an excellent example of a regulator, an academic body, and an industry working together to improve safety outcomes.

Introduction

ONR independently regulates nuclear safety and security at 35 nuclear licensed sites in GB. ONR also regulates transport and ensures that the United Kingdom meets its safeguards obligations. Its duty is to ensure that the nuclear industry controls its hazards effectively, has a culture of continuous improvement, and maintains high standards.

The role of organisational culture in maintaining nuclear safety is well established. Reports of investigations into notable events such as Three Mile Island (Kemeny, 1979), Chernobyl (IAEA, 1992), Davis Besse (NRC, 2002) and Fukushima (Kurokawa, 2013) provide compelling evidence of the importance of establishing an effective nuclear safety culture. Much academic and business research over the past 40 years has also established the critical role of organisational culture in achieving good business and safety performance (Deal and Kennedy, 1982; Kotter, 2008; Lee & Yu, 2004; Morrow et al, 2014; Sackmann, 2011; Stemn et al, 2019).

Safety culture emerged as a concept following the 1986 Chernobyl disaster (IAEA, 1991) and since then it has been an important focus area for many major hazards industries (Fleming et al, 2018), a key aspect of which is attempts to develop models and measures of safety culture. Within the nuclear sector, work has been undertaken to measure safety culture (Fleming et al, 2018; Morrow et al, 2014), however some of these lack strong validity (de Castro et al, 2013; Goncalves & Waterson, 2018), meaning that they may not accurately measure what they say they measure and may not predict important safety outcomes well. Given the overriding priority of safety within the nuclear industry and the importance of regular safety culture assessment, it is important that dutyholder organisations within Great Britain's nuclear industry can measure and understand their safety culture and work towards improving it.

In the *Chief Nuclear Inspector's Annual Report of Great Britain's Nuclear Industry* (ONR 2022), the chief nuclear inspector acknowledged the importance of safety culture in securing good safety outcomes and retained safety culture as one of ONR's three priority themes to ensure levels of increased industry attention on safety culture for the remainder of the 2022/23 reporting year.

ONR recognised the limitations of existing measures and in 2022 commissioned research to develop a model and measure of safety culture, which the nuclear industry may use to measure its culture and learn from good practices. ONR partnered with a team from The University of Manchester's AMBS, led by Professor Sharon Clarke, and supported by the Thomas Ashton Institute for Risk and Regulatory Research. This research concluded in July 2023 and each of the 17 dutyholder organisations which manage GB's 35 nuclear licensed sites participated in it. The future use of this validated safety culture measure across GB's nuclear industry will improve the rigour of assessments, allow longitudinal benchmarking, and provide a common industry language for communicating safety culture. This will create more coherency in this field and can facilitate exchange between organisations, for example, to explore results, gain insights into good practice, and to learn lessons.

Research Activity

In this section I briefly outline the research activity that AMBS's academic team undertook. ONR will publish a more comprehensive description of the research activity on its website in the autumn of 2023, and an academic journal article written by the academic team will follow.

The academic team first undertook a comprehensive literature review of existing safety culture models, for example James Reason's safety culture model, and those published by the International Atomic Energy Agency and the Institute of Nuclear Power Operations. They then undertook several interviews with internationally recognised academics and industry experts to develop an initial safety culture model which comprised of six dimensions and 20 sub-dimensions.

With an initial model now developed, the academic team conducted interviews with staff and contractors across eight organisations to develop survey items for each of the model's dimensions. They then conducted several 'Think Aloud Protocols' with a representative cross-section of GB's nuclear industry – this is an interview technique whereby the participant speaks aloud their thoughts when reading a survey item so that the interviewer can ascertain whether the item is relevant, representative, specific and clear. At this point all 17 dutyholder organisations which operate, or conduct operations on, GB's 35 licensed sites had contributed to the research.

The next step was to undertake a survey across a sample of the industry. This first survey, undertaken across eight organisations with 952 responses received, sought to test the internal validity of the model and measure. The academic team undertook confirmatory factor analysis of the survey results and found there to be good overall model fit: the full model is psychometrically robust, all factors are discriminant, and there is strong convergent validity. The measure includes both aspects that are close to the safety climate construct and distinct aspects of safety culture. This step confirmed that the model works, and the tool measures the model.

The next step was to address the measure's appropriateness. The key questions to address were: Does the measure predict safety outcomes? Does the measure operate similarly across sites / organisations? Is this a sensible measure to use? With the model and measure now revised, the academics conducted a second survey across 15 of the 17 organisations which operate, or conduct operation on, GB's 35 licensed nuclear sites, and received 3480 responses. Further confirmatory factor analysis confirmed that the measure retained a good fit, that the model is psychometrically robust, and that all factors are discriminant. The academic team made then several minor modifications to further improve its fit. Figure 1 shows the final model, and the reader can find descriptions of its dimensions and sub-dimensions in appendix A.

Through their analysis, the academic team found that the safety culture tool significantly positively predicted participants ratings of organisational safety performance, and positively predicted participants ratings of individual performance. They were able to conclude that the model explains a great proportion of variance in employees' own estimates of the overall quality of their organisations' safety performance, and that the tool predicts more variance in organisational level performance than individual-level performance, suggesting that the tool captures reflections on organisational features.

Figure 1: GB nuclear industry safety culture model

The penultimate phase was to undertake known-group analysis to determine whether the measure can discriminate between groups, for example can it detect differences in safety performance across organisations? To address this the academic team developed a safety performance indicator tool and asked ONR inspectors to rate each organisations' safety performance. They then placed the organisations into high and low performing groups and found that high performing organisations scored significantly higher than low performing organisations on the total safety culture score and all six safety culture dimensions. They then undertook a further test by placing the organisations into three groups – high, medium, low – and found that high and medium performing organisations scored significantly higher than low performing organisations on the total safety culture score and each of the six dimensions, and that high performing organisations scored significantly higher than medium performing organisations on three dimensions: Senior Leadership, Accountability and Reporting. They concluded that: the safety culture measure reflects differences in inspector ratings of organisational safety performance; each sub-dimension is sensitive to differences between organisations rated as having high and low safety performance, and between organisations rated as having medium and low safety performance; the safety culture dimensions of Senior Leadership, Accountability and Reporting appear to be crucial for distinguishing between organisations rated as having high and medium safety performance.

The final phase was concerned with the measure's feasibility. To address this, the academic team developed and validated three lengths of measure:

- Full form: 60 items (4 questions per sub-dimension)
- Short form: 30 items (2 questions per sub-dimension)
- Super-short form: 15 items (1 questions per sub-dimension)

The development of short-form measures reduces survey fatigue with no detriment for measurement validity: the trade-off being less information is available for potential intervention or follow up. Organisations can also use each of the six dimensions as stand-alone measures to track improvements as part of more targeted interventions.

Industry results

Figure 2 shows the industry safety culture results from the second survey (n=3480; 15 of GB's 17 nuclear licensed sites). The lowest possible score is 1 and the highest possible score is 5, on all dimensions expect for Disengaged where lower scores indicate better safety culture.

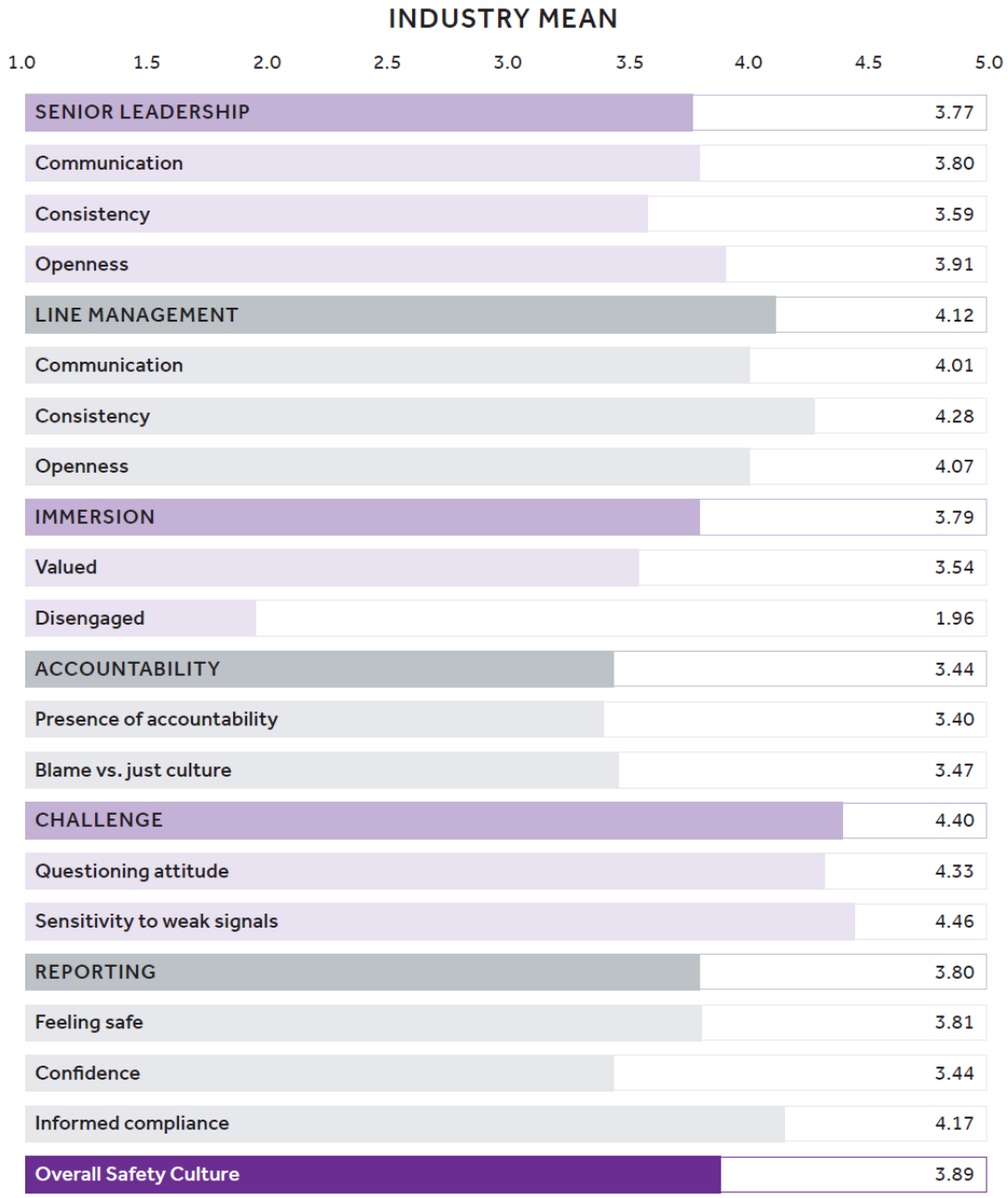

Figure 2: GB nuclear industry safety culture performance

It is of note that the scores on each dimension are high which reflects the high standard of safety within the nuclear industry, for example the Challenge dimension has an industry mean of 4.4 which indicates that levels of challenge in the nuclear industry are very high. Accountability is the lowest scoring dimension (mean = 3.44), and whilst still a high score, it is worthy of further exploration as it indicates that more could be done to ensure that people are held to account for their performance, and in a fair way, without undue blame and by adopting a learning approach to accountability. Participants scored their line management higher than senior leadership, with the Senior Leadership: Consistency sub-dimension (mean = 3.40) and the Line Management: Consistency sub-dimension (mean = 4.28) being the biggest differentiator within these dimensions, which indicates that participants perceive the behaviour of their line manager to be consistent with their messaging more so than their senior leaders. Once again, it is important to remind the reader than the scores for all dimensions and sub-dimensions are high, so this indicates an area for further exploration rather than an area of concern.

It is also important to note that these results are based on a sample size of 3480 participants, which is more than an ample sample size for validating the model and measure, however this is not a full industry survey, and the reader should not interpret the results as such. Nevertheless, the information presented in figure 2, provides useful insights into the nuclear industry's safety culture and how organisations can use the tool to measure and benchmark their safety cultures. For example, each participating organisation was provided with an individual report which benchmarks their performance in two ways: (1) by comparing their means scores to the industry mean scores; and (2) by identifying their percentile rank on each sub-dimension relative to that of the 15 participating organisations (top quartile, mid ranges, bottom quartile). This is useful for benchmarking purposes.

Discussion

The academic team developed the model and measure specifically for GB's nuclear industry and sought feedback from industry representatives throughout its development. The result is a state-of-the-art bespoke tool which is uniquely suited to the assessment of safety culture in GB's nuclear industry. The academic team developed it to the highest standards of psychometric rigour, and importantly, it predicts safety performance as rated by the nuclear industry workforce and ONR inspectors. The tool measures both elements of safety climate and safety culture and builds on the extensive field of safety culture research and practice conducted since the concept emerged in 1986 following the Chernobyl disaster (IAEA, 1991).

The results of the second survey which the academic team conducted to validate the model and measure are high and this reflects the high standard of safety within the nuclear industry. These results also provide useful safety culture insights which are worthy of further investigation. As organisations adopt the model and conduct the survey across their whole workforce, this will result in a larger data set which will provide a more accurate and nuanced picture of safety culture at facility, function, organisation, and industry levels. Although this tool provides the most comprehensive and nuanced assessment of safety culture in the nuclear industry to date, ONR and the academic team recommend that organisations use the tool as a diagnostic in conjunction with qualitative data and broader evidence to develop policy.

ONR is now working collaboratively with GB's nuclear industry and its Safety Directors' Forum to encourage the 17 organisations which operate, or conduct operations on, GB's 35 licensed sites to adopt the model and measure to accurately measure their safety cultures, benchmark results, learn from good practices, and further improve their safety performance. This is progressing well with several organisations having already committed to adopting it. During 2024, AMBS plans to undertake further work to administer the survey across participating organisations, gathering a much larger data set upon which they will conduct further analysis to gain richer insights.

The model's dimensions and the measure's items may be adapted for use by other high hazards industries. This may however result in inaccurate measurement unless an academic partner undertakes appropriate testing to ensure that the measure is both valid and appropriate for use in a different industry context. The academic team at AMBS can advise on how to conduct this. ONR is open to its use by other industries for non-commercial purposes as this would provide opportunities for wider benchmarking and cross-industry learning. Interested parties should direct their enquiries to contact@onr.gov.uk.

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Appendix A

Description of the model's six dimensions and 15 sub-dimensions

Senior Leadership

Strong safety leadership is of the upmost importance to an organisation's safety culture. Senior leadership consists of three sub-dimensions, which describe the main leadership attributes that shape safety culture in nuclear organisations. These are Communication, Consistency and Openness.

Senior Leader Communication	The extent to which participants perceive that senior leaders communicate the importance of safety in a clear, consistent, and frequent manner. This dimension not only considers whether communication takes place but also how it takes place (e.g., are leaders visible and do they talk to workers in a way that upholds safety standards?).
Senior Leader Consistency	The extent to which the behaviour of senior leaders is seen as consistent with their messaging. This is also referred to as 'walking the talk' and 'practicing what they preach' when it comes to safety.
Senior Leader Openness	The extent to which senior leaders are open to workers' feedback and ideas regarding safety. This includes elements that foster opportunities to provide feedback (e.g., encouragement) and the reaction to such feedback/ideas (e.g., actions taken).

Line Management

Line managers play an important role in workers' daily experiences. The main attributes that shape safety culture from a line management perspective are the same as those for senior leaders: Communication, Consistency, and Openness. However, they are manifest through different actions. Workers often perceive senior leaders and line managers very differently and it is important to differentiate between managerial levels.

Line Manager Communication	The extent to which participants perceive their line manager to communicate the importance of safety in a frequent, clear, and engaging manner. This dimension not only considers whether communication takes place but also how it takes place (e.g., engaging in difficult conversations to uphold safety standards, and proactively checking-in with workers regarding safety).
Line Manager Consistency	The extent to which the behaviour of line managers is seen as consistent with their messaging and whether line managers uphold the safety standards discussed by senior leaders.
Line Manager Openness	The extent to which line managers are open to, create opportunities for (e.g., asking for it), and take seriously (e.g., implementation / behaviour change), workers' safety ideas and feedback.

Immersion

Immersion is an emotional component of safety culture that comprises of two sub dimensions: Feeling Valued and Disengaged, regarding safety and general performance. The degree to which employees feel immersed within the organisation is a crucial component that influences safety culture in the nuclear industry.

Valued	The extent to which employees feel respected, trusted, and valued within the organisation. This includes whether the organisation recognises and rewards individual efforts and good safety behaviours.
Disengaged	The extent to which employees feel detached and withdrawn from the safety culture. This comprises whether workers are switched-off and see safety as a tick-box exercise rather than an overarching priority that they actively contribute to.

Accountability

In the nuclear industry, it is of upmost important that individuals are accountable for their safety behaviours. Accountability has two sub-domains that describe common forms of accountability: Presence of Accountability and a Blame vs. Just Culture.

Presence of Accountability	The extent to which individuals are held accountable for their actions regarding safety. This requires appropriate action when poor safety behaviours are displayed and is applicable to people at all levels of the organisation.
Blame vs. Just Culture	The extent to which individuals are held to account in a fair way, without undue blame, and by adopting a learning approach to accountability.

Challenge

A crucial component of safety culture in the nuclear industry is to recognise and challenge behaviours and assumptions that could adversely impact safety immediately or in the future. Due to the high standard of safety within this industry, accidents or disasters occur rarely. However, remaining vigilant to spot and communicate warning signs early remains essential. Challenge culture includes two sub-dimensions: Questioning Attitude and Sensitivity to Weak Signals.

Questioning Attitude	The extent to which individuals are comfortable challenging safety policies, procedures, behaviours, and norms, even if the challenge impacts productivity or questions senior leader actions.
Sensitivity to Weak Signals	Remaining vigilant for minor issues that may be warning signs or precursors of something more significant (e.g., being mindful that even non-nuclear activities can impact nuclear safety).

Reporting

Reporting closes the safety culture circle and builds upon all previous dimensions. It plays an inevitable part in the sustainability of an organisation's safety culture as it not only contributes to the identification, tracking, and management of safety events but also to the level of compliance workers exhibit. This dimension comprises of three essential components: Feeling Safe, Confidence and Compliance.

Feeling Safe	Feeling safe to raise safety concerns without fear of personal consequence. This includes whether individuals who raise safety concerns are rewarded or seen as troublemakers.
Confidence	Workers are confident that any safety concerns raised will be acted upon. Here, the speed with which concerns are acted upon, even if they challenge other important organisational goals (i.e., productivity), and the effectiveness of the reporting system are important.
Compliance	The extent to which individuals understand the significance of and comply with safety rules and procedures. This requires individuals to be fully informed of the safety risks and requirements relevant to their job rather than blindly carrying out safety procedures that are poorly understood.