

Safety culture in nuclear power plant construction

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SUMMARY

Safety culture related lessons learned from nuclear power plant construction projects in Finland are presented. A set of questions are proposed for organizations to discuss. The implications of these questions and constraining questions are considered.

KEYWORDS

Safety culture, nuclear safety, construction

Introduction

Strong focus on nuclear safety is required from the very beginning of a nuclear power plant's (NPP) life-cycle to avoid latent defects in the design or uncorrected errors in the construction, and to make sure the licensee develops adequate capability to safely operate the plant. To facilitate the importance of nuclear safety, organizations in the nuclear industry are required to have a good safety culture. This requirement is set in regulatory requirements and industry standards (IAEA 2016, WANO 2013). It applies to the licensee (i.e., the future operator of the plant) and other organizations participating in the design, construction, operation, or decommissioning of a nuclear power plant. International Atomic Energy Agency IAEA defines safety culture as an "assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and [nuclear and radiation] safety issues receive the attention warranted by their significance" (IAEA 1991).

Culture is that which is normal to a group, and thus safety culture affects what is considered normal work, how it should be carried out, and what are the potential warning signals that would indicate risk. The main notion is that culture is something an organization creates for itself, and which, once created, influences the organization. Culture is a result of shared learning experiences that affects how the group will learn in future (Schein 2017). Safety culture can be defined as the shared values, beliefs and assumptions relating to (nuclear) safety (Reiman & Rollenhagen 2018).

Design issues have contributed to accidents across different industrial domains, with about 50 % of events in aviation, rail, chemical and nuclear industries having design errors as contributing factors (Taylor 2007, Kinnersley & Roelen 2007). Various issues connected with the design (e.g. the plant layout and siting) contributed to the Fukushima nuclear disaster during the 2011 Tōhoku earthquake and tsunami (The National Diet of Japan, 2012). In a similar fashion, decisions made in the design phase combined with good operation phase safety culture were associated with the success of the Onagawa NPP to achieve safe shutdown during the same earthquake (Reiman & Rollenhagen 2018). Quality-related problems have been noted in NPP construction projects since the 80s (NRC 1984, STUK 2006). Many of these problems have their roots in inadequate safety culture.

Design and construction of a nuclear power plant

NPP construction projects are typically carried out with a so-called EPC (Engineering, procurement, and construction) contract that is essentially a turn-key contract where the licensee buys a delivery of an operable NPP. However, a turn-key delivery does not release the licensee from its full responsibility for safety already during the construction phase. In addition to being an ‘intelligent customer’ during the plant delivery project, the licensee must take systematic actions to establish, foster and sustain a strong safety culture within the project supply chain. This effort is essential to ensure that all activities in the supply chain are carried out according to requirements, with quality and safety targets met to be able to achieve nuclear safety during all lifecycle phases of the NPP.

NPP projects can be considered complex adaptive systems (Reiman et al. 2015) characterized especially by interorganizational complexity (Milch & Laumann 2016). In complex systems, traditional command-and-control management style needs to be complemented with participative and distributed leadership, shared guiding principles and adaptive management (Reiman et al. 2015, Oedewald & Gotcheva 2015).

In NPP construction, complexity and safety challenges are exacerbated due to the sheer number of companies and contracts involved, long supply chains, continuously changing workforce (especially at the construction site), multiple languages and nationalities and multi-location activities. For example, approximately 2000 subcontractor companies were involved in the Olkiluoto 3 nuclear power plant construction project, reaching up to five contract tiers at the construction site. (Oedewald & Gotcheva 2015). Many of the works require specialized expertise that only few companies in the world possess, and specialized and tailored equipment is used. Quality requirements are different and typically higher than in non-nuclear construction projects. A nuclear power plant, including its systems, structures, and components, is built to withstand accident situations with very different forces and temperatures from standard operation. Many systems have a safety function in addition to their function during normal operation.

During the design phase, many important decisions are made that in addition to nuclear safety affect the reliability, industrial and radiation safety, and maintainability of the power plant. Latent weaknesses or inadequacies in design, manufacturing and construction need to be avoided by organizational processes (review, quality control, configuration management, safety analyses etc), leadership, and a healthy safety culture. With construction and decommissioning included, a nuclear power plant has over a hundred-year life-cycle. This highlights the importance of the high quality of processes (including documentation) as well as the quality of the systems, structures, and components. Finally, each NPP design needs to be licensed according to national legislation and regulatory requirements. This means that before and during the construction phase redesign of the basic design and safety analyses are carried out in addition to detailed design, construction, manufacturing, installation, and control / verification activities.

Methods and goals of the paper

There have been two major NPP construction projects in Finland during the last decade: Olkiluoto 3 NPP (OL3) and the recently terminated Hanhikivi 1 NPP (FH1). The construction of OL3 started in 2005. It is currently in test operation and planned to be in commercial operation during 2023. The FH1 licensing process, basic design and site preparatory works started in 2014, and the project was terminated during Spring 2022. We have worked as safety culture specialists and contract researchers in these two projects jointly for over 20 person years. The paper builds on our experience and lessons learned during the period from 2006-2022. A two-day lessons learned exercise was held, facilitated by a research scientist (the second author), to extract the key lessons.

We propose a set of questions that each NPP project must ask and find a shared solution, if they wish to build a culture that contributes positively to nuclear safety. We will also provide examples of constraining questions that are too narrow and easily lead to misuse the safety culture concept. We identified four categories of questions:

- defining the key concepts,
- identifying how to assess and influence culture,
- realizing what is the added value of a cultural approach to safety, and
- deciding how to consider the context.

Defining the key concepts

The first set of questions refers to the need to agree on how the definitions and models of the key concepts such as culture and safety are understood in the project. Many industries, including the nuclear, tend to use both concepts without an explicit definition (Reiman & Rollenhagen 2014). During the construction phase, this is especially confusing as nuclear safety is abstract and, on the surface, it seems to refer to an operational power plant with nuclear fuel and nuclear reaction in the core. Occupational safety issues are easier to observe, especially during construction activities. Without explicit definition, safety culture may become associated mainly with occupational issues. However, occupational safety and process, or nuclear safety are two distinct types of safety that require different approaches to manage (Hopkins 2019).

Nuclear industry has produced good guidance on the attributes of a healthy safety culture, but to fully understand what “culture” is and how “safety” is achieved during the construction phase, dialogue is needed within and between the participating organizations. More scientific models, such as Schein’s (2017) model of organizational culture, clarify the essence of what culture is. Merely taking an existing definition and safety culture model and using that does not guarantee that its content is understood.

Table 1: Questions concerning the key concepts.

Question	Description	NPP construction
What safety are we talking about?	There is a need for clarity concerning what safety we are talking about: Nuclear safety, occupational safety, environmental safety, security	The distinction matters especially during NPP construction when occupational safety issues easily dominate over nuclear safety.
How do you define safety culture?	It is important to agree on a definition of safety culture that indicates how it differs from technical concepts and e.g. safety management systems.	Definition can include nuclear and occupational safety. Sometimes the term “nuclear safety culture” is used when the focus is solely on nuclear safety.
How does safety culture affect (nuclear) safety?	Since nuclear safety can be immediately endangered only after loading of the nuclear fuel, the mechanisms of influencing nuclear safety during construction need to be clarified.	The preconditions for reliable and safe operation are created during construction. Different types of organizations affect safety differently.

Defining the concepts jointly with the participating companies, and communicating them actively is important, since many organizations and individuals involved in the project lack knowledge of how safety culture relates to nuclear safety. Companies often associate safety only with occupational safety issues, not with nuclear safety. Further, it may be unclear to many how the construction phase affects the nuclear safety of an operating plant. In a nuclear power plant, structures, systems, and components may have different functions during emergency that exceed or differ from their

quality requirements during normal operation. The strict quality requirements and use of certain methods and procedures, documentation requirements etc. may seem unimportant and excessive to participating companies if nuclear safety aspects are not understood (see also the question below about context). It must be constantly reminded that many of the decisions and actions made during the construction phase can have consequences years, if not decades, later. Many quality defects during construction have their roots in well-intentioned behaviour to get the job done with a quality that is “good enough” for the purpose, but without adequate understanding of what the purpose really is.

Identifying how to assess and influence culture

After defining safety and culture, the project organizations need to identify how culture can be influenced, and how one knows whether the culture supports safety or not. There needs to be an agreement on what is a nuclear safety related event during design and construction. Typical nuclear events such as a reactor scram, unavailability of safety systems, leaks, contamination, or radiation dosages cannot yet happen. What can happen are various non-conformities in design review, construction and manufacturing activities, or even in quality control and assurance (e.g. failing to notice a non-conformity). Other potential nuclear safety related events include senior management making decisions without consulting the appropriate experts, making contracts based solely on cost, or neglecting employee concerns on a safety related matter.

Table 2: Questions concerning assessment and influence.

Question	Description	NPP construction
How do we know the strengths and weaknesses in our safety culture?	This also includes the question of who defines the criteria for a good safety culture, and what model to use.	There is a need for agreement on what is a nuclear safety related event during construction and what are the warning signs of declining safety culture.
How does one assure safety culture in the supply chain?	During construction, the future operator as well as the plant supplier need to assure safety culture in their supply chain.	Complex supply chains require grading of attention to most safety-significant companies, as well as contractual requirements for safety culture.
How does one systematically influence safety culture?	How to develop safety culture? Can you influence culture directly? Leadership and systematic culture development are important.	Leadership is about creating, maintaining, and changing culture. The importance of leadership is emphasized due to the abstract nature of nuclear safety during the construction phase.

Agreement on the attributes of good safety culture needs to be achieved between the project parties. However, too simplistic models easily lead to overemphasis on easily counted and observable activities. This does not support the added value of safety culture concept and further emphasizes the tendency to associate safety culture with more easily observable occupational safety issues.

An approach to assure safety culture in the supply chain should be agreed. Contractual requirements play a major role when managing the supply chain, and the main supplier / contractor as well as the future operator of the plant need to make sure safety culture issues are included in contracts. They also need to make sure the contracts allow them access to the sub-suppliers to ensure the adequacy of their safety culture development. However, supply chain will consist of several independent companies, and it is unrealistic to assume that any contractual requirement would lead to a radical and fast culture change. Rather than aim to change the culture, the owner and the plant supplier can gradually steer the culture in the supply chain by working together with the companies on safety culture issues. Also, an awareness of how the supply chain companies really behave and what

underlying cultural logics dictate their actions is important even if it is impossible to change them. It is also important to grade the attention to the most important suppliers and make sure they in turn assure safety culture in their supply chain. However, especially at the construction site contractors must be scrutinized independently of the company they are working for.

It should be realized that leaders have an essential role in the creation of culture (Schein 2017). Leadership is an important concept that needs to be properly understood by any safety critical organization. In a nuclear construction project, the importance of leadership is emphasized due to the long-time perspective needed to assure nuclear safety – values and shared priorities are essential to properly manage nuclear safety issues that, even if neglected during construction, will most likely never harm the personnel neglecting them. The line organization thus creates culture as well as safety. Safety (culture) specialists do not create the culture, they can merely facilitate and monitor its development.

Realizing what is the added value of a cultural approach to safety

The third set of questions is about realizing the added value of cultural approach to safety during NPP construction. Safety culture can be considered the link, or a moderator between the quality of the management system, its implementation, and the final product. Safety culture specialists focus on the human and organizational drivers and barriers of quality, going deeper than the quality specialists into the subjective and social issues such as norms, beliefs, and values. By adopting this wider perspective, cultural approach should contribute to systems thinking (Reiman & Rollenhagen 2014). It should also contribute to an understanding of how different types of organizations (design, manufacturing etc.) tend to have a distinct view on safety and their role in achieving it. Some of these differences are cultural, rooted in learned basic assumptions (Schein 2017).

Table 3: Questions concerning the added value of safety culture.

Question	Description	NPP construction
How does safety culture assurance differ from quality management?	Quality and safety are closely related concepts. Quality management is also an established discipline and personnel in projects recognize quality as an issue to be integrated into the management system.	Safety culture is the link between the management system, its implementation, and the final product.
What is the added value of the safety culture approach?	The project needs to understand why safety culture approach is required and what it adds to the existing approaches.	Safety culture can remind about the effects of personnel and organizations on nuclear safety during the construction phase and about the systemic influences on safety in general.

The development of a safety culture must serve the objectives of the organization, it is not a goal in itself. The development must be in line with the organization's strategy, and not, for example, a "counter-campaign" by the safety department or a program separate from the general development of the organization or the project. All project participants need to acknowledge the importance of culture for nuclear safety. Taking culture seriously has implications for the entire project governance (Oedewald & Gotcheva 2015).

Deciding how to consider the context

The fourth set of questions have to do with the context; understanding the specific requirements of nuclear construction on safety culture and deciding on an approach to systematically develop safety culture in the project.

Table 4: Questions concerning safety culture in a nuclear project.

Question	Description	NPP construction
What requirements does the context set us?	Issues to discuss include what good leadership is in this context, how the contracts facilitate / hinder good quality work and how the supply chain should be managed.	Project environment: High turnover, multicultural context with language issues, people inexperienced in nuclear, education from basic to doctorate, schedule pressures combined with heavy regulation.
How to take multicultural issues into account?	A specific question for large projects involving companies and individuals from all over the globe concerns multicultural issues.	Issues regarding leadership, authority and communication are especially relevant for the NPP construction project.
How to approach safety culture in nuclear power construction?	This is a holistic question about how to proceed with the concept of safety culture in NPP construction.	Systems thinking, shared values, understanding of nuclear safety, future orientation, information flow, and influence of organizational structural issues such as contracts are important.

A common argument is that if safety (or quality) suffers, the production will soon follow suit. The challenge is that during construction, neglect of nuclear safety may manifest years, if not decades, later. For example, design solutions influence the maintainability of the plant and the subsequent radiation dosages that the maintenance personnel will receive. Thus, the role (and instrumental value) of nuclear safety differs during the construction phase from that of the operation phase. During operation, nuclear safety is a guarantee of continued operation (of making money, that is). Even more importantly, the plant is producing electricity, and nuclear safety is a prerequisite for the continued production. However, during the construction phase, the company does not produce anything yet. During the operation phase many safety and development issues can be taken care of while the production continues and only in problematic or uncertain cases the plant needs to be shut down. Analysis and careful consideration (while the plant is in operation) are socially accepted by all parties. However, during construction, analysis and careful consideration may take time away from the schedule, and as there is no production, all issues that take time also cost money. Nevertheless, the schedule is not the enemy either, but rather an important aspect of organizing the work that should contribute to quality and safety while keeping the costs in line.

During nuclear construction, attention needs to be devoted to communication and flow of information. Networks and long supply chains naturally reduce the amount of information reaching the licensee – proactive communications and alternative channels are needed. Safety observations and safety concern reporting systems need to be set up as alternative channels for raising quality and safety issues. It must be constantly reminded that many of the decisions and actions made during the construction phase can have consequences for the safety and reliability of the operational power plant in the future. Multicultural work environment creates additional challenges for clear communication. Especially at the construction site, where multiple languages are spoken, attention needs to be paid to the clarity of messages. Translation issues, and translation errors, is another challenge. Finally, terminology differs between countries (and even organizations). A project terminology needs to be agreed with all participants. Another issue related to communication concerns the role and authority of the supervisor. In the Nordic countries communication style is rather straightforward and it is culturally acceptable for a worker to openly question management decisions. This may not be the case in some other cultures.

In the project world, the time perspective is typically short and requirements for practical achievements acute. In contrast, nuclear safety is a chronic issue that is not settled by any deadline.

The “overriding priority of nuclear safety” is much more abstract and difficult concept during construction, but even more important as a cultural guiding principle. Project environments are characterized by high turnover, multicultural context with multiple languages spoken, people with varying experience in the nuclear, varying education levels, cascading schedule pressures, and fragmentation of tasks between companies. It is a demanding environment for long-term safety thinking. Commitment and expectations of the licensee’s senior management are the starting point for safety culture in the entire project. Safety genuinely needs to be a shared value in the project. A long-term development program is needed to achieve this, not only a safety assessment document for the regulator.

Constraining questions and counterproductive approaches

One of the major challenges of working with safety culture in the nuclear industry is, paradoxically, the fact that good safety culture is a (contractual, industry best practice, peer group, and regulatory) requirement. This easily leads to a situation where the supplier or a sub-supplier is trying to prove they have a good safety culture, rather than openly trying to identify their weaknesses and develop activities. This is exacerbated by the fact that there are often quite detailed behavioural and attitudinal requirements for safety culture. These requirements are then submitted by the owner to the supplier for implementation. Safety culture risks becoming an intellectual exercise, a camouflage for real operations, where the supplier knows what to say and present to the auditor or representative of the owner. Safety culture policies and programs become “fantasy documents” (Clarke 2001) and safety specialists create a new discourse, a fantasy discourse, that is practiced between safety specialists of the companies. The challenge of two worlds, one of paper and one of practice, is typical to any safety-critical organization, but it is especially prevalent in any project setting with contractual requirements for plans, programs, designs, verification reports, etc.

Table 5: Constraining questions in safety culture development.

Constraining question	Description	NPP construction
How do you quantify safety culture?	Safety analyses require that risks are quantified. If safety culture influences nuclear safety, this effect needs to be a number, or so the logic goes.	The effect of safety culture on nuclear safety may be described in the Preliminary Safety Analysis Report, but its quantification should be avoided.
What exact behaviour and actions do you want to see?	This question is often asked if safety culture is a regulatory or contractual requirement.	It leads easily to overemphasis on easily counted and observable activities, and thus a focus on occupational safety.
How do you certify safety culture or verify in audit?	Whenever there are contractual or regulatory requirements, these need to be verified in some manner, typically by an inspection or an audit.	The limits of the traditional audit approach need to be realized. Audits can reveal a lot about how the organization develops culture, but not much about culture as such.
How many cultures do we need?	Safety culture is sometimes considered as one of several cultures that an organization has or needs.	Project schedules and costs create pressure to devise a “project culture” as a counterforce to safety culture. This hinders attempts to create a company-wide culture.

Another counterproductive approach is to focus merely on easily implemented and measured activities, such as trainings and issuing posters and booklets. If these are the only activities the company does to develop safety culture, they will further contribute to the fantasy nature of safety culture. These activities are easy to verify, but they do not reveal much about the actual culture.

Senior management may sometimes think they need a “project culture” in addition to, or even to counteract, safety culture. However, this approach risks making both “cultures” superimposed and artificial. The organization should develop one culture that emphasizes safety and acknowledges the other important goals of the project, quality, schedule, and cost.

Recommendations and conclusions

Understanding the concepts of culture and safety are key to assuring nuclear safety during the construction phase. Systems thinking and a future orientation are needed to be able to consider effects that manifest in time. Values and leadership are critical for assuring nuclear safety during the pre-operational phase – the moral dimension of culture is emphasized (Rollenhagen 2010) in addition to the structural aspects (contracts, the management system) supporting its development.

For a company that is building a nuclear power plant, nuclear safety refers to how the company develops long-term organizational conditions and ability to assure nuclear safety during the entire life-cycle of the plant and how it verifies the designed and built safety conditions and ability of the plant (as designed, as built, and as documented). Safety culture in such a company should facilitate the understanding and management of the proper organizational condition and ability. Safety culture should also facilitate the discovery of any underlying weakness in the system. There are always defects, errors and mistakes in complex projects, but without trust and open climate these are not reported and may remain latent until the operation phase.

Nuclear safety, and thus safety culture, look different from the perspective of the various participating organization in an NPP project (construction, manufacturing, design, etc.). Rather than talking about safety culture idiosyncrasies of a lifecycle (e.g. construction phase) in general, it is recommended to talk about idiosyncrasies of different types of organizations. One reason for this is the fact that life-cycle phases coincide: while (non-nuclear) construction starts, nuclear related design and licensing is still ongoing, and manufacturing of so called long-lead items (such as the reactor pressure vessel) starts early and lasts well into the nuclear construction phase. Future research should clarify the differences in safety culture between the various types of organizations participating in complex safety-critical projects.

To properly consider safety culture in a project environment, contracts and supply chain management in general is in a key role: Conditions for good safety culture are created before the project execution fully starts. However, contracts are also one of the main potential hindrances to the development of safety culture since contractual arrangements may promote the above illustrated constraining questions rather than an open dialogue on cultural aspects of safety. If the contracts reward timely delivery and costs over quality, thorough verification and documentation and joint learning, the supply chain safety culture will learn and develop accordingly.

In conclusion, systems thinking, shared values, understanding of nuclear safety, future orientation, information flow, and influence of organizational structural issues such as contracts are important issues to consider in NPP construction projects. Leadership, communication, and authority issues need also to be considered especially at the multicultural construction site. The project parties need to agree on how definitions and models of the key concepts such as culture and safety are understood, and how culture can be influenced, and how one knows whether the culture supports safety or not. In addition, the added value of cultural approach to safety during NPP construction needs to be realized. Finally, an approach fit to the project realities need to be decided and implemented. Simplification and quantification of safety culture should be avoided, as well as the reduction of culture to mere safety behavior. Culture needs to be understood as result of joint learning of the group, that influences how the group perceives, thinks, feels, and acts.

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