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Safety management challenges and tensions in the European nuclear power industry

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Abstract

This paper provides an analysis of major management challenges and tensions within the European nuclear power industry in the context of safety. The results show that human resource management, organisational climate and culture, and public confidence and trust are the three most challenging areas for nuclear managers across Europe. Managerial tensions typically relate to the setting of priorities and maintaining focus, and to the need to find a balance between diverging demands and expectations, such as perceived conflicts between economy- and safety-related objectives. Overall, the results suggest that nuclear managers need and use complex models for structuring their realities and that the safety of a nuclear power plant cannot be managed independently of the other goals of the plant organisation.

Keywords: Nuclear power industry; Management; Safety; Challenges; Tensions; Europe

1. Introduction

Over the past decade, utility and nuclear power plant (NPP) managers have been confronted with a number of new challenges. Especially, ageing plants and equipment (OECD/NEA, 2000a), an ongoing generation change (OECD/NEA, 2001), increasing competition as a result of the progressive deregulation of electricity markets (Bier, Joosten, Glyer, Tracey, & Welch, 2001) and mounting political pressures (OECD/NEA, 2004) have been shaping the scope and nature of managerial concerns and responsibilities in many

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countries. The managers have responded in different ways. For example, subcontracting has accelerated as a means of optimising the use of resources and of introducing cost savings (Kettunen, Mikkola, & Reiman, 2004). Further investments in plant life cycle management and performance development have been seen as a feasible way to take better advantage of the existing capacity, as the construction of new NPPs has proved impossible in Western countries—with the exception of Finland (OECD/NEA, 2000a, 2004). In general, NPP managers have managed to find ways of dealing with the challenges in a constructive and successful manner.

There are, however, examples of events within the nuclear power industry where a striving for short-term economic advantage as well as sheer indifference have gained the upper hand. The criticality accident at a Japanese nuclear fuel conversion facility in 1999 is a recent and well-documented case of such behaviour. The case study of Furuta et al. (2000) revealed a clear conflict between the business interests of the company operating the fuel conversion facility and the applicability of the facility to the kind of operations it was actually used for (the company wanted to speed up the production of uranium solution at a plant that was not well suited to that purpose). A number of failures in the area of safety management were identified, which included, for example, poor management oversight, poor training and deliberate procedural violations. In particular, the case demonstrated how important it is to invest in building a good safety culture, to identify the most important safety-critical functions to be managed, and to establish appropriate goals, policies and priorities to support the management of potentially conflicting goals and expectations.

It can be assumed that all NPP managers, including those of the best performing and most progressive plants, also have to deal with highly challenging and complex issues on a regular basis. For example, while there are often alternative ways of introducing cost savings and of boosting productivity, such measures must be implemented without compromising safety. If the chosen way of proceeding is subcontracting, the full and undivided responsibility for the safety of the plant will nevertheless remain with the licensee (an organisation with a government licence to operate a NPP). In addition, although political pressures and vocal anti-nuclear interest groups challenge NPP managers in many countries, the managers are still expected to invest in plant performance development in the long term and to secure a steady supply of affordable electricity for the plant owners (i.e. utility companies) and society as a whole. Although a lot has been written about safety management and the nuclear power industry in general, it is difficult to find descriptions of how the NPP managers themselves perceive the situation: i.e. issues that are felt to be particularly challenging, the extent to which they are safety related, and the sort of conflicts of interest they have to deal with. Such information would provide interesting insights into the management of safety-critical systems and organisations in competitive markets.

2. Safety management in safety-critical industries

One factor connecting utility companies and NPPs, contractors, regulators and researchers working in the field of nuclear power is the recognition of the paramount importance of safety. This is manifested in the form of extensive and conservative norms, procedures and laws that control nuclear power-related activities worldwide. The role of plant management cannot be underestimated, however, because formal requirements alone do not guarantee safe operations. This is why active safety management is needed. (Haber, O'Brien, Metlay, & Crough, 1991; OECD/NEA, 1999a, OECD/NEA, 1999b; Reason, 1995).

Safety management refers to organisational measures that seek to identify, assess and control *risks* in order to guarantee nuclear, personnel and environmental safety (see e.g. OECD/NEA, 2006). These risks include, among others, occupational accidents (a risk pertaining to all industrial facilities), accidental releases of radioactive substances and, in the worst-case scenario, a meltdown of the reactor core. Management is responsible for "recognizing the safety significance of both the design of the installation and the way in which it is operated and maintained, and to put in place suitable organizational processes to manage risks" (p. 13). Good safety management implies, for example, that the organisation is well structured, that the lines of authority and corresponding responsibilities are clearly defined, and that the safety policy, requirements and procedures are well established, understood and observed. In particular, the aim should be to promote a strong safety culture and to achieve good safety performance.

For the layman, the term safety management often stands for a focused set of activities to control a particular hazardous operation or process—the underlying assumption being that the safety-related operations of an organisation can be easily defined and separated from the other (non-hazardous) ones. In practice, the task of securing a good safety performance from a complex system, such as a NPP, is a comprehensive challenge, because safety is an outcome of several organisational, individual, technical and environmental factors, which also interact with each other (e.g. Rasmussen, 1997; Reason, 1995; Reiman & Oedewald, in press). The safety performance of a NPP, or any other industrial installation that is used for the processing of hazardous substances, depends on the reliability of various technical systems, the way they are operated and maintained, and the likelihood that possible defects in those systems or applied operating procedures can be identified and restored in a timely manner. Securing a proper allocation of management attention over a number of competing focus areas and issues is therefore an important element of good safety performance (Rollenhagen, 2006; Wahlström & Rollenhagen, 2004).

The concept of *tension* proves useful in the analysis of safety management-related issues. In this paper the term tension is used to refer to a generic priority setting or resource allocation challenge, or to a challenge of balancing two or several at least partly conflicting objectives or expectations. An excellent account of potential tensions with respect to safety and other *goals* in high-risk organisations is provided by Sagan (1993, pp. 37–38). Sagan claims that tensions do exist for various reasons—even when a high safety level has been recognised as the priority official goal by the organisation's leaders. His first argument is that pressures to maintain high production rates exist in most hazardous industries. Such pressures may be only slightly moderated by an increasing focus on or investments in safety (cf. Rasmussen, 1997). Second, although political leaders and authorities desire increased safety, differences in the prioritisation of goals between an organisation and the administrative authority supervising its operations can still exist. Third, even if administrative elites and organisational leaders have consistent objectives favouring safety, they may be misinformed about the nature or frequency of dangerous operations by lower-level managers or employees, "whose interests include keeping their jobs and therefore not getting caught when the rules are violated" (p. 38). Moreover, the upper management may also be detached from operational realities due to frequent changes in the management team and/or because of the low priority of the business or facility concerned. For example, a case study of the accident at the Union Carbide's pesticide plant in 1984 in Bhopal, India, indicated low management priority as one of the root causes of the accident (Shrivastava, 1992). In consequence, there may be different conceptions of the *actual* as well as the *sufficient* level of safety of particular systems, their operation or their state at any given point in time.

Many tensions and dilemmas in high-risk industries relate to *methods* of managing and regulating safety. One of the most interesting debates in the area relates to *redundancy*, i.e. duplication and overlap of critical components, systems, functions and/or personnel to improve safety. Although redundancy in general does increase safety, it may also have unexpected and counter-productive effects if not properly managed. There are at least three main reasons for this. First, redundancy increases the interactive complexity of systems and organisations (hereafter 'systems'), thus making them prone to unanticipated common-cause failures. Second, in addition to increasing complexity, redundancy also tends to make systems more opaque. Individual failures are thus more likely to remain unnoticed and uncorrected, and may accumulate over time (i.e. become latent). This implies that a rare event may trigger an avalanche of unexpected failures, which can turn out to be difficult to handle. Third, awareness of redundant backup systems may create false impressions of abundant safety margins. This may provide an incentive to take advantage of the situation, which may lead to a gradual and insidious degradation of the built-in safety margins in pursuance of increased efficiency and profits (Rasmussen, 1997; Sagan, 1993, pp. 39–40).

Another interesting discussion relates to *centralised* and *decentralised* decision-making models in different organisational contexts. Most NPPs are hierarchical work organisations with centralised and well-defined decision-making procedures. According to a commonly shared view, a centralised decision-making model applies well to the management of processes that can be characterised by tight *couplings* and linear *interactions*. Such a process does not allow delayed control measures, but the number of important control parameters is limited and the behaviour of the process is usually well understood and relatively easy to predict (as a result of its linearity). On the other hand, if the process can be characterised by loose couplings and complex (or non-linear) interactions—implying that processing delays may be allowed whereas the number of important control parameters is high and the behaviour of the process is difficult to understand and predict—a decentralised decision-making model may work better. The challenge with nuclear power generation is that the process to be controlled (i.e. nuclear fission) may be characterised by *both* tight couplings *and* complex interactions. In terms of the distribution of decision-making authority, the theoretical paradox is as follows: centralisation is effective because it contributes to the management of tight couplings by providing the means for a fast and co-ordinated response, while decentralisation is effective because it makes it easier to cope with uncertain situations by empowering those who have the best possible knowledge, skills and position for their management (Perrow, 1984, pp. 88, 96, 332; Sagan, 1993, pp. 40–41; Weick, 2001, pp. 231–232).

Within the context of safety management there are many interesting questions that have no satisfactory solution, some of which may perhaps be labelled as 'eternity questions'. On most questions of this kind, there are conflicting and often equally well-grounded views both in industry and academia. Further empirical studies are thus needed. In this article we will first provide an overview of the nuclear power industry in the context of managerial work. After a description of methods, we will report our findings on the predominant safety management challenges and tensions within the industry in five European countries. We will also contrast our findings with other applicable research in the area and assess the validity of selected safety management theories and models. Finally, we will identify the major implications for the management of NPPs and for organisation and management research.

3. The nuclear power industry in the context of managerial work

Most of the NPPs in operation today were built during the 20-year period from 1965 to 1985. There are many reasons for the practical standstill in new construction projects in Western countries following that period. The most important one is political opposition which is mostly based on three main arguments: the risk of severe accidents, the handling and final disposal of nuclear waste, and the proliferation of nuclear weapons. Many non-governmental organisations, such as Greenpeace, have been actively campaigning against nuclear power. Various societal pressures have led to political decisions to phase out nuclear power, at least in Belgium, Germany, Italy and Sweden. The relative weight of *politics* is therefore one of the most distinctive characteristics of nuclear power in comparison to most other industries.

In countries where the political climate is predominantly against nuclear power and where nuclear power accounts for a large share of electricity generation, the NPP managers are also confronted with an interesting *societal dilemma*: they have to defend the *raison d'être* of their industry while maintaining capability for a steady supply of electricity for society. The case of Sweden provides an illustrative example: almost half of the country's electricity is still generated by NPPs, even though a decision to phase them out was made as far back as 1980, in the aftermath of a referendum in which the majority of Swedes voted against the further development of nuclear power in the country. So far, two out of 12 units have been prematurely shut down in Sweden, Barsebäck 1 in November 1999 and Barsebäck 2 in May 2005. Nevertheless, in the spring of 2006 all Swedish licensees were actively planning for power upgrades at their plants (OECD/NEA, 2004 and the websites of SKI, FKA, Ringhals and OKG).

There are also many other factors that pose quite specific challenges. The most important one could be formulated as an absolute demand for *safety*. In addition to a potentially damaging impact on people and the environment, any incident or accident at a nuclear facility typically results in disproportionally large costs that far exceed the costs of measures that could have prevented the event. Another safety-related feature of the industry is extensive international and national *regulation*, which in practice implies that operating without accidents is not good enough. Licensees must also be able to prove that their plants are and will stay safe under all circumstances. In addition, increasing *competition*, caused by the deregulation of the electricity market, has put many utility companies in a new situation. They have lost the sheltered position in which they were able to recover their operating and maintenance expenses in the form of electricity tariffs. This change put a lot of pressure on the utilities that run nuclear power units to decrease costs and to stay competitive without compromising safety.

Turnover of personnel has been small, which means that the average age of the work force within most NPPs has been steadily increasing. People who were involved in the commissioning of the present NPPs have already retired or will retire in just a few years' time. Moreover, political opposition and perceptions of diminishing career prospects have apparently made young qualified people more hesitant of seeking education and employment in the nuclear power industry. The number of students graduating at bachelor's and master's level in nuclear science and engineering has been decreasing since 1990 in the OECD member countries (OECD/NEA, 2000b). This in turn translates into recruitment challenges and greater reliance on the licensees' in-house training programmes. In short, the challenge is to secure a successful *generation change* in the industry (IAEA, 2004).

NPPs are *technically complex* and operationally demanding entities. They usually incorporate different technologies, hazardous substances and many interrelated sub-systems. For example, in many plants old and new technologies are used side by side in the control and instrumentation systems, adding to the system integration, maintenance and modification challenges (IAEA, 1998). During annual plant outages (refuelling and maintenance periods) more than 1000 employees representing both the plant organisation and its contractors may work on various assignments on the same site, which creates demanding work planning and co-ordination challenges and also increases risk levels (Barriere, Luckas, Whitehead, & Ramey-Smith, 1994; Pyy, 2000). Plant outages are intentionally planned to be as short as possible to minimise revenue losses, while the scope of the work to be completed is usually huge, ranging from reactor refuelling to software updates. Modifications of plant systems and equipment are particularly demanding: they necessitate extensive safety analyses and add to the challenge of maintaining the integrity of plant documentation (Wahlström & Kettunen, 2000).

Responses to the special demands of the industry consist of a combination of technology, organisation and people-oriented actions. To ensure safety, plants are managed through an extensive set of rules and guidelines, such as licence conditions, technical specifications, management control procedures, maintenance programmes, work instructions and quality systems. The minimum educational and competence requirements for all key managerial and employment positions are typically determined by the national regulator. Control room operators are regularly trained and examined using full scale simulators. External contractors must certify their operations and personnel before obtaining eligibility to tender for services relating to NPPs. Most technical modifications as well as major organisational change initiatives are subjected to a safety analysis before their implementation is approved. In comparison to most other industries, the construction, operation, maintenance and modification of NPPs are subject to a far greater number of *formal requirements and procedures*. International co-operation with respect to the development of safety standards and procedures is also relatively intensive.

Despite the global nature of the industry and the large number of common factors, there are also notable country-specific differences in the status of nuclear power. The size and age of the industry, the nuclear share of electricity generation, and support among various interest groups in society vary from one country to another. In addition, while most European countries with operating NPPs are either reluctant to build new units, or inclined to phase out the whole industry, the Finnish government and the Finnish parliament have both supported the application of the Finnish power company TVO to build a new nuclear power unit (see TVO's website). In Europe the differences in this respect are particularly large and give rise to an assumption that the NPP managers' 'problem space' may include a notable country-specific element.

Table 1
Participants[a] and applied data acquisition methods

Organisation (Owner)	Type of organisation	Country	Data acquisition methods		Participants by management level[b]			Total
			Metaplan	Interviews	Top	Senior	Middle	
Olkiluoto (TVO)	NPP	Finland	1	4	1	3	11	15
Pohjolan Voima Oy	Utility company	Finland	–	1	1	–	–	1
Forsmark (FKA)	NPP	Sweden	2	–	1	9	9	19
Ringhals (Ringhals)	NPP	Sweden	2	–	–	7	10	17
Oskarshamn (OKG)	NPP	Sweden	2	–	–	4	7	11
Sydkraft AB	Utility company	Sweden	–	1	1	–	–	1
Vattenfall AB	Utility company	Sweden	–	1	1	–	–	1
Grafenrheinfeld (E.ON)	NPP	Germany	1	–	1	5	5	11
Almaraz[c]	NPP	Spain	2	–	–	3	8	11
Cofrentes (Iberdrola)	NPP	Spain	2	–	–	4	6	10
UNESA	Industrial association	Spain	–	2	2	–	–	2
Oldbury (BNFL)	NPP	UK	2	–	–	5	8	13
BNFL plc	Utility company	UK	–	6	6	–	–	6
WANO Paris Centre	Industrial association	France	1	–	–	–	10	10
Total					14	40	74	128

[a]The data collected from Krümmel NPP (Germany) and Wylfa NPP (UK) as part of the LearnSafe project were not included in this analysis.
[b]Definitions are given in the text.
[c]Almaraz is jointly owned by Compania Sevillana de Electricidad, Iberdrola, and Union Electrica Fenosa.

4. Methods

4.1. Data acquisition

Most of the data were collected as part of the LearnSafe project (see the LearnSafe website) during the spring of 2002. The data were generated in response to the question "What are the perceived emerging challenges in the management of NPPs in the context of safety?" using Metaplan sessions and semi-structured interviews. A summary of participating organisations and applied data acquisition methods is given in Table 1.

In a Metaplan session, data can be collected from several participants at the same time. During each session, participants were asked to individually identify and write down on separate sheets of paper four to five key challenges (statements) in response to the research question. The sheets were then collected, attached to the wall of the meeting room, and arranged into larger thematic groups by the participants. In some sessions, the most important statements and thematic groups were also identified.[1] The researchers organised the sessions, guided participants through the discussions, and documented the results. A total of 15 Metaplan sessions were conducted as part of the study, of which 14 were held at eight NPPs in Finland, Germany, Spain, Sweden, and the United Kingdom. One session

[1]This was not carried out in all the sessions and interviews in a systematic way. As a result, given weights were not utilised in the subsequent analyses of this study (see also Section 4.2, Phase 3).

was held at the world association of nuclear operators (WANO) in Paris, France. Usually two Metaplan sessions were held at each location: one for senior and another for mid-level managers (there were three exceptions as depicted in Table 1). On two occasions, the plant manager also participated in the Metaplan session. At WANO some of the participants represented countries that were not directly involved in the study (e.g. France, South Africa, Russia and the USA).

Semi-structured interviews were used to gather data from 11 top utility managers representing Pohjolan Voima Oy (Finland), Sydkraft AB (Sweden), Vattenfall AB (Sweden), UNESA (Spain) and BNFL plc (UK), and from the top and senior managers of TVO, a Finnish power company operating the Olkiluoto NPP. Prior to the analysis, data from the interview transcripts were reduced to short summary statements of perceived challenges. Those summary statements were then integrated with the statements generated in the Metaplan sessions. The combined number of statements in the data set was 593.

In this study, directors and business unit heads at the corporate level as well as plant managers qualify as 'top utility managers'. The term 'senior manager' refers to the immediate subordinates of the plant manager, such as division and function heads, and to the members of the plant's management team (excluding the plant manager). Section and group heads, as well as people whose relative position in the plant organisation remained unknown, were classified as 'mid-level managers'. A total of 128 top utility, senior and mid-level NPP managers participated in the study, representing general management as well as all major functions of an NPP, including operations, maintenance, engineering, HSEQ (health, safety, environment and quality) and various support functions (such as finance, personnel and information technology services).[2] All Metaplan sessions and interviews were organised by the local LearnSafe partner and were carried out using the local language with the exception of the WANO Paris Centre, where English was used. Data gathered from utility companies and NPPs in Finland, Sweden, Germany and Spain were afterwards translated into English by the LearnSafe research team. The data analysis was based on these translated statements.

4.2. Data analysis

Data analysis was conducted in four main phases using a number of complementary quantitative and qualitative methods. *Phase* 1 started with a brainstorming session and the definition of a new classification model. The original groups of challenges formulated as part of the Metaplan sessions were heterogeneous, making comparisons between particular plants and countries difficult. For example, similarly named groups of challenges formulated in separate sessions could turn out to be quite different in terms of their content, and vice versa (similar content, different names). Therefore a decision was made to reclassify the statements using one common model. The new classification model was developed by the researchers during the LearnSafe project, and it came to include the following dimensions: (1) Economic and financial (or 'Money'), (2) Workforce and competence ('People'), (3) Technology, (4) Systems and procedures, and (5) Environment. These five dimensions were assumed to cover the major generic domains of a NPP

[2] The line-up of participants was determined by the organisations concerned. Therefore, the researchers did not have full control over the number of participants or the position (relative rank, area of responsibility) they held in their organisations.

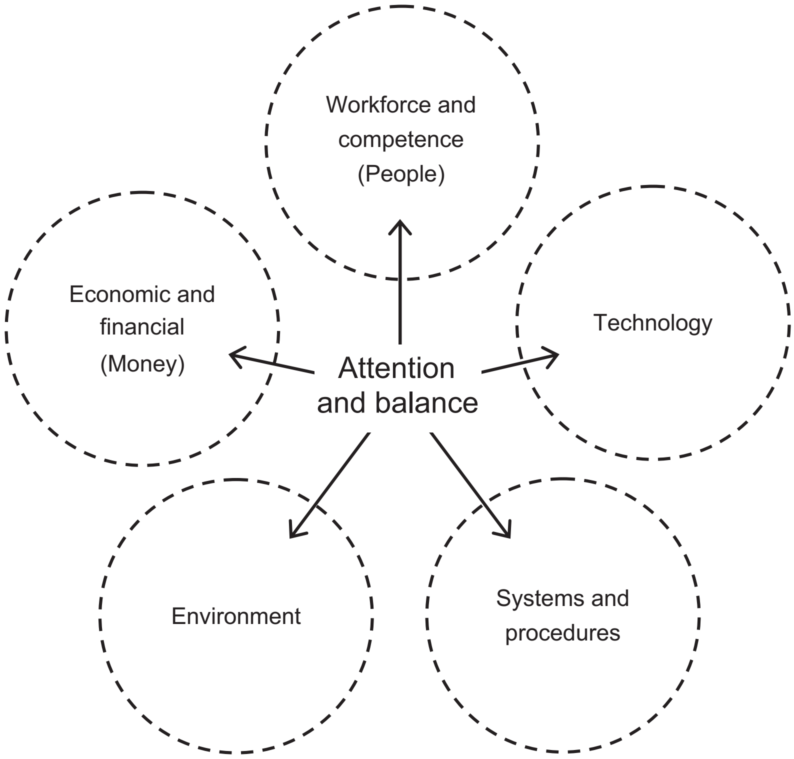

Fig. 1. The five-dimensional model used for the classification of statements.

manager's job. The model can be seen as a modified version of earlier characterisations of factors influencing organisational learning and safety (Baumont et al., 2000) and areas of management decision-making (Rollenhagen, 2006; working paper in, 2002) in the context of nuclear power. The model is presented in Fig. 1.

The five dimensions of the classification model were interpreted as *fuzzy sets*.[3] The use of fuzzy sets is motivated by the fact that the statements, representing the participating NPP managers' perceptions of various challenges and related influence mechanisms within their own organisations and the industry in general, often related to each other and various topic areas in different ways. In consequence, they did not easily fit into mutually exclusive categories. By using fuzzy sets, particular challenges could be placed in one or several categories at the same time with different weights or degrees of membership. The resulting five-dimensional data space also allowed the use of quantitative clustering techniques, as explained below.

In *Phase* 2 the statements were classified. The classifications were performed independently by three researchers representing three different research organisations (VTT Technical Research Centre of Finland, Lancaster University Management School in the UK, and Technical University of Berlin in Germany). The statements were presented in random order, and all references to particular countries, plants and sessions were concealed during the classification process. The researchers were requested to classify the

[3]In classical set theory, the membership of elements in relation to a set is assessed in binary terms, i.e. an element either belongs or does not belong to the set. By contrast, in fuzzy set theory elements' degree of membership in relation to a set can vary within the closed interval of [0,1] and can thus be e.g. 1/2 or 1/4. Kantrowitz, Horstkotte, and Joslyn (1997) provides a good introduction to fuzzy sets and fuzzy logic.

statements with respect to the dimensions of the classification model on the basis of their (assessed) degree of membership using a scale of 0–100, 0 denoting no membership and 100 very strong membership. Therefore, each researcher assigned each statement an array of five integers.

In *Phase* 3 the classified statements were analysed. The classified data were combined and the average values of assigned degrees of membership were subjected to a series of cluster analyses. The average values were used, because that was assessed to be the most feasible way of integrating the results of diverging classification strategies into one unified classification and to avoid bias. There were, for example, large and systematic differences between the researchers regarding their tendency to link statements to Systems and procedures (on average, this dimension by was considered *four* times more important by the German and the Finnish researcher than their British colleague). Another notable difference related to the perceived importance of Money as an attribute of identified challenges (the German researcher gave this dimension around *twice* as much weight as his two colleagues).[4] The cluster analysis was regarded as an efficient way of structuring the data (consisting of data points in the five-dimensional data space). A hierarchical cluster analysis was conducted to determine the optimal number of clusters (see Hair, Anderson, Tatham, & Black, 1998). On the basis of the clustering (agglomeration) coefficients, a nine-cluster solution was selected.[5] A *K*-means cluster procedure was used to create nine clusters. These nine new clusters were interpreted to represent concurrent management challenges (or challenge areas) in the European nuclear power industry. The clusters were named by emphasising challenges located close to the corresponding cluster centres.[6] The relative size of a cluster, measured by the number of statements included in proportion to all statements, was also interpreted to represent its relative importance. The clustering solution was illustrated by means of multidimensional scaling (ALSCAL) and the Euclidean distance model. Associations between the clusters and the selected background variables of Country, Organisation (including participating NPPs, utility companies and industrial associations) and Management level (top, senior and mid-level managers) were studied by means of cross-tabulation and χ^2 tests.

In *Phase* 4 predominant tensions were identified by reclassifying all the statements according to the following two-step procedure. First, all statements that were interpreted to *explicitly* refer to various tensions in general, or to the challenge of managing specific goal conflicts in particular, were picked out from the dataset. Second, the selected statements were classified into mutually exclusive categories. The categories were formulated on grounds of the key themes emerging from the data. The classifications were performed by the authors of this paper on the basis of a consensus of opinion.

[4]The results of the classification process demonstrate the difficulty of quantifying qualitative data and the importance of integrating the views and expertise of several people into the process.

[5]The agglomeration procedure does not produce unambiguous results. According to the coefficients, 2, 3, 6 and 16 cluster solutions also appeared plausible. The 9-cluster solution was chosen for practical reasons, because it provided a good compromise between the manageability and resolution power of the emerging data structure.

[6]Since the five-dimensional classification model was introduced by the researchers and since the researchers also classified the statements and clustered the data, the proposed solution summarises the researchers' view of the problem space given the whole empirical dataset.

5. Results

5.1. Management challenges in the European nuclear power industry

According to the analysis, the challenges can be conveniently grouped into nine clusters. These clusters were named as follows: (1) Economic pressures, (2) Human resource (HR) management, (3) Nuclear know-how, (4) Rules and regulation, (5) Focus and priorities, (6) Ageing, modernisation and new technologies, (7) Public confidence and trust, (8) Climate and culture, and (9) Miscellaneous (a number of challenges without a common denominator). These clusters provide an overview of today's challenges to NPP management in the context of safety in Finland, Germany, Spain, Sweden and the United Kingdom. The *largest* clusters in terms of challenges included were HR management (22.3%), Climate and culture (17.4%) and Public confidence and trust (12.8%). These three clusters were interpreted as the NPP managers' most important problem areas in the five participating countries.

The HR management-related concerns include such issues as age distribution of personnel, early retirement, recruitment of new personnel, and maintaining competencies. In short, they relate to the challenge of maintaining a sufficient level of competence within the plant organisation. Maintaining personnel motivation, building a proper safety culture, fighting complacency, and managing mental and emotional strain are examples of challenges that were grouped under the term Climate and culture in this study. These challenges have mostly to do with work motivation and related organisational factors. The third cluster, Public confidence and trust, contains challenges relative to the threat of sabotage and terrorism, changing political frameworks, irrationality in anti-nuclear attitudes, and distrust in local or regional authorities. In other words, it refers to the perceived challenge of securing the support of other interest groups of the society. In general, the results underline the importance of organisational and human factors in the management of NPPs.

Table 2 shows the co-ordinates of the nine cluster centres. The rows of the table represent the challenge clusters, the columns represent the five dimensions of the

Table 2
Co-ordinates of the cluster centres

Cluster	Classification dimensions				
	Money	People	Technology	Systems and procedures	Environment
Economic pressures	**83.5**	23.6	16.7	47.4	**66.0**
HR management	41.7	**95.7**	14.4	48.5	42.7
Nuclear know-how	37.9	**61.6**	17.9	43.5	**79.8**
Rules and regulation	13.8	23.1	20.3	**78.0**	**84.8**
Focus and priorities	22.9	39.9	19.2	**76.0**	29.7
Ageing, etc.	48.9	10.4	**91.4**	43.1	19.9
Public confidence and trust	18.2	17.1	19.7	30.1	**90.2**
Climate and culture	13.2	**87.2**	10.0	**53.4**	17.3
Miscellaneous	**57.4**	**55.0**	**60.9**	**56.6**	43.8

Numbers in excess of 50 have been bolded to highlight the dimensions that best characterize the identified challenge clusters.

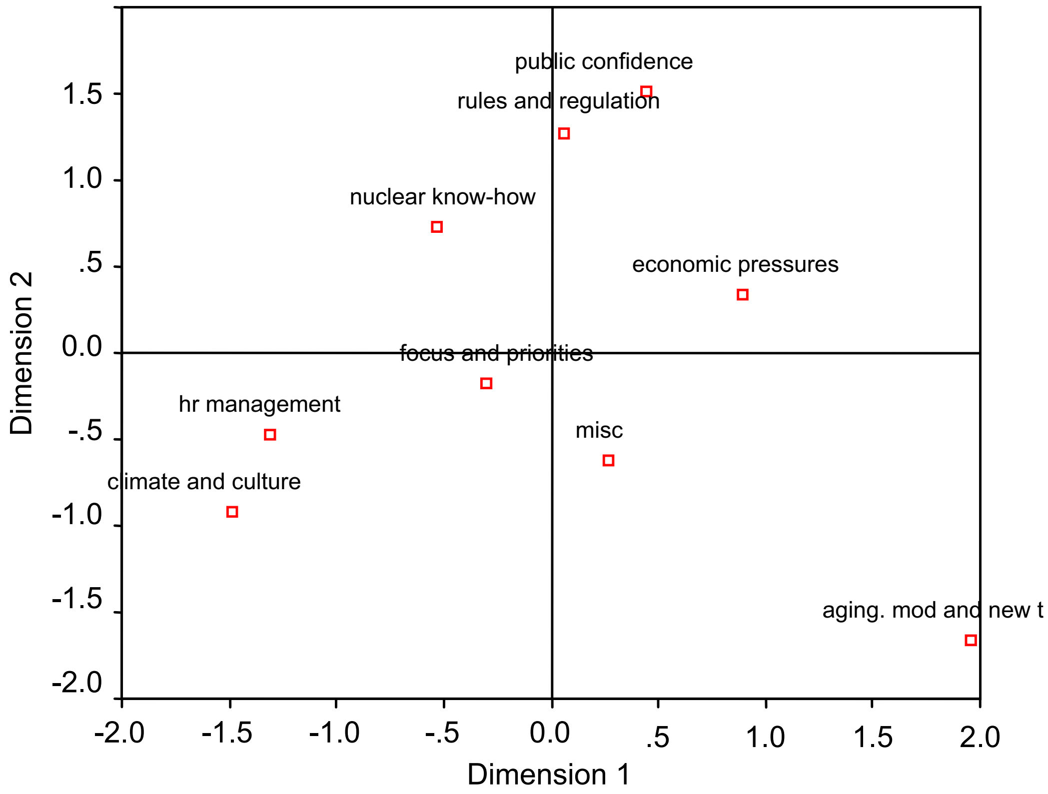

Fig. 2. Euclidean distance model of the nine-cluster solution.

classification model, and the numbers in the cells denote the co-ordinates. As can be seen from the table, Workforce and competence ('People'), Systems and procedures and Environment emerge as dominant managerial issue domains in our analysis: they characterise most clusters in this analysis, including the three biggest clusters.

Multidimensional scaling (ALSCAL) was used to illustrate the mutual interconnections between the nine clusters. The stress factor (the 'badness-of-fit' measure) was 0.0567 (moderate/good) with 10 iterations. The results of the analysis are shown in Fig. 2 (note that dimensions 1 and 2 do not carry any contentual meaning). In the figure the relative distances between the points on the plane correspond approximately to the distances between the cluster centres in the original data space. Proximity in the Euclidean distance model may be interpreted to represent thematic similarity. Therefore, the model suggests, as was expected, that challenges relating to HR management and Climate and culture are qualitatively close to each other. In terms of the corresponding cluster centres, these challenges are strongly related to workforce and competence-related issues, moderately related to management systems and procedures and only slightly or not at all related to technology (see Table 2). If a particular challenge also relates to financial matters or environment, we are presumably talking about HR management, otherwise about Climate and culture. Perhaps surprisingly, challenges relating to Rules and regulation and Public confidence and trust appear to be closely related, too. There are, however, common denominators linking challenges in these two clusters. For example, they are strongly related to external pressures over which NPP managers have little or no control. The special nature of technology-related challenges (aging etc.) is also clearly visible in the model.

Table 3
Cross-tabulation of Cluster and Country (% within Country)

Cluster	Country						All
	Fin	Swe	Ger	Sp	UK	Int.[a]	
Economic pressures	0.0	12.2	15.8	11.2	3.6	**18.8**	10.3
HR management	**21.4**	**28.9**	**18.4**	18.7	26.2	8.3	**22.3**
Nuclear know-how	5.4	10.6	10.5	8.0	3.6	4.2	7.8
Rules and regulation	1.8	6.1	5.3	8.0	7.1	2.1	6.1
Focus and priorities	16.1	10.6	7.9	3.2	15.5	14.6	9.6
Ageing, etc.	17.9	9.4	13.2	3.2	11.9	8.3	8.8
Public confidence and trust	10.7	10.6	5.3	20.9	1.2	**18.8**	12.8
Climate and culture	**21.4**	8.3	15.8	**23.5**	**27.4**	6.3	17.4
Miscellaneous	5.4	3.3	7.9	3.2	3.6	**18.8**	5.1
Total (%)	100.1	100.0	100.1	99.9	100.1	100.2	100.2
Total (*n*)	56	180	38	187	84	48	593

Bold numbers highlight the most important challenge clusters in each participating country.
[a]'Int' refers to data gathered from WANO (several nationalities) and from three Nordic top utility managers, representing Pohjolan Voima Oy (Finland), Sydkraft AB (Sweden) and Vattenfall AB (Sweden), who were interviewed as a group.

To identify major similarities and differences between the five participating countries, the statements were cross-tabulated with respect to Cluster and Country (Table 3). Note that Table 3 contains percentages (instead of absolute cell frequencies) to facilitate comparisons between the countries.

A first look at the table reveals that there are many similarities between the five countries. For example, challenges relating to either HR management or Climate and culture were generally emphasised in all countries (the international group being a clear exception), whereas Rules and regulation-related issues were not. In all five countries, the largest challenge cluster was either HR management or Climate and culture, or they shared the top position as in the Finnish dataset. However, the relative importance of Economic pressures was perceived differently in different countries. In Finland financial matters were not regarded as significant from the safety point of view, while in German and Sweden, as well as amongst the representatives of the international group, their relative importance was at least moderate. And in Sweden, Climate and culture-related challenges were given far less emphasis than in the other four countries covered in this study.

The χ^2 test conducted for the data indicated that Cluster and Country were significantly related ($\chi^2 = 127.38$; df $= 40$; $p < 0.001$). This suggests that, despite obvious similarities, challenges tend to be emphasised differently in different countries. In a similar way the statements were then cross-tabulated with respect to Cluster and Organisation as well as Cluster and Management level, and were subjected to χ^2-tests. The tests indicated that also Cluster and Organisation were significantly related ($\chi^2 = 181.45$; df $= 88$; $p < 0.001$),[7]

[7]Note that in this analysis the statements expressed by the three top Nordic utility managers (Pohjolan Voima, Sydkraft and Vattenfall) were combined. Therefore, the number of organisations in the analysis was 12 (instead 14, see also Table 1) and the degrees of freedom 88 (instead of 104).

suggesting that different challenges are emphasised in different organisations. It is worth mentioning that notable differences were also identified within single countries (e.g. between two plants in the same country). However, Cluster and Management level were not significantly related ($\chi^2 = 24.18$; df = 16; $p \approx 0.086$). This suggests that NPP managers appear to worry about the same things irrespective of their relative rank (top, senior or middle).

5.2. *Managerial tensions*

In total, 107 of the 593 statements (18%) were interpreted to explicitly refer to various tensions or challenges of managing conflicting demands. These 107 statements (hereafter referred to as tension-related statements) were first classified into three main categories on the basis of their general characteristics as follows: (1) statements referring to general (unspecified) industry or organisation-related tensions, (2) statements referring to the challenge of maintaining focus, setting correct priorities and/or managing the flow of information, and (3) statements with an explicit reference to a particular goal conflict. These category 3 statements were further classified into 13 thematic subcategories, which were later named to represent their focal content. Fig. 3 illustrates the classification process.

The identified categories were named as follows: (1) General industry and organisation-related tensions, (2) Focus and priorities (due to its close resemblance to the corresponding challenge cluster), (3.1) Economy vs. safety, (3.2) Licensee vs. regulator views on safety and new technology, (3.3) Tradition vs. renewal, (3.4) Operational efficiency vs. personnel development, (3.5) Preparing for a phasing out while ensuring sufficient competences and motivation, (3.6) Short-term vs. long-term optimisation, (3.7) Formalism vs. reasoning, (3.8) Performance vs. risk-based safety assessment, (3.9) Employing specialists vs. generalists, (3.10) Shared vs. personal accountability, (3.11) Competition vs. co-operation between utilities, (3.12) Old vs. new generation, and (3.13) Miscellaneous (various tensions without a common denominator).

The *biggest* categories were Focus and priorities (19/107 statements), Economy vs. safety (13 statements), and Licensee vs. regulator views on safety and new technology

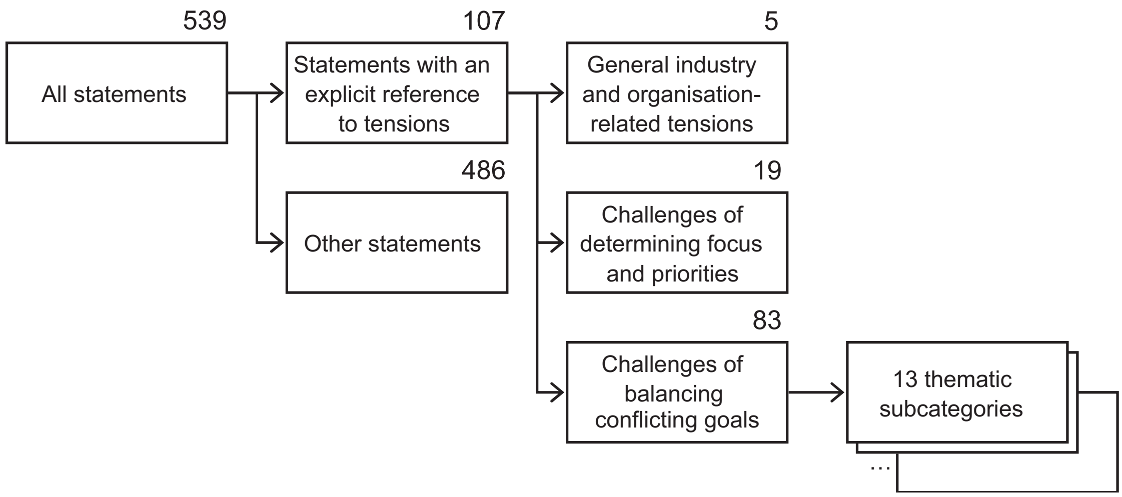

Fig. 3. Identification of tensions.

(12 statements). Also Operational efficiency vs. personnel development (11 statements) and Formalism vs. reasoning (11 statements) emerged as sizeable categories in our analysis. These five categories were interpreted to represent the predominant tensions and goal conflicts in the management of NPPs in the five participating countries.

Focus and priorities includes such challenges as optimisation of investments, (the difficulty of) concentrating on the essentials and avoiding so-called 'zero projects', balancing between various areas of plant operations that require management attention (e.g. safety, plant, people and technology) and managing large volumes of information. In other words, this tension has to do with the *process* of setting priorities and securing sufficient oversight over a large number of issue domains that compete for management attention.

The tension between economy and safety can mostly be attributed to the deregulation of the electricity market, increasing competition and related cost-saving pressures that need to be managed without compromising nuclear, industrial (personnel) and environmental safety. Some of the participants of the study were, however, concerned about the possible future need to compete with "lower safety" in the absence of other economically feasible alternatives. This translates into the classical dilemma of establishing a balance between efficiency (economy) and effectiveness (safety) in a situation where operational efficiency is already on a relatively high level.

The licensee-regulator tensions seem to stem from partially diverging views on the appropriate focus areas and forms of safety-related work and investments. For example, some licensees were of the opinion that regulatory requirements are often misguided, causing additional and unnecessary costs without yielding comparable safety benefits and diverting management attention away from more important issues. On the other hand, the regulators' doubtful attitude towards the application of new technology (e.g. programmable automation) was often regarded as counterproductive in the sense that it prevents the licensees from benefiting from technological advances and good industry practices developed elsewhere (which also contributes to the relatively high cost of nuclear power-related equipment and services).

The tension between operational efficiency and personnel development is characterised by a number of contradictory development trends and objectives. Reduction of personnel and use of contractors add to the employees' as well as the managers' workload, but the managers still need to build motivation and maintain high standards of operation. In this connection it is worth recalling that the quest for greater efficiency is not solely motivated by economic concerns; a number of other contributing factors—such as recruitment challenges, for example—also create additional pressures to utilise existing personnel resources as efficiently as possible.

Finally, it is evident that there are strong tensions concerning the appropriate scope and level of detail of formal procedures and instructions in the context of nuclear power. On the one hand, it is a rather common view that high-risk industries should be subject to a stringent regulatory supervision and that the operators themselves should apply formal management methods. On the other hand, the data reveal that NPP managers complain about excessive bureaucracy and paperwork, excessive dependence on rules and procedures in regulating human performance, and the expectation that safety is reinforced by 'working to procedures'. The conflict between formalism and (freedom of) reasoning and situational judgement relates to a large extent, although not entirely, to different views held by licensees and regulators.

5.3. The interrelationship between the identified challenges and tensions

Cross-tabulation of the tension-related statements with respect to Tension and Cluster revealed interesting information on the nature of the identified management challenges in the nuclear power industry. Various tensions characterise challenges especially in the areas of rules and regulation (cluster 4), focus and priorities (cluster 5), and economic pressures (cluster 1). Maintaining focus and setting priorities thus emerges as one of the key features of the NPP managers' problem space: it impacts upon managerial decision-making within several specific issue domains. Money is also an important factor contributing to various tensions, although economic pressures themselves did not appear to be among the most important management challenges. On the other hand, challenges relative to ageing, modernisation and new technologies (cluster 6), and public confidence and trust (cluster 7) appeared to be more straightforward and less paradoxical.

The two most important challenge clusters, HR management (cluster 2) and climate and culture (cluster 8), were moderately characterised by tensions. The analysis, however, revealed interesting insights into the nature of these challenge areas. For example, all statements that referred to tensions between the old and new nuclear employee generations (tension 3.12) and two thirds of the statements that were assessed to relate to the emerging conflict between operational efficiency and personnel development (tension 3.4) originated from within the HR management cluster. This is most probably related to the fact that the challenge of maintaining necessary competences received so much attention. In addition, all statements referring to tensions between shared and personal accountability (tension 3.10) originated from within the Climate and culture cluster, which is likely to contribute to motivational challenges.

6. Discussion

The results suggest that HR management, organisational climate and culture, and public confidence and trust are the three most challenging areas of management in the context of safety for nuclear managers across Europe. Perhaps surprisingly, various economy- and technology-related issues were not that much emphasised. These findings, however, are well in line with the results and projections of many earlier studies. The challenge of securing sufficient competence resources has been addressed, for example, by several task groups operating under the auspices of the OECD Nuclear Energy Agency (OECD/NEA, 2000b, 2001). With respect to climate and culture, the potentially negative effects of various performance enhancement programmes and/or uncertain future employment prospects on employee motivation have been identified, for example, by Bier et al. (2001). The emergence of public confidence and trust as the third most important challenge area is no surprise either, in the face of the fact that two of the five participating countries have officially decided to phase out nuclear power due to political reasons (e.g. OECD/NEA, 2004).

There were significant differences between the participating countries and organisations. On the one hand, this seems natural since the nuclear power programmes in the five European countries covered in this study, as well as individual plants in those countries, are also different in many ways. An interesting finding of the study was, however, that the perceived relative importance of various challenge clusters is not related to management level, i.e. managers' relative position in the utility or plant organisations. This may stem from the fact that, until recently, all top and senior NPP managers have usually been recruited internally from within the plant organisation, or at least within the industry. This is gradually changing, however. It is beyond the scope of this study to evaluate the safety consequences of this development trend.

The results of the study also suggest that there is no straightforward relationship between the distinctive features of the NPPs' operating environment and the perceived importance of challenges that explicitly refer to such features or are otherwise assumed to be influenced by them. For example, public confidence and trust, together with rules and regulation, emerged as the least challenging areas of management activity in Germany, although it is a well known fact that a lack of public support for the use of nuclear power and mounting political pressure forced the German utilities to conclude a contract with the government on a gradual phasing-out of operating NPPs (OECD/NEA, 2004). There were many corresponding discrepancies in the data. This suggests that perceived challenges should not be mechanistically linked to, or derived from, any particular societal (e.g. political or economic) process.

Our findings on managerial tensions in many respects parallel Sagan's (1993) views on conflicting objectives in the management of safety critical organisations. For example, the tension between safety and economy and the divergence of views between industry (i.e. licensees and utility companies) and administrative authorities supervising their operations (i.e. regulatory bodies) were clearly visible in our data, although the identified tensions were not that dramatic as one could have expected (i.e. there were no overt confrontations). However, regulatory roles and practices constitute an interesting quest for future research and development work. Regulatory requirements were often referred to as a source of additional managerial concerns. Some of the requirements were even evaluated to be counterproductive in terms of their safety implications, although the regulator is supposed to contribute to the safety of nuclear power. Such disputes may partly stem from the characteristics of applied regulatory approaches. For example, the dilemma embedded in the prescriptive regulatory regime is that the licensees being regulated are both expected to follow precise rules defined by the regulator *and* to assume full responsibility for the safety of their operations (cf. Kirwan, Hale, & Hopkins, 2002). This arrangement, though very common, can be regarded as somewhat contradictory and worth further evaluation.

The question of the proper application of redundancy, and especially its effect on perceived personal accountability, also emerged in our analysis (Sagan, 1993; Rasmussen, 1997). The underlying uncertainties manifested themselves in the form of two mutually related tensions: formalism vs. reasoning (3.7) and shared vs. personal accountability (3.10). In this particular case the perceived tensions had mostly to do with backing up human and organisational performance by means of formal management control procedures without compromising employees' personal vigilance, motivation and sense of responsibility. This finding gives rise to an assumption that these tensions may be connected to the perceived importance of climate- and culture-related challenges.

Contrary to our initial expectations, the frequently paraded tension between centralisation and decentralisation of decision-making authority did not appear to be an issue for the NPP managers who participated in this study. Although some of the statements could be linked to this theme through reasoning and generalisation, its relative weight remained insignificant. It is, therefore, more likely that prevailing industry recipes, or institutionalised rules and assumptions on how business is to be conducted within a particular industry or professional community, simply prevent NPP managers—and probably also regulators—from considering alternative decision-making procedures and organising methods (see e.g. Spender, 1989; Koivisto, 2005; and Tsoukas, 1996). It is concluded that the underlying question has more to do with making room for controlled renewal (tension 3.3) than with the features of the chosen management model.

Although the participating NPP managers were requested to pay special attention to safety-related challenges, the picture that emerged from the analysis was a rich one, covering different aspects of industrial management. In general, our findings suggest that managers require, and implicitly use, more complex frameworks for structuring their realities than the five-dimensional classification model (see Fig. 1), or any of the reference models assessed in this study (some of which can, however, partly cover the problem space of today's nuclear managers). The widely referenced Competing Values Framework introduced by Quinn and Rohrbaugh (1983), which emphasises tensions between internal versus external focus and control versus flexibility, is also far too simple and generic to adequately describe the managerial tensions identified in the study. The results, however, support Cameron's (1986) and Quinn's (1988) notions that managers should avoid putting reliance on overly rational and linear management models and that it is important to be able to use multiple frames of reference simultaneously. Cameron (1986) went even further by stating that the most effective organisations are characterised by paradoxes and that "the need to solve all simultaneous contradictions, in fact, may inhibit excellence by eliminating the creative tension that paradoxes produce" (p. 549).

Organisational challenges and tensions cannot be eliminated but they can and should be openly acknowledged and managed. Our major recommendations for the nuclear power industry may be summarised as follows:

- It is of utmost importance to invest in the development of necessary competences, good work motivation and safety culture. In addition to employee motivation and plant safety, such measures will also contribute to the public image of the industry.
- The challenge of maintaining focus and setting priorities needs to be acted upon. If there are no effective processes in place for managing conflicts between scarce resources and ambitious goals, paralysis may result.
- Possible tensions between economy and safety need to be acknowledged. This does not mean that the two objectives should be regarded as contradictory or that a choice should be made between the two extremes. A constructive dialogue is needed to determine and justify what is safe enough and by what means that safety target is to be reached.
- Safety cannot be managed independently of the other goals and operations of the organisation. Safety management should integrate all elements, functions and processes of an organisation that might have an impact on its safety, either directly or indirectly.

Tensions have received considerable attention in management research. However, they have been approached using differing terminology and theoretical frameworks. Some authors speak about the need to manage ambiguity and paradox (Peters & Waterman, 1982; Berglund, Strannegård, & Tillberg, 2004) or to establish a balance between chaos and order (Waldrop, 1992). Quinn and his colleagues (e.g. Cameron & Quinn, 1999; Quinn, 1988; Quinn & Rohrbaugh, 1983) in particular have written about managers' need to handle competing expectations and values while trying to enhance the effectiveness of their organisations. Moreover, organisational culture research has been interested in how conflicting goals are perceived—or are not perceived—and handled in organisations (Cameron & Quinn, 1999; Martin, 2002; Reiman & Oedewald, 2004; Trompenaars & Hampden-Turner, 1998). Tension has thus emerged as a salient phenomenon, but the question is whether it already qualifies as a clear and useful concept? Future research should aim to clarify the concept of tension in the context of organisation and management research and to assess its usability for different applications. In addition, further applied research should aim to produce approaches for the effective and constructive management of tensions.

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