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Methodological Evidence from Studies in Nuclear Power Plant Maintenance Organizations

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Teemu Reiman

Academic Dissertation

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Keywords organizational culture, sociotechnical systems, nuclear power plants, maintenance organizations, safety management, safety models, core task modelling

Abstract

Failures in industrial organizations dealing with hazardous technologies can have widespread consequences for the safety of the workers and the general population. Psychology can have a major role in contributing to the safe and reliable operation of these technologies. Most current models of safety management in complex sociotechnical systems such as nuclear power plant maintenance are either non-contextual or based on an overly-rational image of an organization. Thus, they fail to grasp either the actual requirements of the work or the socially-constructed nature of the work in question.

The general aim of the present study is to develop and test a methodology for contextual assessment of organizational culture in complex sociotechnical systems. This is done by demonstrating the findings that the application of the emerging methodology produces in the domain of maintenance of a nuclear power plant (NPP). The concepts of organizational culture and organizational core task (OCT) are operationalized and tested in the case studies. We argue that when the complexity of the work, technology and social environment is increased, the significance of the most implicit features of organizational culture as a means of coordinating the work and achieving safety and effectiveness of the activities also increases. For this reason a cultural perspective could provide additional insight into the problem of safety management. The present study aims to determine; (1) the elements of the organizational culture in complex sociotechnical systems; (2) the demands the maintenance task sets for the organizational culture; (3) how the current organizational culture at the case organizations supports the perception and fulfilment of the demands of the maintenance work; (4) the similarities and differences between the maintenance

cultures at the case organizations, and (5) the necessary assessment of the organizational culture in complex sociotechnical systems.

Three in-depth case studies were carried out at the maintenance units of three Nordic NPPs. The case studies employed an iterative and multimethod research strategy. The following methods were used: interviews, CULTURE-survey, seminars, document analysis and group work. Both cultural analysis and task modelling were carried out. The results indicate that organizational culture in complex sociotechnical systems can be characterised according to three qualitatively different elements: structure, internal integration and conceptions. All three of these elements of culture as well as their interrelations have to be considered in organizational assessments or important aspects of the organizational dynamics will be overlooked. On the basis of OCT modelling, the maintenance core task was defined as balancing between three critical demands: anticipating the condition of the plant and conducting preventive maintenance accordingly, reacting to unexpected technical faults and monitoring and reflecting on the effects of maintenance actions and the condition of the plant. The results indicate that safety was highly valued at all three plants, and in that sense they all had strong safety cultures. In other respects the cultural features were quite different, and thus the culturally-accepted means of maintaining high safety also differed. The handicraft nature of maintenance work was emphasised as a source of identity at the NPPs. Overall, the importance of safety was taken for granted, but the cultural norms concerning the appropriate means to guarantee it were little reflected. A sense of control, personal responsibility and organizational changes emerged as challenging issues at all the plants.

The study shows that in complex sociotechnical systems it is both necessary and possible to analyse the safety and effectiveness of the organizational culture. Safety in complex sociotechnical systems cannot be understood or managed without understanding the demands of the organizational core task and managing the dynamics between the three elements of the organizational culture.

Reiman, Teemu. Assessing Organizational Culture in Complex Sociotechnical Systems – Methodological Evidence from Studies in Nuclear Power Plant Maintenance Organizations [Organisaatiokulttuurin arviointi monimutkaisissa sosioteknisissä järjestelmissä – Metodologinen tutkimus pohjautuen kolmen pohjoismaisen ydinvoimalaitoksen kunnossapito-organisaation arviointiin]. Espoo 2007. VTT Publications 627. 136 s. + liitt. 169 s.

Avainsanat organizational culture, sociotechnical systems, nuclear power plants, maintenance organizations, safety management, safety models, core task modelling

Tiivistelmä

Onnettomuuksilla vaarallisten teknologioiden kanssa työskentelevissä teollisissa organisaatioissa voi olla kauaskantoisia seurauksia sekä työntekijöiden että yhteiskunnan turvallisuudelle. Psykologialla on keskeinen rooli näiden teknologioiden turvallisen käytön varmistamisessa. Kunnossapitotyötä on tutkittu työpsykologian kentässä vähän huolimatta sen merkityksellisyydestä laitoksen turvallisuudelle ja käytettävyydelle. Lisäksi useimmat nykyiset teoriat turvallisuudesta monimutkaisissa sosioteknisissä järjestelmissä (kuten kunnossapito-organisaatioissa) joko perustuvat ylirationaaliselle ihmiskuvalle tai sitten ne ovat epäkontekstuaalisia. Tämän takia ne eivät tavoita joko kyseisen työn sosiaalisesti rakentunutta luonnetta tai kyseisen työn todellisia vaatimuksia.

Tutkimuksen yleisenä tavoitteena on kehittää ja kokeilla metodologiaa organisaatiokulttuurin kontekstuaaliseksi arvioimiseksi monimutkaisissa sosioteknisissä järjestelmissä. Tämä toteutetaan osoittamalla, minkälaisia tuloksia kehitettävällä menetelmällä saadaan ydinvoimalaitoksen kunnossapitotyöstä. Organisaatiokulttuurin ja organisatorisen perustehtävän käsitteet määritellään ja testataan tapaustutkimuksissa. Tutkimuksessa lähtökohtana on oletus, että työn, teknologian ja sosiaalisen ympäristön monimutkaistuessa kasvaa organisaation kulttuurin merkitys organisaation turvallisuudelle ja tehokkuudelle. Tämän takia kulttuurisen lähestymistavan monimutkaisiin sosioteknisiin järjestelmiin voidaan olettaa tarjoavan täydentävää käsitystä näiden järjestelmien turvallisuuden hallinnasta. Tutkimuksessa tarkastellaan, (1) mitkä ovat monimutkaisten sosioteknisten järjestelmien organisaatiokulttuurin keskeiset osatekijät, (2) mitä vaatimuksia kunnossapitotehtävä asettaa organisaatiokulttuurille, (3) miten kohdeorganisaatioiden nykyinen kulttuuri tukee kunnossapitotehtävän vaatimusten havaitsemista ja täyttämistä, (4) mitä yhtäläisyyksiä ja eroja kohde-

organisaatioiden kulttuurissa on, ja (5) miten arvioida monimutkaisten sosioteknisten järjestelmien kulttuuria.

Tutkimus muodostui kolmesta tapaustutkimuksesta Pohjoismaisten ydinvoimalaitosten kunnossapito-organisaatioissa. Tapaustutkimusten erityinen tavoite oli kyseisten organisaatioiden kulttuurien arviointi. Tutkimuksissa käytetyt menetelmät olivat: henkilöstöhaastattelut, CULTURE-kysely, seminaarit, dokumenttianalyysi ja ryhmätyöskentely. Menetelmillä analysoitiin sekä kulttuuria että kunnossapitotehtävää. Tulosten perusteella organisaatiokulttuuria monimutkaisissa sosioteknisissä järjestelmissä voidaan kuvata kolmen laadullisesti erilaisen elementin vuorovaikutuksena: rakenteelliset piirteet, sisäinen yhteneväisyys ja kulttuuriset käsitykset. Nämä kolme elementtiä keskinäisine vuorovaikutuksineen on otettava huomioon organisaatioarvioinneissa. Muuten tärkeitä puolia organisaatioiden toiminnan dynamiikasta jää huomioimatta. Perustehtävämallinnuksen perusteella määriteltiin kolme kunnossapitotehtävän kriittistä vaatimusta: (1) laitoksen kunnon ennakointi ja ennakkohuollon suorittaminen sen mukaisesti, (2) ennakoimattomiin teknisiin vikoihin reagoiminen ja (3) laitoksen kunnon monitorointi ja tehtyjen kunnossapitotoimenpiteiden reflektointi. Tulokset osoittavat, että turvallisuutta arvostettiin jokaisella laitoksella, ja siinä mielessä he jakoivat vahvan turvallisuuskulttuurin. Muut kulttuurin piirteet sen sijaan erosivat laitosten välillä, ja näin ollen kulttuurisesti hyväksytyt tavat ylläpitää turvallisuutta erosivat. Myös käsityksissä kunnossapitotyöstä oli eroja laitosten välillä. Kaikilla laitoksilla vikakorjaukset ja tekniset haasteet koettiin motivoivana ja kunnossapidon käsityömäistä luonnetta korostettiin. Kaiken kaikkiaan turvallisuuden tärkeyttä pidettiin itsestään selvänä, mutta vallitsevia kulttuurisia normeja tarkoituksenmukaisista keinoista turvallisuuden varmistamiseksi ei juuri reflektoitu. Hallinnan tunne, henkilökohtaisen vastuun kokemus ja organisatoriset muutokset nousivat esille psykologisina erityiskysymyksinä.

Tutkimuksessa esitetään, että on sekä mahdollista että tarpeen arvioida monimutkaisten sosioteknisten järjestelmien turvallisuutta ja tehokkuutta arvioimalla niiden organisaatiokulttuuria. Turvallisuutta ei voida ymmärtää ja hallita ilman ymmärrystä organisaation perustehtävän vaatimuksista ja kulttuurin osa-alueiden ja niiden välisten vuorovaikutusten hallintaa.

Preface

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Contents

List of original publications

The present study in based on the following five publications and together with them constitutes the academic dissertation of the author:

Article I	Oedewald, P. & Reiman, T. (2003). Core task modelling in cultural assessment: A case study in nuclear power plant maintenance. *Cognition, Technology & Work,* 5, 283–293.
Article II	Reiman, T. & Oedewald, P. (2004). Measuring maintenance culture and maintenance core task with CULTURE-questionnaire – a case study in the power industry. *Safety Science,* 42, 859–889.
Article III	Reiman, T., Oedewald, P. & Rollenhagen, C. (2005). Characteristics of organizational culture at the maintenance units of two Nordic nuclear power plants. *Reliability Engineering and System Safety,* 89, 333–347.
Article IV	Reiman, T. & Oedewald, P. (2006). Assessing the maintenance unit of a nuclear power plant – identifying the cultural conceptions concerning the maintenance work and the maintenance organization. *Safety Science,* 44, 821–850.
Article V	Reiman, T. & Oedewald, P. (In press). Assessment of complex sociotechnical systems – Theoretical issues concerning the use of organizational culture and organizational core task concepts. *Safety Science*.

In the text the publications are referred to by the Roman numerals I–V.

1. Introduction

Failures in industrial organizations dealing with hazardous technologies can have widespread consequences for the safety of the workers and the general population. Psychology can have a major role in contributing to the safe and reliable operation of these technologies. Accident investigations and empirical studies have shown that human and organizational failures dominate compared to hardware failures contributing to an accident or incident (Ghosh & Apostolakis, 2005; Reason, 1990). This dissertation applies work and organizational psychology to organizations dealing with potentially hazardous technologies and contributes to Human Factors (HF) research in that area. The general goal of Human Factors is to make the human interaction with systems one that enhances performance, increases safety and increases user satisfaction (Wickens et al., 2004, p. 2). HF is often considered a sub-discipline of work and organizational psychology (Chmiel, 2000).

Human Factors research has its roots in the Second World War and the vast amount of deaths attributed to interface design problems in aircraft. Another practical source of research was the diminishing vigilance of radar operators who were often unable to spot approaching airplanes. The human factors paradigm has been from the start dominated by the search for human errors – both potential and realised – and the building of various barriers to either prevent these errors or to mitigate their consequences. These barriers have been of many kinds, ranging from technical fixes, increased or enhanced rules and procedures, training, recruitment, and redundant safety systems to fostering of safety attitudes and values, and “safety culture”. HF research has been from the beginning a multidisciplinary endeavour, first of engineering and (experimental) psychology, and gradually also of sociology, anthropology and social psychology. The fact that the roots of HF are in engineering and experimental psychology is a mixed blessing, since due to these early influences “human factors and systems safety is stuck with a language, with metaphors and images that emphasize structure, components, mechanics, parts and interactions, cause and effect” (Dekker, 2005, p. 10). This has been done at the expense of language and concepts emphasizing process, intentions, motives, meanings, subjective experience and social phenomena.

Rasmussen (1997, p. 183) has noted that in spite of all the efforts to design safer systems, severe, large scale accidents still happen. He questions whether safety research has adequate models of accident causation (see also Pidgeon & O'Leary, 2000; Hollnagel, 2004). Rochlin (1999b, p. 7) has criticized the narrow and instrumentalist definition of safety as the antithesis of risk, or as a residual set defined in terms of the negation or absence of risk. Human contribution to system reliability and accidents is a complex issue and it is made even more complex by the changes in society and technology. Dekker (2005, p. 2) argues that with the growth in complexity and size of the organizations, the nature of accidents is also changing. They are not anymore caused by single human errors but rather by normal people doing what they consider to be their normal work (cf. Hollnagel, 2004). Furthermore, reliance on technology creates new types of hazards. Dekker (Ibid., p. xi) argues that one of the problems faced by human factors research of today is that apparently safe systems can drift into failure (see also Rasmussen, 1997). More and more accidents are attributed to so-called organizational factors such as norms, procedures, responsibilities, managements systems and company culture (ACSNI, 1993; Reason, 1997; van Vuuren, 2000; Hollnagel, 2002, 2004). The concept of human error and the individual-level theories of accidents have been found to be insufficient for effective management of safety, and attention has shifted to organizational theories (cf. Reason, 1993).

However, the current organizational theories are unable to explain and predict the social and psychological mechanisms contributing to the safety and effectiveness of modern industrial organizations. In the present study it is argued that many theories of accidents and safety in industrial organizations are either based on a static and overly-rational model of an organization or are non-contextual. Thus, they are reactive in their search for errors and analysis of previous accidents and incidents, or disconnected from the actual work in the organization by their focus on general safety attitudes and values. At the same time, general organization research has begun to increasingly emphasize the dynamic and interpretative aspects of organizations. Safety management approaches based on this interpretative view of the organization are still rare. We can thus raise the question of whether safety research has an adequate model of the dynamics of complex industrial organization (see also Hollnagel, 2006, p. 9; Dekker, 2005).

The difficulties of managing these complex sociotechnical systems[1] have received a lot of attention in connection with various organizational accidents (e.g. the explosion of the Challenger space shuttle, see Vaughan (1996), Chernobyl nuclear accident or the fire at the Piper Alpha offshore platform, see Wright (1994a) and Paté-Cornell (1993)). In Turner's (1978) terms these events have been *disasters*. This means that the accidents have brought the previous approaches and assumptions about safety into question. A disaster is something that was not supposed to take place according to the existing framework of thinking, but it happened nevertheless. The event was thus in contradiction to the cultural conceptions about safety and the appropriate means for guaranteeing it (Turner, 1978; Turner & Pidgeon, 1997). These "false" conceptions had been gradually rooted in the culture of the organization as it was carrying on with its daily practices. These conceptions should be studied and their contribution to organizational effectiveness and safety should be assessed in advance. This should be done before or during the *incubation period* of an accident (Turner, 1978), when the preconditions of the accident are created and small errors accumulate into a larger crisis. We argue that when the complexity of the work, technology and social environment is increased, the significance of the most implicit features of organizational culture as a means of coordinating the work and achieving the safety and effectiveness of the activities also increases (cf. Perrow, 1986, p. 130; Weick, 1987, 1995, p. 117; Dekker, 2005, p. 37). For this reason a cultural perspective to complex sociotechnical systems might provide additional insight into the problem of management of safety.

The aim of the present study is to study organizational assessment in complex sociotechnical systems. It is presumed that the characteristics of complex sociotechnical systems manifest well in the maintenance activity of a nuclear power plant (NPP). This is due to the nature of the work (complex, spatially and temporally distributed, multidisciplinary) and the specific safety critical context (nuclear power generation) of the work. Furthermore, the current challenges of maintenance activity (e.g. retirement of key personnel, ageing of the plant

[1] The terms sociotechnical system has become a euphemism in the human factors tradition referring to the object of study. It has lost its original connotation of an open systems view of an organization as composed of interrelated systems (cf. Cooper & Foster, 1971, p. 468). Since every modern organization is a sociotechnical system, the word "complex" indicates an organization that rates "highly on several of the following dimensions: large problem space, social, heterogeneous perspectives, distributed, dynamic, potentially high hazards, many coupled subsystems, automated, uncertain data, mediated interaction via computers, disturbance management" (Vicente, 1999, p. 5).

equipment and modernizations, new demands for power production, see IAEA, 2003, 2005; Bier et al., 2001; Reiman et al., 2006) make it a practically relevant research domain. The present study is based on the following premises, which are elaborated in the remaining Sections of the Introduction and in Section 2:

1. There is a practical need to monitor, anticipate and manage the safety of complex sociotechnical systems. Research conducted in these organizations thus has to contribute to their effectiveness, which is composed of safety, productivity and employee health (Vicente, 1999).

2. Most current theories of safety in complex sociotechnical systems are either based on an overly-rational image of an organization or they are non-contextual. Thus, they fail to grasp either the socially-constructed nature of the work in question or the actual requirements of the work. This premise is elaborated in Section 1.1 and 1.2.

3. Organizations are treated as organizational cultures. Organizational culture is thus a "root metaphor" (Smircich, 1983) for the organization. We draw on evidence from interpretive organizational theories and discuss the nature of complex sociotechnical systems in light of these theories. This premise is elaborated in Section 1.3.

4. Maintenance work has previously been studied little from the Human Factors perspective, and yet maintenance activities have a large contribution to both system safety and accidents (Reason, 1997). Studies that have been made are mainly studies of maintenance errors. Studies of normal work and culture of maintenance are needed (cf. Bourrier, 1998, 2002; Svedung & Rasmussen, 1998; Norros, 2004). This premise is elaborated in Section 2.

In the next Section it is argued that there are three main underlying models of safe organization in the human factors tradition. The first model focuses on safety management systems and organizational structures. The second model focuses on error management and decision making. The third model focuses on safety attitudes and safety culture. In addition to these models, there are two more holistic theories of the effectiveness of complex sociotechnical systems; High Reliability Organizations Theory and Normal Accidents Theory. These are depicted in Section 1.2. After that, in Section 1.3 interpretative theories of organizations are presented along with the argument that complex sociotechnical systems could be conceptualized as organizational cultures.

1.1 The theoretical basis of the current prevalent organizational models of safety

Most current models of safety management and system safety are based on a rational or a non-contextual image of an organization. They thus originate from a "traditional" mechanistic paradigm of organization science (Waring, 1996, p. 13; Dekker, 2005). This paradigm emphasizes the rationality and instrumentality of organizations. Organizations are considered to be mechanistic. They are "set up to accomplish a specific task and to advance quite precise objectives, and they have a formalised structure which determines the distribution of authority and the division of labour" (Brunsson & Olsen, 1993, p. 2). The purpose of the organization is self-evident and explicit for everyone. Organizational routines are considered as well-defined, regular and stable forms of behaviour used to accomplish organizational goals. Procedures are used to define the appropriate behaviour. The role of management in supervising and directing the organizational behaviour is emphasized. This rational-instrumental theory of an organization is based on the assumption that people set explicit goals, make rational choices and act on the basis of objective facts (see also Etzioni, 1964; Williamson, 1975; Weber, 1978; cf. Scott, 2003). The theory can be claimed to be based on a positivist (cf. Hempel, 1965) image of a human conduct. Deviations from these rational norms are human errors, resulting mainly from motivational problems (cf. Dekker, 2005, p. 77). Sagan (1993, p. 16) includes in this tradition also the High Reliability Organizations Theory, to be described in Section 1.2. Also La Porte and Consolini (1991, p. 23) have noted that organizations with nearly failure-free performance (high reliability organizations, that is), "come close to meeting the conditions of closed rational systems" (but see La Porte, 1994, p. 209).

Another current model of safety management is based on the open systems model of an organization. This moved the focus beyond the mechanistic view to a more process-oriented view of organizations. This was an important addition, but we argue that these theories neglected the important issue of work context as well as the socially constructed and sometimes dysfunctional sides of organizational reality. The open systems model of an organization gained prominence in the 50s and 60s, partly due to the Tavistock paradigm (see Rice, 1958; Miller & Rice, 1967), and partly due to the works of e.g. Simon (1957), Parsons (1951), and Selznick (1948). The mechanistic view of an organization was challenged. The organismic analogy and equilibrium as the ideal state of the system were the constituent characteristics of this approach. The system's ability to self-regulate based on the selection and interpretation of environmental inputs was emphasized. The interactions of the system and its environment were considered mostly linear and functionalistic (serving some specific purpose or need). (Burrell & Morgan, 1979; Scott, 2003) One of the most influential open systems models was that of Katz and Kahn (1966). Their work also laid "the most important theoretical foundation for later culture studies" (Schein, 1990, p. 11). Open systems models emphasized process over structure and abstraction over description of the actual work (Burrell & Morgan, 1979; Barley & Kunda, 2001; Scott, 2003).

Barley and Kunda argue that since the dawn of systems theory in the end of the sixties "work has slipped increasingly into the background as organizational theory converged on the study of strategies, structures, and environments as its central and defining interests" (Barley & Kunda, 2001, p. 76). The same remark applies also to organizational culture research in general (except e.g. Kunda, 1992; see also Orr, 1996) and safety culture in particular (except e.g. Gherardi & Nicolini, 2002). Barley (1996, p. 405) points out: "Researchers usually discuss work in terms of increasing complexity and interdependence, delayering, the permeability of tasks, and so on, concepts that essentially conflate work with forms of organizing. Discussions of what people do and how they do it are rare." Barley and Kunda (2001; Barley, 1996) call for a reintegration of studies of work and organizing (see also Orr, 1996, p. 152; Alvesson, 2002, p. 153). Rasmussen (2000, p. 872) also points out that even in the safety critical area, "management theories tend to be independent of the substance matter context of a given organization".

According to many researchers (e.g. Rasmussen, 1997; Waring, 1996; Hale & Hovden, 1998), the open systems model of an organization has been very prominent also in safety science. In open systems models, errors and subsequent accidents are considered to be mainly caused by deviations and deficiencies in information processing, in the available information, or in the motivational and attitudinal factors of the decision makers. Collective phenomena such as group norms or values, were also introduced as a potential source of errors. Normal Accidents Theory, to be described in Section 1.2, fits the open systems model (cf. Sagan, 1993, p. 43; Perrow, 1984).

The concept of *safety culture* bears strong resemblance to the open systems theory and its refinements (such as the organizational culture theory). The term was introduced after Chernobyl nuclear meltdown in 1986 (IAEA, 1991; cf. HSE, 1997). It was proposed that the main reasons for the disaster and the potential future accidents did not only include technical faults or individual human errors committed by the frontline workers. The management, organization and attitudes of the personnel were also noted to influence safety for better or for worse. A proper “safety culture” was quickly required by the regulatory authorities, first in the nuclear area and gradually also in other safety-critical domains. The role of management in creating and sustaining a safety culture was emphasized[2]. As other human factors research in the nuclear industry, safety culture research and development work has also until quite recently mainly focused on plant operations and not on e.g. maintenance issues (IAEA, 2005, p. 46).

The sometimes careless and vague use of the term safety culture has resulted in criticism among academic organizational researchers (e.g. Hale, 2000; Guldenmund, 2000; Pidgeon, 1998; Cox & Flin, 1998). According to them the concept of safety culture has become a catch-all concept for psychological and human factors issues in complex sociotechnical systems. The critique e.g. expresses a concern that safety culture is not seen as a contextual phenomenon, but as a kind of general ideal model without adequate consideration of the work itself being carried out in the organization in question. Reflections of the ideal model-thinking can be seen in the emphasis on formal safety training and general safety attitudes (e.g., “always put safety first”) as a means of fostering a safety culture. This has limitations: "Safety is not a separable form of knowledge. It is not something that is learned as such ... it is an aspect of

[2] Safety culture studies and development programs have been conducted in e.g. nuclear industry (Ostrom et al., 1993; Lee, 1998; Lee & Harrison, 2000; Harvey et al., 2001, 2002; see also IAEA, 1991, 1996a, 2005), aviation (McDonald et al., 2000), offshore platforms (Mearns et al., 1998, 2003; Cox & Cheyne, 2000), chemical industry (Donald & Canter, 1994), manufacturing (Williamson et al., 1997; Cheyne et al., 1998), healthcare sector (Singer et al., 2003; Pronovost et al., 2003) and the transport sector, including railways (Clarke, 1998, 1999; Farrington-Darby et al., 2005).

practice" (Gherardi & Nicolini, 2002, p. 216; cf. Gauthereau, 2004). One could say that safety is as much an aspect of practice as is any element that makes a skilful worker. But what constitutes a skilful worker in different work domains and tasks? For this we cannot apply universal criteria, and the same applies to safety. Thus, it can be claimed that the concept of safety culture does not describe the organizational reality sufficiently well. This can lead to definitions and measurements that are too abstract and non-contextual. They are thus disconnected from the *daily work* in a particular organization (cf. Barley & Kunda, 2001). A more contextual approach is needed that emphasizes simultaneously the productivity, safety and health of the sociotechnical system (cf. Vicente, 1999).

The roots of the safety culture concept lie in the wider concept of *organizational culture*[3]. Meek (1988) has noted that the culture concept was originally borrowed from the structural-functional paradigm of the anthropological tradition (see also Bacharach, 1989, p. 499; Wright, 1994b, p. 2)[4]. This paradigm relies heavily on the organism metaphor for the organization and on the social integration and equilibrium as goals of the system (Parsons, 1951; Durkheim, 1982; Radcliffe-Brown, 1958; cf. Schultz & Hatch, 1996). These characteristics were also found in earliest theories of organizational culture (e.g. Baker, 1980; Ouchi, 1980; Schein, 1985; Kilmann, 1985; Wiener, 1988; Wilkins & Ouchi, 1983; Barney, 1986). Only shared aspects in the organization were considered as part of the culture. Alvesson (2002, pp. 43–44) argues that these theories of organizational culture had a bias toward the positive functions of culture in addition to being functionalist, normative and instrumentally biased in thinking about organizational culture. Culture was considered a tool for the managers to control the organization. The safety culture concept seems to be derived from this tradition of organizational culture[5] (cf. Cox & Flin, 1998; Richter & Koch, 2004; Mengolini & Debarberis, 2007). Many definitions of safety culture (see e.g. IAEA, 1991; Geller, 1994; Reason, 1997, p. 220; Roughton & Mercurio,

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[3] For the history of the concept and various definitions and operationalizations of organizational culture, see e.g. Pettigrew (1979), Smircich (1983), Schein (1985, 1990), Meek (1988), Alvesson and Berg (1992), Denison (1996), Hawkins (1997), Morgan (1997), Alvesson (2002), Martin (2002) and Reiman and Oedewald (2006a).

[4] Still, Wright (1994b, pp. 2–3) notes that "for an anthropologist, reading this literature [on organizational culture] there are moments of recognition closely followed by the discovery of familiar ideas being used in disconcertingly unrecognizable ways" and continues by arguing that the functionalist "focus on consensus seems to be a key point of difference between organizational studies and [modern] antropology".

[5] Other traditions are described in the next Section.

2002; Hopkins, 2005, p. 12) imply that only those organizations where safety is an overriding priority and a shared value have a “safety culture” (cf. Hale, 2000; Cox & Flin, 1998, p. 191).

In the next Section the two most prominent scientific approaches to complex sociotechnical systems, namely High Reliability Organizations Theory and Normal Accidents Theory are reviewed.

1.2 High Reliability Organizations and Normal Accidents theories

The High Reliability Organization (HRO) group (La Porte, 1996; Rochlin, 1999a) formed in 1984 at the University of Berkeley by Todd La Porte, Karlene Roberts and Gene Rochlin, and the work of Karl Weick at the University of Michigan (Weick, 1987; Weick & Roberts, 1993) have been influential in illustrating the organizational aspects of safety and reliability of safety critical organizations. They had observed that the attention paid to studies and cases of organizational failure was not matched by the number of parallel studies of organizations that are operating safely and reliably in similar circumstances (Rochlin, 1996, p. 55; cf. Perrow, 1994b, p. 9). The HRO group’s aim was to identify facets of these “high reliability organizations” that *differentiate* them from ordinary organizations and to *understand the design and management* of HROs (La Porte, 1996; Roberts, 1990). Their original work concentrated on two nuclear powered aircraft carriers (Roberts, 1989, 1990; Roberts et al., 1994a, 1994b; La Porte & Consolini, 1991), Pacific Gas and Electric Company’s Diablo Canyon nuclear power plant (Schulman, 1993a, 1993b, 1996; Klein et al., 1995) and the Federal Aviation Administration’s air-traffic control system (La Porte & Consolini, 1991; Schulman, 1993a; Klein et al., 1995). They employed workshops with the managers from the organizations, field observations, interviews, archival data and surveys (Roberts, 1989, pp. 113–114).

The HRO theories emphasize the significance and possibilities of organizational culture, redundant organizational structures and functions, process orientation, decentralized decision making based upon the expertise needed in emergencies, training and good organizational design and management including the prioritization of safety as an overriding goal for creating a “high reliability organization" capable of "nearly failure-free" operations (La Porte & Consolini, 1991, p. 23; Roberts, 1990, p. 160; Roberts et al., 1994a; La Porte, 1996; Weick & Sutcliffe, 2001; Weick et al., 1999).

On the other hand, the advocates of Normal Accidents Theory (NAT, Perrow, 1984, 1994b; Sagan, 1993) have illustrated the potential dangers of interactive complexity (which produces bizarre and unanticipated failures) and tight couplings (which cause the failures to escalate rapidly out of control) prevalent in e.g. nuclear industry, modern weapons systems, aviation and chemical industry. Perrow (1994b, p. 3) writes that "no matter how much training, how many safety devices, planning, redundancies, buffers, alarms, bells, and whistles we build into our systems, those that are complexly interactive will find an occasion where the unexpected interaction of two or more failures defeats the training, the planning, and the designing of safety devices". Sagan (1993, pp. 43–44) argues that "normal accidents theorist take a natural open system [in contrast to HROs closed rational systems] approach perspective in which organizations and members of organizations are self-interested actors with potentially conflicting interest, and in which organizations are strongly influenced by broader political and social forces in the environment". He (ibid., p. 29) notes the works of Cohen, March and Olsen (1972, 1988) on conflicting goals and non-rational decision making prevalent in organizations as an important influence on NAT. Also Clarke (1989), Starbuck and Milliken (1988), and Vaughan (1996) have contributed to NAT.

Sagan (1993) presents an overview of the main differences between HRO[6] and NAT (Table 1). He (Ibid., p. 45) notes that many of the "specific conditions that the high reliability theorist argue will promote safety will actually reduce safety according to the normal accidents theorists." For example, redundancy can make the system more complex and opaque. Furthermore, according to Sagan (1993), some of the characteristics identified by HRO as necessary for safety are considered impossible to achieve by NAT. For example, learning is hampered by denial of responsibility and reconstruction of the actual events to fit with the prevailing image of operations.

[6] To which Sagan (1993, pp. 14–17) includes in addition to Berkeley school the works of Wildavsky (1988), and of Marone and Woodhouse (1986).

Table 1. Competing perspectives on safety with hazardous technologies (Sagan, 1993, p. 46).

High Reliability Theory	***Normal Accidents Theory***
Accidents can be prevented through good organizational design and management	Accidents are inevitable in complex and tightly coupled systems
Safety is the priority organizational objective	Safety is one of a number of competing values
Redundancy enhances safety: duplication and overlap can make “a reliable system out of unreliable parts.”	Redundancy often causes accidents: it increases interactive complexity and opaqueness and encourages risk-taking.
Decentralized decision-making is needed to permit prompt and flexible field-level responses to surprises.	Organizational contradiction: decentralization is needed for complexity, but centralization is needed for tightly coupled systems.
A ”culture of reliability” will enhance safety by encouraging uniform and appropriate responses by field-level operators.	A military model of intense discipline, socialization, and isolation is incompatible with [American] democratic values.
Continuous operations, training, and simulations can create and maintain high reliability operations.	Organizations cannot train for unimagined, highly dangerous, or politically unpalatable operations.
Trial and error learning from accidents can be effective, and can be supplemented by anticipation and simulations.	Denial of responsibility, faulty reporting, and reconstruction of history cripples learning efforts.

Sagan (1993, p. 13) notes that the theories are based on mixtures of abstract deductive logic and inductive empirical observation, and that the authors within each school by no means agree on all details concerning organizational safety[7].

Sagan’s book (1993) provoked a public debate between the theories in the 90s (Sagan, 1994; Perrow, 1994a; Clarke, 1993; La Porte, 1994; La Porte & Rochlin, 1994, Perrow, 1999, Rijpma, 1997). Clarke (1993), for example, criticized the HRO theory for granting too much validity to managers’ views, statements and interests, for taking a non-critical stance toward official statements and records

[7] Sagan presents four additions/supplements to NAT. He illustrates possible negative effects of discipline and “strong organizational culture” on safety, such as excessive loyalty and secrecy, disdain for outside expertise, and possible cover-ups of safety problems in order to protect the reputation of the institution. Second, he questions how leadership priorities (of safety) are transformed into organizational behaviour in complex organizations. He notes how the priorities of other important actors in addition to the leaders affect decisions and behaviour. Third, Sagan discusses the constraints on learning, and “the resourcefulness with which committed individuals and organizations can turn the experience of failure into the memory of success”. Fourth, he warns how the organization in question can influence the researcher to accept the self-image of the organization with too little criticism. (Sagan, 1993, pp. 252–259)

and for putting emphasis on only the positive aspects of organizational culture. It was also pointed out that the HRO group does not clearly state whether or not the features that they have identified are necessary or sufficient for safe operation (Sagan, 1993, 1994; Perrow, 1994a). La Porte and Rochlin (1994, p. 225), in their rejoinder to Perrow and Sagan, respond to the criticism by arguing that "there was something to be learned from these organizations about the organizational and socio-cultural conditions that were *necessary* for relatively safe and productive management of technologies in the 'NAT' domain". They continue by stating that "nowhere has the Berkeley HRO group ever stated, argued, or implied that these conditions were *sufficient*" (La Porte & Rochlin, 1994, p. 225). Their goal has not been to create a theory of accidents, but a theory of reliability. Nevertheless, they have avoided taking a stand on what could be the missing characteristics (to make them sufficient for safety) or how large a variance of safety the current characteristics explain (Oedewald & Reiman, 2006a). The same remark applies to Normal Accidents Theory. Neither of the theories has thus been able to produce adequate models of accident causation or safety causation (cf. Rasmussen, 1997; Dekker, 2005).

HRO and NAT have illustrated the significance of organizational factors such as organizational structures, management, and organizational culture to safety and reliability of complex sociotechnical systems[8] (cf. Turner, 1976; ACSNI, 1993, p. 10; Rasmussen, 1997; Reason, 1997; Apostolakis, 1999; OECD/NEA, 1999; Sorensen, 2002; Ghosh & Apostolakis, 2005). Furthermore, the HRO group has especially emphasized the importance of studying normal work. Perrow (1994b) also emphasizes the study of organizations that had not yet had an accident. But since the HRO group (nor the NAT) has not decided on the criteria for reliability, they have not developed methods for assessment and development of safety critical organizations (the work of Weick and Sutcliffe [2001] is an exception, although their book is non-contextual and aimed primary at other than safety critical organizations). *The present study can be seen as contributing to the organizational theory of safety critical organizations that both* of these approaches have advanced.

[8] It should be noted that Perrow has never used the concept of culture in his texts. I am grateful to Professor Jan Hovden for pointing this out.

The HRO and NAT theories have concentrated on studying the social process of organizing the work (Rochlin, 1999a; Schulman, 1993b), the structural features of these organizations (Perrow, 1984; La Porte & Consolini, 1991; Sagan, 1993; La Porte, 1996; Roberts, 1993), decision making and management of these organizations (La Porte & Consolini, 1991; Roberts et al., 1994b; Rochlin, 1999a), the cultural features of HROs (Roberts et al., 1994a; Klein et al., 1995), the psychological requisites of the personnel working in these organizations (Schulman, 1993a; Weick & Sutcliffe, 2001; Weick & Roberts, 1993), and the political and societal aspects of the organizations (Perrow, 1984; Sagan, 1993; La Porte, 1996) – all of them undeniably important factors as such. They have to a very limited extent, however, systematically modelled the demands of the work in the different contexts, analysed the conceptions of the personnel concerning the work and its risks, or considered the psychological effects of the organizational characteristics to the personnel. What the HRO theories and NAT have discussed little is *the possibility of having diverse views on the meaning of reliability, accidents, risks and adequate organizational practices inside the given organization*. Even more importantly, they neglect the psychological dimension of working in complex safety-critical organization: *how the personnel experience and cope with their work and the associated risks*. The temporal dimension is usually also lacking in both HRO and NAT theories; *how has the culture formed and changed in time, and what effects can the current culture have in the future if it does not change, where is the organization heading to*. What are lacking are accounts of *how the personnel conceptualise their work and its demands* in high reliability organizations and how they cope with the associated risks. Finally, HRO theories have not focused on maintenance activities. NAT has identified maintenance as being one of the precursors to accidents in many cases, but NAT has not studied maintenance work specifically (Perrow, 1984).

HRO theory and NAT have refrained from giving predictions concerning the future of the organization. Rochlin states that the "lack of a theory of agency" means that one cannot give prescriptions or evaluative statements concerning the high reliability organizations. He concludes that at this stage it is "more appropriate to continue to be descriptive" (Rochlin, 1999a, p. 1552; see also Klein et al., 1995). We agree with Rochlin that the safety-critical and complex nature of the working environment sets unique requirements for any psychological intervention in the work or in the organization. Still, Rochlin actually commits evaluation when stating to focus attention on organizations "that are broadly and generally considered to be safe" (Rochlin, 1999a, p. 1552). HRO takes past behaviour as the proof for future safety. The same problem occurs in the “deeper” theories of organizational culture (e.g. Schein, 1985, 2004), where future behaviour is predicted as a repetition of past behaviour or manifestation of assumptions born out of past behaviour. As noted in the introduction one of the problems faced by human factors research of today is that apparently safe systems can drift into failure (Dekker, 2005; Rasmussen, 1997). Current organizational theories are unable to explain the mechanisms of this organizational drift.

We acknowledge the imperative of the evaluative approach to organizational culture in complex sociotechnical systems. In the safety-critical field especially, research must aim at producing results that approximate "reality" as closely as possible. In addition, we state that psychological research conducted in potentially hazardous working environments has to aim at changing things, not merely at describing them. Furthermore, the theory must be able to give predictions of the future direction of the dynamics of the complex sociotechnical system. In the next Section interpretative theories of organizations are presented along with the argument that complex sociotechnical systems could be conceptualized as organizational cultures.

1.3 Complex sociotechnical systems as organizational cultures

The functionalistic view of an organization (and the human being) that is emphasized by the rational-instrumental paradigm and to some degree also by the open systems paradigm has been widely challenged (cf. Burrell & Morgan, 1979; Sandelands & Drazin, 1989; Scott, 2003). Waring and Glendon (1998, p. 175) criticize safety management systems that are based on an overly-rational image of the organization and argue that they may be only partly effective while creating an illusion that the risks have been fully controlled (see also Waring, 1996, p. 46; Dekker, 2005, p. 2; Perin, 2005). Rollenhagen (2006, p. 76) points out that an important aspect of safety management is the “belief systems and values associated with various issue domains, and in particular, to what extent these belief and values are made *explicit* in the decision process”. McDonald et al. (2000) and McDonald (2001) argue that evidence from aviation maintenance indicates that the current quality and safety management systems seldom provide an adequate picture of the way the work is actually carried out (see also Hopkins, 2005).

Theories of the organization have begun to increasingly centre on systems of meaning and the way these are constructed in action (Silverman, 1971; Scott, 1995; Czarniawska-Joerges, 1992; Weick, 1995; Hatch, 1997). The definition of organizational culture has been revised in less functionalistic terms (see e.g. Smircich, 1983, 1985; Hatch, 1993; Schultz, 1995; Alvesson, 2002; Martin, 2002). In contrast to the functionalistic theories of culture described in the Section 1.1, the more interpretive-oriented theories of organizational culture emphasize the symbolic aspects of culture such as stories and rituals, and are interested in the interpretation of events and creation of meaning in the organization (cf. Geertz, 1973; Pettigrew, 1979; see also Frost et al., 1985, p. 17; Turner, 1971). The power relations and politics existing in all organizations but largely neglected by the functionalistic and open systems theories have also gained more attention in the interpretive tradition of organizational culture (cf. Kunda, 1992; Wright, 1994b, p. 23; Vaughan, 1999; Alvesson, 2002; Weeks, 2004).

The prevalent image of an organization has gradually changed, at least in research domain. Culture has been proposed a "root metaphor" for the organization (Smircich, 1983; Morgan, 1997). Weick (1979, 1995) has emphasized that instead of speaking of *organization*, we should speak of *organizing*. What we perceive as an organization is the (temporary) outcome of an interactive *sense-making* process (Weick, 1979). Tsoukas (2001) states that an organization is an emerging pattern, and that stability and change as well as rules and improvisation are all necessary features of an organization (see also Tsoukas & Hatch, 2001; Feldman & Rafaeli, 2002). Feldman (2000, p. 613) describes organizational routines as "emergent accomplishments", and thus constantly changing and internally dynamic. Tsoukas and Chia (2002, p. 570) propose that "organization must be understood as an emergent property of change. Change is ontologically prior to organization – it is the condition of possibility for organization". Even the heavily proceduralized and centralized complex sociotechnical systems adapt and change their practices locally and continually (cf. Bourrier, 1999; Snook, 2000; Dekker, 2005; cf. Mintzberg, 1983).

Schultz (1995, p. 5) argues that the cultural way of studying organizations is to study the meanings and beliefs which members of organizations assign to organizational behaviour and how these assigned meanings influence the ways in which the members behave themselves (cf. Czarniawska-Joerges, 1992; Weick, 1995; Alvesson, 2002, p. 106). Interpretation and *duality* (cf. Giddens, 1984) of organizational structure including its technology have been emphasized both in the theories of the organization and the organizational culture. Orlikowski (1992, p. 406) argues that "technology is physically constructed by actors working in a given social context, and technology is socially constructed by actors through the different meanings they attach to it". She also emphasises that "once developed and deployed, technology tends to become reified and institutionalized, losing its connection with the human agents that constructed it or gave it meaning, and it appears to be part of the objective, structural properties of the organization" (Ibid, p. 406). Creating meanings is not always a harmonious process; power struggles, opposing interests, and politics are also involved (Alvesson & Berg, 1992; Starbuck & Milliken, 1988, p. 331; Gephart, 1984, p. 213; Young, 1989; Linstead & Grafton-Small, 1992; Sagan, 1993; Wright, 1994b; Pidgeon & O'Leary, 2000; cf. Weeks & Galunic, 2003, pp. 1336–1337).

Social scientists of mostly anthropological or sociological background have described the nature and dynamics of "culture" and the social construction of the work in case studies (see e.g. Orr, 1996; Rochlin, 1999a; Bourrier, 1999; Gherardi & Nicolini, 2002; Hutchins, 1995). Their findings illustrate the social and interactive nature of organizations. They have empirically shown how the central features of work and organization (including safety) are constructed in interaction in the daily work (cf. Geertz, 1973). Similar ideas have been proposed also by e.g. Weick (1987, 1995), Kunda (1992), Barley (1996), and Alvesson (2002). *Our approach to organizational culture derives strongly from the work of the researchers mentioned above.*

The concept of organizational culture does not offer criteria for the assessment of the organization or its specific tasks. It is more descriptive in nature when used within the interpretive tradition. Furthermore, understanding the organizational life and its dynamics is not enough. In addition to this, the work and its requirements have to be understood in order to develop organizational behaviour and enhance the effectiveness of the sociotechnical system in question (cf. Barley, 1996; Rasmussen, 1997, p. 197). From the point of view of an organizational assessment, ethnographies produce interesting results about the culture of the workplace, but that is not sufficient. The aim of ethnographic research is not to extract criteria for assessment, or evaluate the cultural features that they depict (cf. Geertz, 1973; Smircich, 1983; Martin, 2002). Surprisingly few organizational theories of safety critical domain have tried to assess the organizations or define explicit criteria for an effective sociotechnical system, as was illustrated in Section 1.2.

Next we will review the results from the previous human factors studies on maintenance. We will then conclude on the benefits of the cultural approach to safety critical organizations, maintenance work and maintenance organizations in particular and point out the limitations of existing research concerning the maintenance of complex sociotechnical systems.

2. Review of previous organizational research on maintenance work

2.1 Research in NPP maintenance

Maintenance as an activity or the maintenance work itself in the nuclear industry has not been studied much from the human factors perspective, although in the recent years it has been receiving increased attention (IAEA, 2005; OECD/NEA, in preparation). Most human factors research has focused upon control room crew performance in (simulated) disturbance and accident conditions (Pyy, 2001; Salo & Svenson, 2001; Carroll et al., 1998, p. 110). Because maintenance routines and plant modifications are the activities that intervene most with the plant equipment, they are also the dominant sources of technical faults. The majority of behavioural scientific studies of the maintenance work have relied on this fact. Those studies have aimed at classifying, predicting and preventing human errors or minimizing their consequences (Reason, 1990, 1997; Laakso et al., 1998; Fleishman & Buffardi, 1999; Isobe et al., 1999; Pyy, 2001; Svenson & Salo, 2001; Toriizuka, 2001; Reason & Hobbs, 2003). Ethnographic or cultural studies of maintenance are rare, including studies of "normal work".

Reason and Hobbs (2003) note that the most common human errors in maintenance in nuclear power plants as well as in aviation industry are errors of omission[9]; failing to do something that should have been done (see also Reason, 1990; Hobbs & Williamson, 2003). They also note that these errors are commonly associated with reassembly or installation activities. They further argue that different forms of errors are associated with incidents threatening the safety of operation and with incidents threatening worker safety (Reason & Hobbs, 2003, p. 59). Thus different remedies are needed to address both types of outcomes. Reason and Hobbs (2003, pp. 63–74) describe the following factors that increase the frequency of maintenance errors ("error provoking factors"): documentation problems (quality of content and form of presentation), time pressure, poor housekeeping and tool control, inadequate coordination and communication, fatigue, inadequate knowledge and experience, problems with

[9] Separating human errors into errors of omission (failing to do something) and errors of commission (doing something wrong) and violations has been first proposed by Swain and Guttmann (1983; see also Rasmussen, 1982).

procedures (out of date, non-understandable, non-existent) and personal beliefs (such as illusions of control and invulnerability).

Laakso et al. (1998; see also Pyy, 2001) reviewed approximately 4400 failure reports from Olkiluoto NPP from the period of 1992–1994 and searched for human errors related to maintenance. They were especially interested in human related common cause failures[10] and the mechanisms causing these failures. For single human errors, they identified instrumentation and control (84 cases out of total of 206 single human errors) plus electrical equipment (40 cases) as being more error prone than the rest of maintenance. Laakso et al. (1998) identified 14 common cause failures from the failure reports. The distribution of common cause failure was similar to single errors; they all occurred to either instrumentation or electrical equipment. Also, similar to single human errors, the most dominant error category was that of commission (cf. Reason & Hobbs, 2003). Weaknesses in work planning and in the design and layout of the equipment from the maintainability point of view (cf. Seminara & Parsons, 1982) contributed to many of the human errors identified by Laakso et al. (1998).

Laakso et al. (1998) further identified that most errors had stemmed from the refueling outage periods and plant modifications, and almost 60 % of them were discovered during the power operation after the outage. Later studies by Laakso (2005, 2006) and Pyy (2001) have provided corroborative evidence on the types and objects of human errors in maintenance. For example, Laakso (2006, p. 17) notes about common cause failures that had occurred at Loviisa and Olkiluoto NPPs that “the plant modifications appeared to be the origin, but also the predetermined preventive maintenance was found to be a significant source [of failures]” and that “weaknesses in the planning of maintenance and operability verification seem to contribute as underlying causes into the occurrence of human common cause failures in the half of the cases at both sites”.

In addition to human error studies, some specific maintenance tasks (such as NDT, non-destructive testing of the equipment, see e.g. NRC, 1986; Kettunen,

[10] Common cause failures (CCF) are failure causes or mechanisms, that may apparently result or have resulted in multiple functionally critical failures in redundant components in real demand situations (they are unable to fulfil correctly their required function) (Laakso et al., 1998, p. 10). In relation to human error this means that a repeated human action affects several redundant trains of a safety system or several safety systems immediately or in a longer time span.

1997; Norros & Kettunen, 1998; Enkvist et al., 1999; Enkvist, 2003) and special situations (mainly annual refueling outage, see e.g. Haber et al., 1992; Carroll et al., 1993; Gauthereau, 2003; Bourrier, 1999; Jacobsson Kecklund, 1998; Jacobsson & Svenson, 1991) have been studied from the human factors perspective. Some studies have focused on work stress during the outages (Jacobsson & Svenson, 1991; Doniol-Shaw, 1997; Jacobsson Kecklund, 1998), some on mental procedures needed in troubleshooting (Rasmussen & Jensen, 1974) and some have focused on information management and support systems in maintenance (Isobe et al., 1999).

Norros and Kettunen (1998) studied the conceptions of the NDT inspectors concerning their task, its demands and its quality. They interviewed 15 inspectors who participated in the annual outages of both Finnish NPPs in 1996, and videotaped four actual inspections. On the basis of the interviews, two different conceptions concerning the quality of the inspections were found. An interpretative conception (8 interviewees) was characterized by taking into account the uncertainties involved in the situated activity. A conception that emphasized standard performance (7 interviewees) was characterized by relying on procedures and systematic methods. At least in one previous case in a Swedish NPP the fear of radiation had been noted to influence the reliability of the inspection (Dahlgren & Skånberg, 1993). According to Norros and Kettunen (1998), though, only a few inspectors stated that the presence of radiation causes them extra work pressure. They identified two distinct strategies to cope with radiation. Six interviewees emphasized the planning and preparation in order to minimize the exposure. Seven interviewees emphasized psychological aspects of coping with the radiation, such as concentration and systematical working. (Norros & Kettunen, 1998).

Carroll et al. (1998) studied decision making in the context of maintenance. They present evidence for the failure to give "due consideration for preventive maintenance" (cf. Seminara & Parsons, 1982, p. 186) in two domains; nuclear and chemical. They show how mental models and implicit assumptions influence decision making. Carroll et al. (1998, pp. 109–110) argue that difficulties in managing maintenance arise, in part, from limitations in mental models, which they define as individual, shared and embedded beliefs and understandings. They write: "Preventive maintenance is a prototypical activity that seems to be a low priority in the face of immediate demands to keep the machines running at lower cost, and the ultimate effects of deferred maintenance can be denied, ignored, or blamed on others" (Carroll et al., 1998, p. 110) They then demonstrate how in the chemical industry they tried to change from a culture of "corrective maintenance" to a culture of "preventive maintenance" with a maintenance game. The mental models, however, proved very hard to change (cf. Thomas, 2005).

Bourrier (1996, 1998, 1999) has compared practices in four maintenance units in France and the USA. She spent between 3 to 4 months at each site and conducted a total of 300 interviews. She noted differences between the units in e.g. the coordination of work, the structuring of the tasks and the role of procedures during the annual outages of the plants. Each plant had its own official or unofficial way of following the procedures and acting when the procedures did not cover the work in question. For example, in one of the plants organizational reliability was based on situational improvisation in case no suitable procedures could be found. Foremen gave an unofficial acceptance to the practice and trusted the expertise of their workers and themselves. In another plant reliability was based on following the procedures strictly, and in a case where no procedure existed, there was a procedure with which the appropriate procedure could be quickly produced. According to Bourrier, a drawback of this strategy was that it did not support individual decision making on the part of the workers. In conclusion, Bourrier (1996) states that "local adjustments to and re-arrangements of rules and, at times, even rule violations, are not only constant but necessary for organizations to effectively pursue their goals (Bourrier, 1996, p. 106; cf. Lawton, 1998, p. 88). Gauthereau (2003) studied Operational Readiness Verification (ORV)[11] (see also Hollnagel & Gauthereau, 2001, 2003) by means of ethnographic field study conducted in a Swedish NPP. His results highlight the constant trade-offs between efficiency and thoroughness made by a station technician and the socially accepted nature of the deviations from procedures. He further illustrated the socially constructed nature of the concept of ORV and how different personnel attached different meanings to it.

[11] Operational Readiness Verification – which is done before a NPP can be brought on-line after an outage – refers to the test and verification activities that are necessary to ensure that a system is able to provide its required function at a required time. It thus means that plant systems are able to work as they should and as they have been designed to do (Gauthereau, 2003, p. 35).

In summary, human factors research in nuclear power plant maintenance has been fragmented and it has not produced a holistic picture of the challenges of safe and effective maintenance. The safest and the most efficient way of maintaining the plant and organizing the maintenance activities are not self-evident. Thus, maintenance activities have recently been going through various organizational changes and restructuring initiatives, aiming at e.g. reduced costs, increased availability of machinery, better knowledge sharing and increased flexibility (Reiman & Oedewald, 2005; Reiman et al., 2006; Kecklund, 2004; cf. Bourrier, 1999; Kovan, 2000; Bier et al., 2001; Kettunen et al., 2004). Ageing plants and equipment (OECD/NEA, 2000), the ongoing generation turnover (OECD/NEA, 2001), and the deregulation of the electricity market (Bier et al., 2001) have been the main drivers in the recent organizational changes in maintenance (see also IAEA, 2001; OECD/NEA, 2002).

Maintenance work has also been studied in other domains. There is potentially something to be learned from the challenges of maintenance work in other domains. Furthermore, technicians form an occupational subgroup that potentially shares some characteristics across domains.

2.2 Maintenance research in other domains

Of other safety critical domains, aviation in particular has recently paid plenty of attention to maintenance human factors. Still, also in aviation, psychological research in maintenance has been noted to be "conspicuously absent" (Marx & Graeber, 1994, p. 87). Nevertheless, there have been more studies on aviation maintenance HF than on nuclear maintenance HF especially in the late 90s. Maintenance errors have been traced as a source of several aviation accidents and incidents and it has been reported that the number of maintenance-related accidents has been on the increase (McDonald et al., 2000, p. 154; ATSB, 2001, p. 1). Human errors in aviation maintenance have been studied by e.g. Reason and Hobbs (2003), Hobbs and Williamson (2002a, 2002b, 2003), Marx and Graeber (1994), and Latorella and Prabhu (2000), situation awareness by e.g. Endsley and Robertson (2000), on-the-job training by Walter (2000), team training by Kraus and Gramopadhye (2001), the use of simulator tools and task analysis in training by Cacciabue et al. (2003), problem solving by Rouse

(1979), and safety management and culture by e.g. McDonald et al. (2000). Relevant articles in terms of the present study will be reviewed next.

McDonald (2006) summarizes the results from a series of European projects concerning aircraft maintenance. He notes that the technicians did not follow the procedures routinely. They often justified their violations by reporting that there were "better, quicker, even safer ways of doing the task than following the manual to the letter" McDonald (2006, p. 161; see also McDonald et al., 2000; cf. Dekker, 2005, pp. 134–138; Hobbs & Williamson, 2003, p. 196). Also, according to McDonald (2006, p. 163), for many aircraft maintenance organizations, "there appears to be an unresolved tension between effective planning and the requirement of flexibility to meet the normal variability of the operational environment". He then generalizes from a number of surveys in different organizations the core professional values of aircraft maintenance personnel. These values included the following characteristics:

- strong commitment to safety
- recognising the importance of team-working and co-ordination
- valuing the use of one's own judgement and not just following rules
- being confident in one's own abilities to solve problems
- having a low estimate of one's vulnerability to stress
- being reluctant to challenge the decisions of others.

He (Ibid.) further noted that the above mentioned professional values in many ways matched the deficiencies found in the same organizations. Professionalism compensates for organizational dysfunction. A problem is that the "double standard" of work as formally specified and unofficial ways of working is hidden (McDonald, 2006). McDonald et al. (2000) and McDonald (2001) argue that evidence from aviation maintenance indicates that the current quality and safety management systems do not provide an adequate picture of the way the work is actually carried out, partly due to this "double standard".

Cooke (2002) conducted an in-depth case study of maintenance workers in five manufacturing firms. She illustrated the role maintenance workers play in technological change in their organization. She noted that maintenance workers are seldom consulted before new equipment is purchased, which they found frustrating. Once the new technology is implemented on the shop-floor, the maintenance personnel tended to have a greater input in advancing it (Cooke, 2002, p. 972). The chance to improve the equipment was often experienced as motivating. She further identifies organizational factors which condition "the ability of and the scope for the maintenance personnel to innovate". These include organization of the maintenance work, production pressures, management strategies and organizational politics. Cooke concludes that "shop-floor innovation may be a contest of intelligence among workers ... and a way to establish one's reputation of creativity. Most maintenance workers ... expressed the view that their biggest source of job satisfaction was keeping the plant running and doing the best for the machine." (Cooke, 2002, p. 983)

Orr (1996) has conducted ethnography on the field service technicians' work at Xerox. He noted that the technical knowledge and the professional identity of the technicians was strongly dependent on face-to-face encounters between the technicians and on the task-related stories ("war stories") that they shared (cf. Barley, 1996). These stories "combine facts about the [copying] machine with the context of specific situations" (Orr, 1996, p. 127). He noted that the machines are considered as both "perverse and fascinating" by the technicians. What really interests the technicians is a failure situation they do not understand. (Orr, 1996, pp. 95–97) They take pride in their being able to cope with the machines. The technicians must diagnose, repair, maintain and adjust the machines in an environment which is "inherently unpredictable". Orr (1996, p. 104) notes that "in all of these activities, and perhaps most critically in diagnosis, the technicians must understand the machines." Understanding is central also for the anticipation of and preparation for future problems. Orr points out that the corporation had a different view of the technicians' work, one that emphasised not understanding but rather the following of directive documentation (see McDonald et al., 2000, for a similar finding in aviation maintenance). On the other hand, "in providing directive documentation, the corporation is assuming responsibility for solving the machine's problems, and in the eyes of the corporation, technicians are only responsible for failure to fix a machine if they have not used the documentation. However, while the technicians are quite willing to let the corporation assume any blame, their own image of themselves requires that they solve the problems if at all possible." (Orr, 1996, p. 111)

Sandberg's (2000) study on engine optimizers is worth mentioning although it is not focused specifically on maintenance work. He discovered three qualitatively different conceptions of the optimizing work. The conceptions stipulated which particular attributes of competence (such as "interest in the engines" or practical sense of the engine") were developed and maintained in accomplishing the task. Sandberg (Ibid.) argues that the particular way of conceiving of work delimits certain attributes as essential and organizes them into a distinctive structure of competence at work. He concludes that "workers' knowledge, skills, and other attributes used in accomplishing work are preceded by and based upon their conceptions of work" (Sandberg, 2000, p. 20). Samurçay and Videl-Gomel (2002, p. 159), found that in electrical maintenance work there are needed both technical knowledge derived from engineering science and pragmatic knowledge including an understanding of the overall work process in the organization.

2.3 Conclusions of the existing research

Despite its significance for the reliability and safety of technological systems, there has been relatively little research on maintenance work or maintenance workers either in safety or in conventional domains (Cooke, 2002; Pyy, 2001; Salo & Svenson, 2001). According to Moubray (1992), maintenance issues in general have recently received increasing attention amongst the plant operators, which stems from a "rapidly growing awareness of the extent to which equipment failure affects safety and the environment, a growing awareness of the connection between maintenance and product quality and increasing pressure to achieve high plant availability and to contain costs." (Moubray, 1992, p. 1). Several accident investigations have also uncovered inadequate or faulty maintenance as one of the main contributors to unanticipated events in various safety critical domains including railways, offshore oil drilling, chemical, aviation and nuclear industries (Wright, 1994a; Paté-Cornell, 1993; Marx & Graeber, 1994, p. 88; Hale et al., 1998; Reason, 1997; Reason & Hobbs, 2003; Perin, 2005; Department of Transport, 1989).

The significance of maintenance for safe and reliable operation has also been shown in the studies of maintenance errors and their consequences. Furthermore, organizational issues have been shown to be important for the effectiveness of maintenance (Bourrier, 1999; Seminara & Parsons, 1982, p. 187). For example, research has identified tensions between following the procedure and judgments based on experience in maintenance (Bourrier, 1996, 1999; McDonald, 2006; cf. Orr, 1996; Ignatov, 1999; Woods et al., 1994, p. 80) as well as the influence of shared "mental models" (Carroll et al., 1998), task related "conceptions" (Norros & Kettunen, 1998; Sandberg, 2000), combination of technical and pragmatic knowledge (Samurçay & Vidal-Gomel, 2002) and "professional values" (McDonald, 2006) on the effectiveness of maintenance. Ethnographies of maintenance work in various domains (Orr, 1996; Barley, 1996; Bourrier, 1996, 1999; Samurçay & Vidal-Gomel, 2002) have shown that the maintenance personnel themselves emphasise the importance of wide understanding of the entire sociotechnical system and the work process. This is in sharp contrast to the focus of human error studies. Still, the human error perspective has been the prevalent approach to maintenance in safety critical domains. Task analyses or cultural studies of maintenance work are scarce.

In addition to the many benefits, there are also several drawbacks in error-focused approaches to maintenance work. First, human error can refer to either the cause of failure, the failure itself or to a departure from a standard (Dekker, 2005, p. 49). The attribution of error is a (social) judgment about human performance made with the benefit of hindsight (Woods et al., 1994, p. 3). Second, barriers and attempts to mitigate the effects of possible errors change the system and the type of errors that are possible and probable, creating a need for additional measures. This makes the error approach reactive (Oedewald & Reiman, 2006a). Third, error approaches usually focus on individual (maintenance) workers without adequate consideration of the organizational and cultural factors which might have contributed to the error or to the fact that the situation made sense to the workers at the time. Fourth, error approaches do not consider the organizational and cultural factors that allow the maintenance to function most of the time without errors (cf. Hollnagel, 2004, p. 150). Furthermore, the fact that the informal practices which are a part of any organizational culture can "contribute substantially to system resilience and safety" (Roth et al., 2006, p. 181) is often neglected in human error studies. Thus, in addition to human error studies, cultural studies of maintenance organizations and maintenance work are needed. Furthermore, these studies should take an evaluative approach to the maintenance work.

NPP maintenance satisfies all the conditions of a complex sociotechnical system identified by Vicente (1999, pp. 14–17). Due to the diversity, complexity, the temporal and spatial separation of the tasks and the numerous competence requirements, focusing on a single task (e.g. electric installation), special situation (e.g. outage) or a single psychological problem (e.g. errors of omission) can only partially explain the requirements of maintenance work and the organizational challenges of effective maintenance. On the other hand, these same characteristics make maintenance work challenging to study from a work psychological or human factors perspective as well as demanding to model by traditional normative (cf. Vicente, 2000, p. 112; Shepherd, 1992) task analysis methods. *Accounts of how the personnel themselves construct the maintenance work and its demands and how these demands manifest in the practices and structures of the organization are needed. A systematic modeling of the content and demands of the maintenance work is also needed in order to better understand and evaluate the subjective accounts of the personnel.*

3. Aims of the present study

The general aim of the present study is to develop and test a methodology for the assessment of organizational culture in complex sociotechnical systems. This is done by demonstrating the findings the application of the emerging methodology produces in the domain of maintenance of a nuclear power plant. Concepts of organizational culture and organizational core task are elaborated and tested in the case studies.

The following research questions are set:

- What are the elements of the organizational culture in complex sociotechnical systems? (Articles IV–V)
- What demands does the maintenance task set for the organizational culture? (Articles I, III, IV)
- How does the current organizational culture at the case organizations support the perceiving and fulfilling of the demands of the maintenance core task? (Articles I–IV)
- What similarities and differences there are between the maintenance cultures at the case organizations? (Articles I–IV)
- How to assess the effectiveness of organizational culture in complex sociotechnical systems? (Articles I, V)
    - How to extract the criteria for the assessment?
    - Where to focus the cultural assessment?

Due to the reasons described in the Introduction, the research questions have practical relevance for the safety of modern industrial organizations, especially nuclear power plants. Furthermore, the study of safety critical organizations and the special demands that they place on the employees contributes to the field of work psychology in general. The research has also relevance for the development of the human factors research paradigm.

4. Methods

4.1 Research strategy

Three in-depth case studies (cf. Yin, 1994) form the core data of the present study. The case studies were carried out at the maintenance units of three Nordic NPPs during 2001–2003. The case organizations were Loviisa NPP, Olkiluoto NPP (TVO) and Forsmark NPP (FKA). The specific aim of the case studies was to assess the given organizational culture. The case studies originally combined intrinsic interest in the given organizations and their culture with instrumental interest (Stake, 2000, p. 437) in the maintenance work of a NPP and in the appropriate methods for organizational assessment in safety critical domains. The three in-depth case studies thus formed a collective case study (Stake, 2000, pp. 437–438) in terms of the cultural assessment in complex sociotechnical systems, the elements of organizational culture and the characteristics of the maintenance work of NPPs.

The Loviisa case study was conducted during winter 2001 – spring 2002, TVO case study during fall 2002 – fall 2003 and FKA case during fall 2002 – spring 2003. Additional analyses were carried out during 2003–2005 for the combined data from all the three case studies for the purposes of the present study.

The case studies employed an iterative and multimethod research strategy based on method triangulation (Denzin, 1970; Silverman, 1993; Yin, 1994, pp. 90–94). We advocate the use of both qualitative and quantitative methods for studying organizational culture (Rousseau, 1990; Roberts et al., 1994a; Martin, 2002, p. 235; Yauch & Steudel, 2003).

4.2 Theoretical framework and the measurement model

The main concepts, the theoretical framework and the measurement model of the emerging methodology that is tested in the case studies are introduced next. The data collection and analysis is explained in the next Section.

In the present study organizational culture is conceptualized as a "root metaphor" (Smircich, 1983) for the organization[12] (see Section 1.3). Organizations are thus viewed as socially constructed and constantly in process (Alvesson & Berg, 1992; Alvesson, 2002; Schultz, 1995, p. 5). Organizational reality is considered an ongoing accomplishment, not a stable outcome (Weick, 1993b, 1995). In this cultural process, the content and meanings of safety, productivity and employee well-being are socially constructed (Bourrier, 1999; Rochlin, 1999a; Weick, 1995). Organizational culture enables shared interpretations of situations and makes co-ordinated action and interaction possible and meaningful (Smircich, 1983; Alvesson, 2002).

Martin (1992, 2002) has identified three qualitatively distinct perspectives to organizational culture: integration, differentiation and fragmentation. The integration approach – in line with the functionalist paradigm – emphasizes the unity and consistency of cultural assumptions and the lack of ambiguity. The differentiation perspective "describes cultural manifestations as sometimes inconsistent ... consensus occurs only within the boundaries of subcultures, which often conflict each other" (Martin, 1992, p. 12). In contrast to these, the fragmentation approach focuses on ambiguity as the essence of culture and emphasizes the multiplicity of interpretations that do not coalesce into a stable consensus (Martin, 1992; see also Martin, 2002). It has been emphasized within the differentiation perspective especially that organizations are composed of numerous subcultures. Subcultures form on the basis of e.g. age, ethnicity, job task or education (see e.g. Parker, 2000; Young, 1989; Alvesson, 2002; Schein, 2004, p. 274). Subcultures can also be interorganizational, such as the culture of computer programmers (Gregory, 1983) or aircraft maintenance culture (see McDonald et al., 2000), see also Chatman and Jehn (1994). The existence of subcultures has in some cases been considered as an indication of low integrity of the organizational culture, especially within the integration perspective of organizational culture (Brown, 1995, p. 186; Martin, 2002, p. 99). The perspective that is chosen in the research or development work also has influence on what is considered an effective or well-functioning culture. The

[12] Smircich (1983, p. 353) writes that "when culture is a root metaphor, the researcher's attention shifts from concerns about what do organizations accomplish and how may they accomplish it more efficiently, to how is organization accomplished and what does it mean to be organized". We argue contrary to Smircich that the researcher should focus on what the organization is trying to accomplish and on the socially constructed nature of this "accomplishing". Otherwise not enough attention is paid to the demands of the work (cf. Barley, 1996; Barley & Kunda, 2001).

usually implicit or explicit assumption behind cultural and organizational assessment is that the more integrated the culture/organization (the higher the within-unit consensus), the better. Safety culture assessments also use consensus as one criterion for a good safety culture. On the other hand, it has been argued that strong culture can impair safety as well as improve it (Sagan, 1993, pp. 40–41; Weick, 1998, p. 75). Strong cultural meanings can counteract questioning and independent thinking; cultural assumptions can act as constraints and prevent people from considering alternative ways of acting (Alvesson, 2002, p. 118; Parker, 2000; Kunda, 1992). The crucial issue thus is: What is the correct way of acting that the culture should support? We approach the challenge of adequate criteria with a concept of organizational core task.

Norros and Nuutinen (2002; see also Reiman & Norros, 2002; Norros, 2004, 2005) have introduced a concept termed "core task" for modelling the "outcome-critical content" of process control work in various complex, dynamic and technologically mediated environments (such as air traffic control and nuclear power plant control room). The concept has been used in analysing working practices and personal work orientations in e.g. NPP control room crews' performance in simulated disturbances (Hukki & Norros, 1998; Norros, 1998; Norros & Nuutinen, 2005), anaesthetists' work (Klemola & Norros, 1997; Norros & Klemola, 1999), and ship navigation (Norros et al., 1998; Nuutinen & Norros, 2001, in press). The Core Task Analysis (CTA) Framework (Norros, 2004) was developed on the basis of these studies. In the earlier studies, the perspective has often been the nature of an individual's (e.g. nuclear power plant control room crew, anaesthetist) expertise and daily working practices. We will illustrate the collective motive of the work in the organization by extending and redefining the concept of core task to the organizational level. Development of an assessment methodology for organizational culture was started for this purpose. The emerging methodology was named Contextual Assessment of Organizational Culture (CAOC, see Reiman & Oedewald, 2002a, 2002b).

The CAOC methodology utilises two concepts, *organizational culture* and *organizational core task (OCT)*. Organizational culture was originally defined as the practices, norms, values, conceptions and underlying assumptions (Figure 1) forming over time during the company history and affecting all the company's activities (which are in turn affected by them). These were conceptualized as different levels of culture, corresponding with the model of organizational culture proposed by Schein (1985). The concept of core task combines general goals of productivity, safety and employee well-being, which Vicente (1999) has presented as criteria for effective sociotechnical systems. Thus, it was proposed (Reiman & Oedewald, 2002b; see also Reiman & Oedewald, 2002a; Reiman & Norros, 2002) that the core task concept could be used in assessing the central dimensions of the organization's culture (Figure 1). The definition of organizational culture was adjusted with the aid of the core task concept. Organizational culture was defined as a solution created by an organization for the demands set by the core task (Reiman & Oedewald, 2002a, p. 27; see also Reiman, 2001; Reiman & Norros, 2002; cf. Schein, 1985).

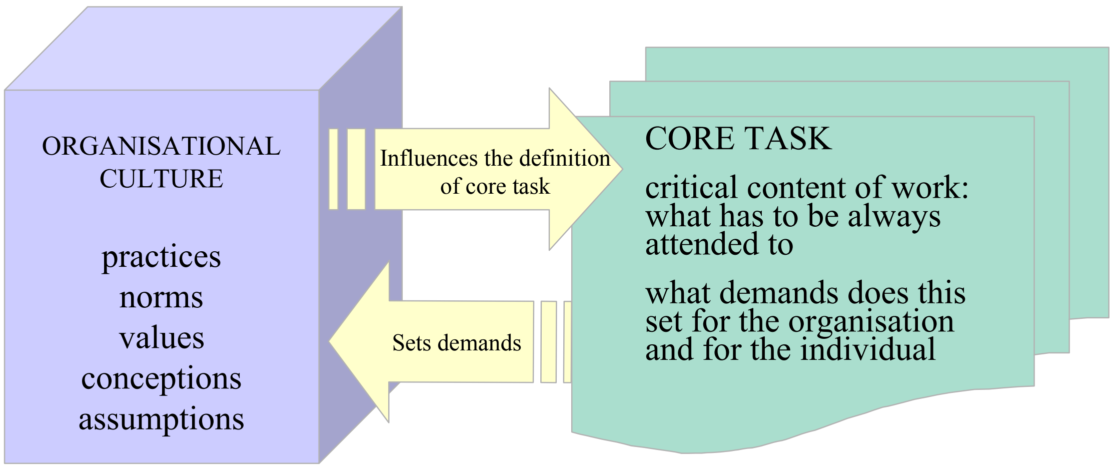

Figure 1. The central concepts of CAOC methodology, a preliminary model (Reiman & Oedewald, 2002b, p. 253).

Organizational culture influences the definition of the core task, which in turn sets demands for the formation of culture. In CAOC-methodology, a conceptualisation of the target organization's culture is made. The theoretical core task model constructed in the study acts as a point of comparison when examining the key features of culture as explained in the next Section and elaborated in the Results.

As argued in the Introduction we emphasise that even in safety-critical domains it is sensible to consider the overall effectiveness of the organization, which consists of the productivity, safety and health of the system (cf. Vicente, 1999).

Therefore we use the concept of organizational culture instead of safety culture and propose that the criteria for any culture should be defined in relation to the task that it is trying to accomplish (see also Norros & Nuutinen, 2002; Norros, 2004). The organization is able to form stable practices as characteristics of its culture by simplifying the reality and by forming preconceptions about the environment. These practices and the actual demands of the organizational core task can sometimes be in conflict. Organizational core task is defined as the shared motive of the activity of the organization. A nuclear power plant e.g. needs more than safety in order to continue its operation. It is postulated that if we can define the requirements set by a particular core task (in this case, maintenance of a NPP), these requirements can be used in assessing the central dimensions of the organizational culture.

Core task analyses have been performed by VTT in different contexts. The analytical method and the data acquisition methods have varied according to the subject area (see e.g. Norros & Klemola, 1999; Hukki & Norros, 1998; Norros & Nuutinen, 2002; Norros, 2004; Nuutinen & Norros, in press; Nuutinen, 2005). In these cases the core task concept has been used differently than in cultural research. In cultural research the objective is the determination of the core task at the organizational level. The focus shifts away from the modelling of actual situations as done in CTA to the modelling of the general conditions of activity e.g. through group work and interviews. The CAOC methodology, the concept of organizational culture and the concept of organizational core task were tested and elaborated in the three case studies in NPP maintenance organizations.

4.3 Data collection and analysis

Quantitative and qualitative methods were used in combination in all the three ways described by Hammersley (1996): triangulation (using data produced by different methods to validate each other), facilitation (one method produces hypotheses to be tested with another method) and complementarity (each method produces qualitatively different, complementary data about the same phenomenon), see also Yauch and Steudel (2003). The same methods and partly also the same raw data (e.g. interview transcripts) were used both to model the organizational core task and to characterize the case organization's cultural profile. Analysis of the data provided by the methods described in Table 2 was thus conducted iteratively for each plant.

The methods that were used for data gathering include organizational culture survey, semi-structured personnel interviews, development seminars, document analysis, working groups, and informal conversations (see Appendixes B–D for more information on the questionnaire and Appendix A for the interview themes). Data gathering was conducted at several organizational levels (cf. Roberts & Rousseau, 1989, p. 136). Observation of the work activities in the field was also conducted, although in complex sociotechnical systems the span of activities is usually so large that everything cannot be observed within a reasonable time period. Thus the observation should be focused on getting an overall impression of the nature of the work, and on some specific critical tasks where the demands of the task are especially salient. The methods were part of the emerging CAOC-methodology, and were thus iteratively developed from each case study to the next (see Appendixes B–D for the development of the survey method). The description of the methods and the data is provided in Table 2. Unless otherwise noted, the author has been involved in all the data collection and analysis. Methods were used for both cultural analysis and core task modelling (see Figure 2).

Table 2. Methods and data collection. LO stands for the Loviisa NPP, TVO for the Olkiluoto NPP and FKA for the Forsmark NPP.

Method	Organization	Data
Interviews of key informants	LO	Semi-structured interviews were conducted for the three members of the project group. The interviews were taped and later transcribed. Each interview lasted approximately one and half an hour. The interview questions were in most respects similar to the those of the personnel interviews (see Appendix B), but focused more on the demands of the maintenance task.
Document analysis	LO, TVO	The main documents of the maintenance units (org. charts, responsibility areas, work permit procedure) were analysed qualitatively.
Group working with the project group	LO, TVO	A project group was established for the duration of the study at both units. The groups included maintenance experts and managers. The demands of the maintenance work were modelled and preliminary results were presented at the meetings. Altogether six sessions were held at Loviisa NPP. The maintenance task was modelled in the first three meetings. After that, the focus of the group working shifted to commenting and discussing on preliminary results rather that generating new raw data. Ten sessions were held at Olkiluoto NPP. In the first two sessions, the maintenance task was modelled. After these sessions, the focus shifted to presentation of raw results, discussion and planning of the feedback and development seminars.
Personnel interviews	LO, TVO, FKA	The interviews had four main themes: one's own work, the maintenance task, organizing of maintenance work and organizational culture (see Appendix B for the specific questions). 19 interviews were made at Loviisa, 20 at Olkiluoto and 12 at Forsmark. The author participated in 9 interviews at Loviisa and at all the interviews at Olkiluoto. Other interviewees at Loviisa were Maaria Nuutinen, Pia Oedewald and Sanna Nikkinen, and at Forsmark Carl Rollenhagen and Irene Erikson. The interviews were taped and later transcribed. Each interview lasted about an hour. Interviews at TVO were carried out in two phases of ten interviews each. The ten last interviews included some specific questions about safety and cultural tensions at the maintenance unit which are not shown in Appendix B.
Survey	LO, TVO, FKA	Organizational culture questionnaire included four measures: 1. workplace values 2. one's own work 3. maintenance task 4 ideal workplace values. The questionnaire consisted of a total of about 100 questions with six-point Likert-type scale and two open questions. The open questions were phrased as follows: 1) "What are the main strengths of your department?", 2) "What are the main targets for development at your department?" Each questionnaire was addressed directly to the personnel, and was accompanied with a sealable envelope, pre-addressed to the research institute. The respondents were assured that the responses would be handled confidentially and that the results could not be traced back to the individual respondents. The questionnaire used at the Loviisa case study differed in some respects from that used in the TVO and FKA studies, see Appendix B and D. The size of the sample at Loviisa was 135, (with response rate of 70 %), at Olkiluoto 84 (response rate 60 %) and at Forsmark 136 (response rate 72 %). Gender was not asked since the units were very male dominated.
Observation of work activities during the annual outage	LO, TVO	The author visited two annual refuelling outages at Loviisa and two at Olkiluoto. During the first outage at Loviisa a night was spent observing the decovering of the reactor in addition to one day of touring around the plant. During the second outage the mechanical workshop was visited. The outages at Olkiluoto were spent touring the plant and observing the ongoing work for the duration of three days altogether. The author also attended the necessary training courses in order to get a pass to the controlled areas of the plants.
Seminars	LO, TVO	A final seminar with about 100 participants from all the levels and tasks of the maintenance unit was carried out at Loviisa. The results of the study were presented to the participants at the seminar which lasted for about three hours. A kick-off seminar was held at Olkiluoto. Preliminary results were presented at a seminar at Olkiluoto. The seminar had approximately 60 participants from the different levels of the maintenance organisation. Two development seminars were arranged at TVO. The seminars were identical in content and were held at the same place outside the plant area. Over thirty persons attended each seminar.
Development groups	LO	Three development groups and a management group from different sections of the Loviisa maintenance unit were established in order to develop the culture in accordance with the new organizational structure, which was set in place after the main data collection Each group met four times (three hour meetings) during a period of six months, with the researchers facilitating discussion. For the purposes of this study, the first two sessions in which the results of the cultural assessment were discussed with the groups and the maintenance core task was presented, were utilised as data.

The **interviews** were semistructured with plenty of follow-up questions. The interviews were recorded with the knowledge and permission of the individuals who were interviewed. The interview themes and questions were formulated on the basis of the theoretical framework and previous studies on organizational culture at the Radiation and Nuclear Safety Authority of Finland (Reiman, 2001; Reiman & Norros, 2002) and at Olkiluoto NPP's operations (Nuutinen et al., 2003). The themes were as follows (see Appendix A):

- One's own work
- The core task of NPP maintenance
- Organizing of maintenance activities
- Organizational culture as perceived by the interviewee.

Interviews serve many different purposes in the cultural assessment process. Firstly, the interviewing of individuals working at different organizational levels and posts gives researchers an understanding of different job descriptions, language and concepts. In this respect the interviewees are informants. Secondly, interviews were utilized in the cultural analysis in two different ways: (1) classification; certain questions concerning the three elements (see Section 5.1) of organizational culture (questions 2, 3, 10, 11, 17 and 19, see Appendix A) were analyzed by categorizing the responses into content groups, e.g. what kind of things are considered as demanding in one's work or what are the main targets for development according to the interviewees. (2) creation of a theory; common themes, that would surface in speech in various ways and contexts, were searched for. The analysis was done from the grounded theory perspective (cf. Charmaz, 1995; Smith, 1995). These themes could then be used to formulate hypotheses and to guide the analysis of questionnaire data. The interviews were also used to test and elaborate specific hypotheses generated by the other methods (e.g. the survey findings or comments at the seminars), see Hammersley (1996). Interviews enabled the interpretation of statistical links found in the questionnaire data and made statistical results more concrete by providing examples of the phenomena in question.

Organizational culture and core task questionnaire (CULTURE) was used to gain an overview of the values that the personnel perceive as being prevalent in their organization, the perceptions of the personnel concerning e.g. the meaningfulness and demands of their own work and their perceptions concerning the maintenance task. Case-specific questions were also added to the questionnaires on the basis of interviews and first group work session at the particular plant. The development of the CULTURE-questionnaire method is described in detail in Appendix D, and CULTURE01- and CULTURE06-questionnaires can be found in Appendixes B and C respectively. Measures of workplace values and one's own work were factor analysed using a principal components solution with orthogonal rotation (Tabachnick & Fidell, 2001). Summated scales were formed on the basis of the factor loadings. ANOVAs were performed to test differences within and between the maintenance units. Correlation analyses were used to inspect the interrelation of the variables. The statements to the open questions of the survey were analysed qualitatively by grouping them into categories by grounded theory based analysis (see Charmaz, 1995). For example, statements "clarification of the work tasks and minimizing insubstantial work", and "organization should be formed according to the work processes instead of technical fields" were grouped under the theme of "organizing of work and division of labor".

Group working with the given organization's experts was applied to the modelling of the organizational core task and to formulating and testing hypotheses relating to the organizational culture. Group working is also an important part of the method's practical contribution to the company; it strives to offer personnel the tools to continue reflecting on the organizational core task and working practices also in the future. Presentation of the raw data concerning both the demands of the maintenance task and the characteristics of the culture offered further hypotheses and explanations for the preliminary findings. The group acted for the entire research as an arena where plausibility (Silverman, 1993) of the results and saturation of the analysis (Strauss & Corbin, 1998, p. 136) was tested.

Seminars were used for three purposes: (1) clarification of emerging themes; e.g. the changes in the roles of foremen at TVO were elaborated in the comments made by the participants at the seminar. (2) Intervention, by presenting the results and facilitating discussion and (3) testing of the plausibility of the results, e.g. if the core task model communicates to the maintenance workers. Seminars were taped and the groupworking that took place there was videotaped when possible.

The organizational assessment consists of three phases (Figure 2):

1. Characterizing the culture of the organization
2. Conceptualizing the OCT demands in order to get appropriate criteria for the assessment of the organizational culture
3. Explaining the effect of the culture on organizational effectiveness by qualitative assessment based on the OCT model and the extracted cultural features.

The CAOC methodology aims at conceptualizing both the "objective" core task demands and the way they are socially constructed in the culture (Figure 1). Furthermore, the CAOC assessment is always an intervention to the organization (cf. Schein, 2004, p. 203). Figure 2 depicts the analysis framework used for the cultural assessment.

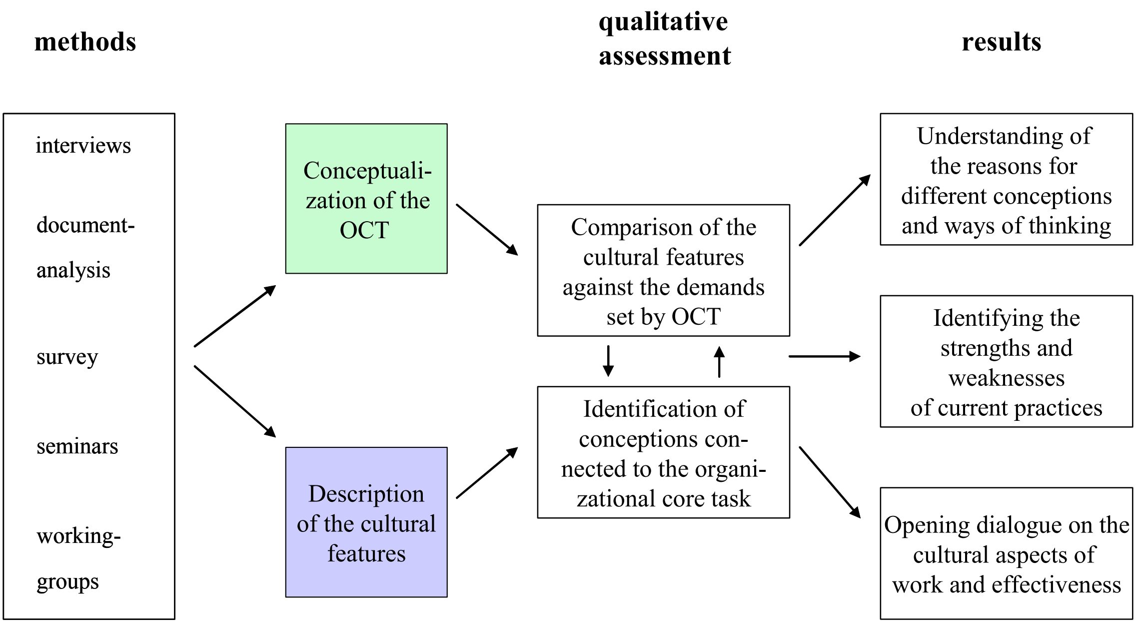

Figure 2. The analysis model of Contectual Assessment of Organizational Culture methodology.

The aim of the cultural analysis (phase 1) is to exemplify the personnel's multiple ways of making sense of and interacting in the organizational context (cf. Rochlin, 1999a; Weick, 1995) and to inspect what types of conceptions are shared among the personnel, and to what extent. The mode of analysis is interpretative (cf. Schultz & Hatch, 1996, p. 538) in its search for the creation of meaning and conceptions in the organization.

The focus of OCT modelling is on the constraints and requirements imposed by the given domain on organizational culture, and less on the situational and task-specific (such as in repairing a certain valve) manifestations of the organizational core task. The emphasis is thus not on cognitive demands as in cognitive task analysis methods (see Schraagen et al., 2000; Vicente, 1999, 2000) nor on working practice demands and situated actions as in the Core Task Analysis (Norros, 2004).

In the analysis of the organizational core task, similar to most task analysis techniques (cf. Kirwan & Ainsworth, 1992; Vicente, 2000; Hollnagel, 2003), we first define the object, goals and subtasks of the activity in question together with the case organization. The aim of core task modelling is to extract demands of the work applying to all activity in the organization. OCT is neither an aggregate of all the tasks the organization has to perform nor a single key-task performed by some critical members of the organization. As a first step toward conceptualising the shared demands the objective of work and the characteristics of the object of work are extracted in an analysis of the research data. Characteristics of the object of work (e.g. technical complexity, age of the components, design basis and the technical specifications of the plant) and the objective of the work (e.g. guaranteeing the power production in a PWR-type nuclear power plant) set constraints and requirements for the organizational core task. Further, society and environment set requirements and constraints that have to be taken into account in one way or another.

The requirements and constraints were modelled together with the domain experts (cf. Norros & Nuutinen, 2002; Vicente, 1999). The domain experts are personnel who have the most extensive technical knowledge of the sociotechnical system in question. Also experts outside the organization in question were consulted in order to decrease the influence of cultural biases on the core task modelling. When modelling the demands of the maintenance task in the work group, the researchers asked questions ("what is the goal of maintenance?", "what is critical in achieving the goal?", "how maintenance of a NPP differs from maintenance of some other facility?", What are the main characteristics of a nuclear power plant?", "How do these characteristics affect maintenance?") and wrote all the answers down on computer screen that was projected to all participants. After the sessions, researchers grouped the material and made e.g. illustrations, which were again discussed at the next meeting. The aim of these sessions was to create a consensus on the objective of the work, on the central characteristics of the object of the work, and on the societal and environmental influences.

Interviews were utilized in the core task analysis. The questions dealing with the goals and critical demands of maintenance (questions 10, 11, 12, 13, see Appendix A) were categorized (see Table 2). The interviewees are also inquired about the most demanding things in their work. This is considered to indicate the manifestation of the constraints and requirements in each employee's personal construction of his/her task. The analyses of interviews tell how the personnel take personally into account the constraints and requirements set by the OCT in their work (cf. Norros, 2004, p. 65). Workers in complex systems construct even the same task in qualitatively different ways (Norros & Klemola, 1999; Sandberg, 2000) and thus the answers vary in content also within the same task domain. In that situation, the *reasons* attached to the descriptions of their work and the core task, and how the respondents communicate the *sense* of their descriptions to the researchers make up the central criteria for inclusion in the OCT model (cf. Charmaz, 1995; Norros, 2004). Managers often have a better overview of the OCT, but they can lack a picture of the discrepancies and conflicts that manifest themselves better at the sharp end of the operations (cf. Corley, 2004, p. 1159). In addition to the above mentioned specific questions, the interviews were analysed in order to find out the interviewees' conceptualizations of the characteristics of the power plant and the influence of the characteristics for the interviewees' work in response to any of the questions.

The analytical process in OCT modelling is more convergent (cf. Schultz & Hatch, 1996, p. 538) than in cultural analysis, which is divergent in its search for multiple interpretations. The purpose of the cultural assessment is not to prescribe the structures (e.g., network organization or matrix organization with particular processes) or practices needed to accomplish the organizational core task. The demands can be fulfilled organizationally in many different ways. In this sense, the approach is formative rather than normative (see Vicente, 1999, p. 110). The organizing of the activity and the activity itself are assessed mainly on the basis of the requirements that they have to fulfil and the constraints that they have to take into account.

Due to the theoretical work on the methodological principles of cultural assessment, the assessments of the maintenance cultures were iterated on several occasions. The assessment summaries presented in the present study are based on the articles and on clarifications made on the basis of the theoretical work on organizational culture and organizational assessment.

5. Results

In this Section, the main results of the study are considered according to the five research questions:

- what are the elements of organizational culture in complex sociotechnical systems (5.1)
- what demands does the maintenance task set for the organizational culture (5.2)
- how does the current organizational culture at the case organizations support the perceiving and fulfilling of the demands of the maintenance core task (5.3)
- what similarities and differences are there between the maintenance cultures at the case organizations (5.4)
- how to assess the organizational culture in complex sociotechnical systems (5.5).

In Section 5.1 the elements of organizational culture in complex sociotechnical systems are defined. The Section is based on *Article IV, Article V*, paper by Reiman and Oedewald (2006a) and the clarifications made in the present study. In Section 5.2 the model of the maintenance core task is presented as abstracted in the case studies. The Section is based on *Articles I, III, IV,* working paper by Oedewald and Reiman (2002) and the clarifications made in the present study. In Section 5.3 the organizational cultures of the three units are first described according to the three elements of the organizational culture and then an assessment summary based on the model of the maintenance core task is presented. The Section is based on *Articles I–IV*, two Finnish language research reports by Reiman and Oedewald (2003, 2004), and one research report by Reiman et al. (2004a). In Section 5.4 the similarities and differences in the organizational cultures at the three units are inspected more closely. The Section is based on *Articles I–IV,* publications by Reiman and Oedewald (2003, 2004), by Oedewald and Reiman (2005), and by Reiman et al. (2004a, 2004b, 2006). Finally, in Section 5.5, a framework for assessment of complex sociotechnical systems is presented, based on the evidence from the case studies and the theoretical work. The Section is based on *Article I, Article V*, working paper by Oedewald and Reiman (2002), two papers by Reiman and Oedewald (2006a, 2006b) and the clarifications made in the present study.

5.1 Elements of the organizational culture in complex sociotechnical systems

From the analysis of the case study data three qualitatively different elements of organizational culture in complex sociotechnical systems having relevance for the cultural assessment emerged. In this Section, these elements of organizational culture are illustrated. Furthermore, the dynamics of organizational culture and its relation to organizational core task are clarified.

Organizational culture includes three interrelated elements of *structure* (organizing of work, formal systems, tools etc.), *internal (social) integration* (climate, norms, tensions, rites), and *conceptions* concerning the work and the organizational core task. These elements represent three qualitatively different ways of focusing on the organization. None of the elements are by themselves adequate for assessing the effectiveness of the organizational culture. All three elements and their interrelations must be considered. Furthermore, subcultures can form according to any or all the elements. For example, subcultures can be differentiated by their conceptions concerning the organizational core task, norms and interaction patterns, or practices. Subcultures can also be similar in respect to some of the elements. Subcultures differentiated by interaction patterns and norms can still share similar conceptions of what is important in the work, even though they may not be aware of the similarities in their conceptions. Our definition of organizational culture thus includes both "ideational" and "material" aspects (cf. Alvesson, 2002; Martin, 2002).

Organizational culture includes the process of formation and reformation of the conceptions concerning the organizational core task and the means to fulfil it. This process of collective sense-making and (re)interpretation of events is the essence of an organizational culture (Weick, 1995; cf. Giddens, 1984; Weeks & Galunic, 2003). Weick (1995) has described the continual and collective reality-building process constantly taking place in the organization. In this process the meanings of various events are deliberated and a common view is formed based on perpetually incomplete information (Weick, 1995). The organization and its members create and recreate the context in which future behaviour occurs – which again shapes the context further (Weick, 1993a; Giddens, 1984; van Maanen & Barley, 1985, p. 35; Hernes & Bakken, 2003; cf. Berger & Luckmann, 1966). Organizational culture thus both influences and is influenced by the meanings, behaviours and individual psychological states (such as sense of control or perceived meaningfulness of the work) of the personnel.

The organizational core task sets demands (constraints and requirements) for the activity in the organization. Activity in turn is an aspect of the organizational culture resulting from the interaction of the cultural elements. For example, how the demands of the work are perceived shapes the structures and practices deemed necessary in the organizational culture and thus influences the organization's way of responding to the OCT. On the other hand, tools and practices embed meanings concerning their proper use, which in turn affects the cultural conceptions.

As illustrated by the upper arrow in Figure 3, the organizational activity influences the components of the organizational core task. This can mean e.g. changing the characteristics of the physical object (e.g. lack of proper preventive maintenance can lead to lower technical reliability and increased faults of the equipment), or by drawing more regulatory and public attention by incidents or accidents. These changes can set new constraints and requirements or alter the old. These are then again interpreted in the culture.

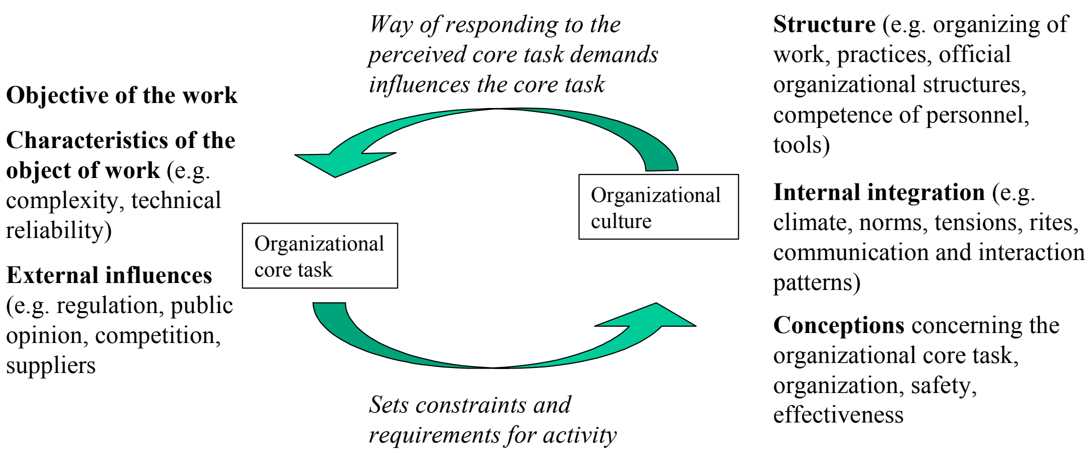

Figure 3. The central concepts and their interrelations.

Conceptions were defined to be the core element of the organizational culture in complex sociotechnical systems. In addition to conceptions, also assumptions were included in the original measurement model (Figure 1). Assumptions were considered to be more unconscious and hypothetical than the conscious and fact-based conceptions. The definition of conception was clarified during the course of the case studies to include also subconscious and implicit elements since they seemed inseparable from the more “fact-based” conceptions. *Conception* can be defined as a person’s way of experiencing and making sense of their world (Sandberg, 2000, p. 12) and the mental attitudes concerning these experiences, the sense made of them (cf. Weick, 1995; Weick et al., 2005). Cultural conceptions incorporate beliefs, assumptions and propositions about the physical and mental objects of the organization, its core task, technology, personnel and environment. It is important to note that conceptions are an element of culture, not an element of individual cognition or psyche in its tradition definition (cf. Schein, 1985). This resembles the ideas of distributed cognition paradigm (Hutchins, 1995; cf. Woods et al., 1994, p. 45; Carroll et al., 1998; Nuutinen, 2006), but with an emphasis on the cultural nature of cognition. Cognitive, attitudinal and emotional elements are fused in the cultural conceptions.

In the case studies, a difference was found between *shared collective conceptions* (shared by most or all the members of the organization), *emergent collective conceptions* (existing in the collective culture but shared and accepted by only few or none of its members), and *embedded conceptions* (conceptions that manifest in the interaction with the tools that embody them). Embedded conceptions exist and are maintained in the structure of the culture, whereas emergent conceptions “exist” at the level of internal integration, mainly norms and communication patterns (Figure 3). The embedded conceptions are usually not reflected in the daily practice. For the personnel, the objects and tools in the environment represent the history of their use. In other words, the tools *mean* whatever they have been used for in the past (Weick, 1993b, p. 353; Hutchins, 1995). Conceptions are not limited to the positive aspects of the work or the organization, nor are they always adaptive in the long or the short term (cf. Schein, 1985). Conceptions can also relate to issues that are *not* considered meaningful in the organizational culture. Organizational culture acts as much a blindfold as an asset if not reflected upon actively (Alvesson, 2002, p. 119; Kunda, 1992; Trice & Beyer, 1993; Weeks, 2004). Weick has also emphasized that "strong cultures can compromise safety if they provide strong social order that encourages the compounding of small failures" (Weick, 1998, p. 75; cf. Sagan, 1993, pp. 40–41) and further drawing on the seminal work of Turner (1978) that "organizations are defined by what they ignore – ignorance that is embodied in assumptions – and by the extent to which people in them neglect the same kinds of considerations" (Weick, 1998, p. 74).

The characteristics of the organizational culture – i.e. the contents of the elements – can be functional, dysfunctional or irrelevant in terms of fulfilling the task requirements and fostering safety, productivity, and employee wellbeing in the organization. These characteristics should be assessed against relevant criteria; what the organization is trying to accomplish (the OCT), and what constraints and requirements this sets for the organizational culture. Many of the cultural characteristics are difficult to designate as clearly functional or dysfunctional (cf. Alvesson, 2002, p. 47), but the organizational core task helps in pointing out the pros and cons of the different characteristics in terms of what the organization is trying to accomplish.

Organizational core task (OCT) refers to the shared objective or purpose of organizational *activity*. Activity means action in a social context with a shared objective. This shared objective is called the collective motive of the activity (Engeström, 1999; Leontiev, 1975). According to psychologist Alexei Leontiev (1975), a proponent of the cultural-historical theory of activity, the constituent characteristic of activity is its orientation to its object. He states that the concept of activity implicitly includes a conception of its motive. He further distinguishes between activity (which has a motive), action (which has a goal) and operations (which are carried out under certain conditions). (Leontiev, 1975) The differentiation between activity and action is of special importance in understanding work in complex sociotechnical systems. Action has a specific goal (such as repairing a leaking valve), but the repairing of the valve is also governed by a wider motive of maintaining the production of a power plant, thus making it a part of the maintenance activity. OCT thus serves as the collective motive of activity in the organization.

The OCT is influenced by three interrelated components (Figure 3):

1) the physical object of the work and its characteristics (such as a certain type of NPP),

2) objective of the work (e.g. to produce electricity safely and efficiently at a competitive price), and

3) society and the environment (e.g. regulation, political climate).

The physical object of the work activity (e.g. particular power plant, manufacturing plant, offshore platform), the objective of the work and society and environment (e.g. deregulated electricity market, harsh winter weather) set constraints and requirements for the fulfilment of the organizational core task (e.g. guaranteeing safe and efficient production of electricity by light boiling water nuclear reactor). These constraints and requirements influence the formation and development of organizational culture as illustrated by the lower arrow in Figure 3.

To summarize, the organization creates and recreates its own constraints which may or may not correspond to the demands of the OCT. Outside pressures are always interpreted in the organization. The organization thus defines the significance of and the appropriate response to these pressures. These definitions and organizational solutions are not fixed. Rather safety and effectiveness are emergent properties of organizational dynamics, with conceptions of OCT playing a central role in directing the dynamics. The demands of the OCT have to be understood in order to be able to evaluate the organizational culture and predict the consequences of the cultural dynamics.

5.2 Demands of the maintenance core task

Mercier (1988, pp. 86–87) characterizes the maintenance work of a NPP as follows: ”It is rare for so many non-repetitive tasks to be concentrated in an industrial environment that is so very hostile to human activity. The forces in this environment are considerable. Temperatures, pressures, the multitude of fluids, mechanical power, omnipresent electricity, even the sheer weight of the equipment … all culminate to make maintenance actions potentially dangerous and to weigh against success. The ‘nuclear’ hazard and the associated radiation protection restraints are simply one more risk, but a risk that is often quite minimal compared to the others.”

In practice, maintenance is carried out in three types of maintenance subtasks: preventive maintenance, corrective maintenance and modifications. Preventive maintenance includes periodic inspections, condition monitoring, tasks specified in the Technical Specifications[13] and periodic maintenance tasks. Corrective maintenance can include fault repairs of components that belong to the program of preventive maintenance and thus should not have failed, or components that are considered non-critical for safety and production and are thus not maintained until they break down. Modifications include modernisation of components; the assembly and testing of new components is done by the maintenance personnel or by the contractors. Maintenance personnel seldom participate in the planning of modifications.

On the basis of the OCT modelling, the overall objective of the maintenance activity was defined as follows: maintaining the operational reliability and the economic value of the nuclear installation so that the power production can continue as long as planned. The characteristics of the object of work were extracted in an analysis of the interview material and group discussions. The characteristics of the nuclear power plant set constraints and requirements for the maintenance task. Three critical demands of the maintenance task were identified by categorizing the constraints for activity: *anticipation, reacting, monitoring and reflecting* (Figure 4).

Anticipating refers to an intention to predict the state of the plant and the effects of actions, as well as to plan the needed actions and resources in advance. Anticipation is connected to the way the power plant is being used, with one planned outage a year. The machinery that is imperative to the production or inaccessible during power operation must be maintained during the annual outage. Because of the complexity of the system, all the other tasks have to be also planned carefully in advance. The safety critical nature of nuclear installations also emphasises the need for anticipation so that radiation can be taken into account.

[13] The Safety Technical Specifications is a document that includes detailed requirements and restrictions of different systems and equipment including the maximum unavailability times of the equipment. These are based on the deterministic safety related rules as well as the probabilistic safety analyses of severe core damage. In addition to this, the required functional tests of the safety significant equipment have been specified in the Technical Specifications. (Sandberg, 2004)

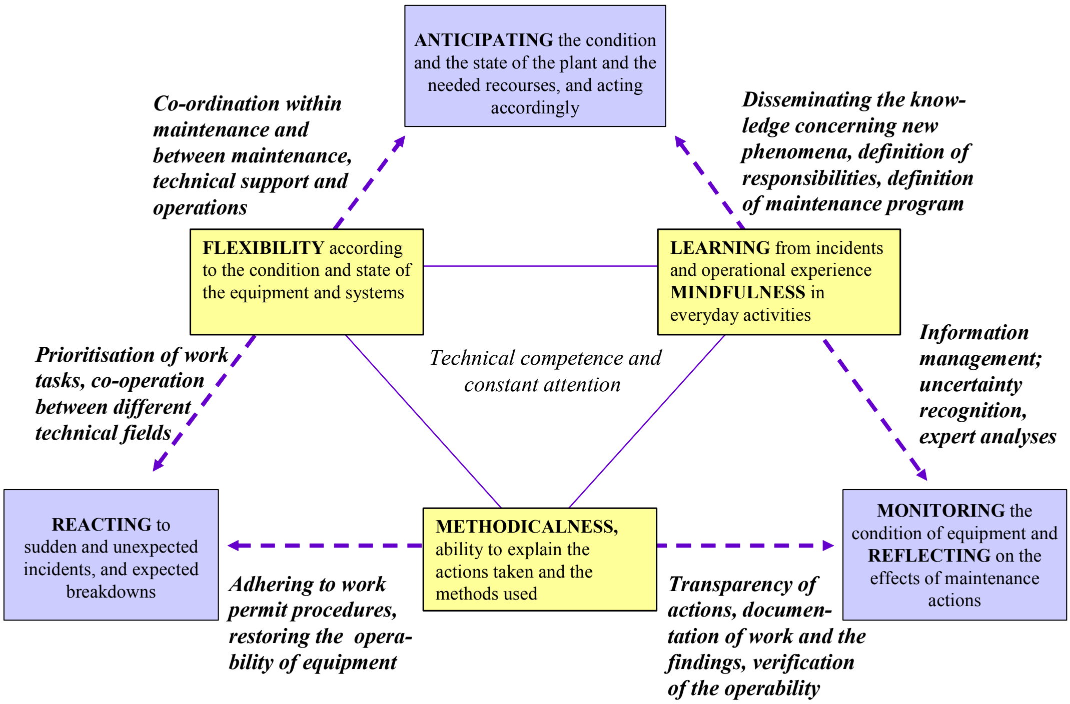

Figure 4. The model of the demands of the maintenance core task, adapted from Article I and III: critical demands (in the corners of the triangle), instrumental demands for the critical demands (between each critical demand), and demands for working practices (in italics, outside the triangle).

Reacting to unexpected conditions is the second critical demand for maintenance. In spite of anticipating and planning, unexpected things may happen. Re-establishing the operability of the equipment after sudden failures or exceptional findings in periodic testing is a critical demand for maintenance. The safety-critical nature of the maintenance of a nuclear power plant requires efficient reaction to deviations since the technical specifications of the plant set time limits for the accepted unavailability of certain systems.

Monitoring and reflecting refers to a demand arising from the inherent uncertainties of complex sociotechnical systems, (see e.g. Perrow, 1984; Vicente, 1999; Norros, 2004) and the mediated and uncertain nature of the knowledge concerning the object of activity. Reflectivity means critical reviewing of the effectiveness and results of one's actions. Changes in the economic environment, and, for example the ageing phenomena of the plant, put more emphasis on continuous condition monitoring and active reflecting of the maintenance strategy. Reflectivity includes challenging the existing conceptions and working practices, which are embedded in the culture of the workplace (see Section 5.1). Reflecting is needed to ensure that the actions taken are appropriate and also to create knowledge for anticipation purposes.

The three critical demands of maintenance have to be taken into account by *all personnel* in *every situation.* The OCT of maintenance is about balancing between anticipating, reacting and monitoring and reflecting. Flexible balancing between anticipating and reacting makes the formulation of shared goals and criteria for plant condition possible. By reacting to novel situations and reflecting on the effects of the action, one creates information about the object of the activity. Information is generalised into knowledge concerning the current condition of the plant in the learning process, e.g. by comparing information to previous experiences and by sharing it with others.

The instrumental demand that is associated with balancing between anticipating and reacting was termed *flexibility*. The need for flexibility was brought up with examples of coordinating the timetables for jobs that require several different areas of expertise or coordinating the resources and prioritising the tasks in a case of a sudden equipment failure. Balancing between the demands of reacting and reflecting requires a systematic and, to a certain degree, pre-specified way of performing actions. That demand was termed *methodicalness.* It means following the procedures, verifying what has been done and documenting the results of the actions. Only then can they be later analysed and reflected upon. Balancing between the demands of reflecting and anticipating necessitates information acquisition and management that we have called *learning and mindfulness*. In order to learn from actions, awareness of uncertainties in the complex system is required, since learning requires challenging existing conceptions and practices. The need for sharing of knowledge and experience is related to learning. An example of learning could be changing the schedule of preventive maintenance on the basis of the history data for the given equipment.

The demands of the maintenance task as abstracted in the present study resemble the demands of knowledge-intensive work, where knowledge acquisition, interpretation and sharing are central for maintaining good situation awareness (see e.g. Endsley, 1995). Maintenance work is a synthesis of manual labor and knowledge intensive work (cf. Barley, 1996; Orr, 1996); it is about *maintaining* the complex technology by anticipating, monitoring, reflecting and reacting to it.

At the Loviisa case study, a development project was started based on the results of the cultural assessment (see Table 2). The project consisted of three development groups, each of which met four times. In the second meeting the maintenance core task model was presented and the participants were asked to think how the demands manifest in their work and to classify their daily tasks according to the critical and instrumental demands of the maintenance task. Almost everyone could identify tasks and situations contributing to each of the demands, as well as tasks that did not seem to fit any of the demands. These tasks were considered by the personnel to be of no relevance to the maintenance core task as they conceptualized it. Usually these tasks were considered frustrating. Furthermore, the participants had a tendency to think of their job as primarily a fulfilment of the demand for reacting (see Section 5.3.1). With the core task model and the help of the facilitators (Pia Oedewald and the author), they were able to perceive their work in a wider perspective that included all the demands of the maintenance task. The model can therefore be claimed to have pragmatic value (and ecological validity) as an instrument in analysing and reflecting upon one's work and the specific tasks. This procedure corresponds also with Silverman's (1993) concept of *respondent validation*.

5.3 How does the organizational culture at the case organizations support the OCT

Maintenance in a nuclear power plant is carried out with a work permit in order to be able to coordinate the different task and facilitate their safe and efficient conduct. The permit is usually signed by a shift supervisor who makes sure that the system is ready for maintenance. The work permit includes the description of work, the necessary precautions to be taken (e.g. radiation protection), and a list of the needed tools and instructions. Maintenance is responsible for both the equipment that is critical to safety and production, and for the secondary areas of the plant (e.g. the yard, the restrooms, lighting and ventilation). Most of the operative maintenance of a NPP consists of pre-planned overhauls or periodic testing. Maintenance activities are usually divided into mechanical (e.g., pumps, valves, welding, machining), construction and real estate (e.g., scaffolding, building structures), electrical (e.g., motors, actuators, cables, power-distribution systems at the plant), and I&C (instrumentation and control, e.g. reactor protection systems, measurements, process computer systems) tasks with specialized workers and organizational units.

Table 3 depicts selected safety indicators during the period 1999–2004 from the Finnish power plants accompanied by corresponding indicators from Forsmark NPP when applicable.

Table 3. Safety indicators during the period of 1999-2004 from the Finnish power plants accompanied by corresponding indicators from Forsmark NPP when applicable (from Tossavainen, 2005; Kettunen et al., 2006, submitted; www.stuk.fi).

Indicator	Plant	Year 1999	2000	2001	2002	2003	2004
Average load factor (%)							
	Loviisa	91,9	87,5	90,1	85,3	89,8	90,1
	Olkiluoto	96,5	95,4	96,4	96,0	96,3	95,6
	Forsmark	87,5	69,9	84,8	85,1	88,5	92,7
Number of INES classified events							
	Loviisa	1	1	0	1	0	0
	Olkiluoto	4	0	1	1	7	0
	Forsmark	0	0	0	0	1	1
Number of reactor and turbine scrams							
	Loviisa	0	0	2	0	0	1
	Olkiluoto	2	0	2	1	1	1
	Forsmark	1	1	0	4	4	0
Ratio of preventive maintenance works to failure repairs of Tech Spec components	Loviisa	1,2	1,6	1,2	1,5	1,0	1,1
	Olkiluoto	3,5	3,4	2,9	1,6	1,5	1,0
Loss of power production due to failures (%)							
	Loviisa	0,2	1,2	1,0	0,1	1,4	0,3
	Olkiluoto	0,2	0,1	0,3	0,7	0,3	1,0

It should be noted that proportionally more failure repairs are conducted at Loviisa NPP than at Olkiluoto NPP. Olkiluoto NPP on the other hand has had more INES[14] classified events than Loviisa or Forsmark. It should also be noted that all the INES events are of the first, least severe class. Furthermore, the

[14] INES means International Nuclear Event Scale. The scale runs from 1 to 7, with the accident at Chernobyl in 1986 classed as Level 7, and the Three Mile Island accident in 1979 as Level 5. All the events in Table 3 have been of INES 1, indicating a minor "anomaly". In Finland STUK decides the scale of the event based on the proposal from the power plant. (Sandberg, 2004)

average load factors of all the three power plants have been consistently high (except for year 2000 at Forsmark when they had large modernization projects), with Olkiluoto NPP having the highest load factor each year. All these organizations can thus be considered High Reliability Organizations (see Section 1.2). In the next Sections, we will present an overview of the main features of the maintenance culture at the three units according to the elements of organizational culture (Section 5.1) and then an assessment summary of the relation of the features to the demands of the maintenance task (Section 5.2).

5.3.1 Loviisa NPP maintenance unit

Structure and organizing of work

Loviisa NPP is owned by Fortum Oyj. The company was founded in 1998 by combining the businesses of Imatran Voima power company (IVO) and of the listed oil company Neste Oyj. Loviisa NPP was previously part of IVO that entered into the trade register in 1932 as a state-owned company. Loviisa NPP has two PWR type units and the net electric power of each unit is 488 MW.

The maintenance department at the Loviisa NPP had approximately 200 full-time employees at the time of the case study in 2001–2002. The average tenure of the personnel was over fifteen years. The maintenance activities at the department were organized into seven sections for mechanical, electrical, instrumentation and construction maintenance, technical design, planning and co-ordination and quality control. The organizational structure was that of a traditional line organization with highly centralized decision-making and specialized units. The plant organization, including the maintenance department, was reorganized after the main data collection in January 2002 (for details of this organizational change see Reiman et al., 2006). The effect of the change on the maintenance culture is beyond the scope of this dissertation and thus the results will concentrate on the culture as before the change.

The daily work was organized at the morning meetings (separate for all sections) where the foremen allocated the work to their subordinates by issuing work permits. The work permit is drafted by the work planners with the plant information system (LOTI) on the basis of a work order. The shift supervisor from the operations department has to approve all the permits. The work permit is prepared after somebody has made a failure notification or the LOTI system has informed of a periodic maintenance. The foreman issues the approved permit to the technician who carries out the job. The technician then returns the permit to the foreman who marks the work as done and adds the findings to LOTI. During the work, the permit is tagged to the machinery under work. The foreman returns the permit to operations, where the approval to restart the system is given after the required tests have been conducted. Each foreman has a certain responsibility area and he coordinates the work done in that area. Failure repairs account for approximately 10 percent of all the work.

Internal integration

Internal integration was not very strong in terms of cohesion and working climate. Employee wellbeing as well as change and development were considered as little valued in the maintenance organization. Values related to the hierarchy and autonomy were also considered as quite low. Safety and deliberation were the most strongly endorsed values of the organization according to the personnel. Financial values were also endorsed to a moderate degree. The personnel characterized their culture as *hierarchical* and *conservative* in decision-making. Co-workers were typically described as *responsible*, *safety-conscious* and *deliberate* in attitude. There existed some dissatisfaction among the personnel with the current organizational practices, such as the amount of bureaucracy and poor cooperation between the sections. The problems of cooperation had in part to do with strained personal relationships between some individuals.

The climate was considered as somewhat deteriorated over the years. The sense of pride in the company and in the plant was not what it used to be. This was partly due to the recent merging and privatization of the firm. The growing economic focus and the loss of decision autonomy to a (psychologically) distant head office were stressful to the personnel. On the level of daily work and practices, though, few changes were perceived. A slightly increased feeling of haste prevailed, but it was also acknowledged that if something was considered important, the required time could always be found. Nevertheless, little stress was experienced by the workers on the average, even though many reported that they seldom had enough time to do their work thoroughly. Job satisfaction was quite good, a result that the personnel found surprising. It had become a habit in the culture to complain about the organization and the work. This *emergent social dissatisfaction* with the work was reinstated with every publicly uttered complaint. Subcultures that differentiated themselves from others by emphasizing their dissimilarity had formed.

Many employees spontaneously reflected on the norm of certainty. Nobody attributed the norm to himself; rather it was attributed as "everybody here says that you should not do anything unless you are absolutely certain". This *conception of certainty* was thus an *emergent* property of the maintenance culture, reproduced and existing only in the interactions and communication patterns of the personnel.

Conceptions concerning the work and the maintenance task

The goal of maintenance was seen quite uniformly as keeping the equipment in good condition to allow safe (and efficient) production of electricity, but the view on the critical means to achieve the goal varied. Some of the personnel emphasized planning and preventive maintenance, some a proficient and motivated personnel, and some monitoring, identification of fault mechanisms and overview of the plant. These conceptions were not influenced by the task or the organizational level. They thus reflected personal orientations toward the maintenance task (cf. Norros, 2004).

The maintenance work was experienced by many as most meaningful when there were technical problems to solve. The large variety of the tasks and the tasks with high safety significance or time pressure were experienced as demanding. Safety was emphasized with many workers explicitly mentioning safety as an integral part of the maintenance task. Economy was usually added as an afterthought, or mentioned as something that is new to the plant. Some workers also considered economy as potentially threatening to safety or the quality of the work. The results implied that *safety was perceived as the primary criterion of effective maintenance* and financial and hierarchical aspects more as internal requirements or constraints.

Assessment

The following main conceptions that are of special relevance in terms of long-term safety of the plant were identified: the emphasis on specialization, the emphasis on certainty and the emphasis on safety as the only criterion of effective maintenance.

Due to the specific responsibility areas the organization had *drifted* to a situation were some tasks had been personified, which meant that only few (or one) persons knew how to carry out a particular task. The problems of this personification to e.g. flexibility and knowledge transfer to newcomers were acknowledged in the organization. Still, the importance of specialization for safe maintenance was not questioned. The personnel were not willing to extend their responsibility areas or change their routines, e.g. practice job rotation, in order to enhance cooperation. These propositions were experienced as directly endangering safety, whereas the lack of co-operation was something they had learned to cope with and compensate for. Thus, the current lack of co-operation was experienced as endangering safety less than a change in the current practices would.

The way of organizing activities provided little help for coordinating the daily activities. In addition, delays in fault repairs were not monitored at the organizational level, but every foreman had to report the delays in his own area. This resulted in organizational activity where everyone prioritized tasks that were directly in their own area of responsibility. The ability of the organization to fulfil the OCT, and especially the requirement of flexibility was thus hindered by the extensive specialization.

The personnel had strong but sometimes quite narrow conceptions concerning safety. The personnel emphasized the importance of reacting to technical faults over e.g. preventive maintenance and condition monitoring. The fact that inflexible or inefficient maintenance could also be a safety risk was mostly denied. Furthermore, everything that was new and unfamiliar was taken as a potential threat to safety and was thus questioned in the culture. The emergent cultural emphasis on certainty also provided a legitimate reason to question all new ideas as potentially dangerous. Thus, the problems perceived in e.g. the organizing of work and in the division of labor were not to be solved by *new* ways of organizing (cf. Weeks, 2004). Finally, the vagueness of the meaning of personal responsibility in the culture made change even more difficult, since responsibility was something that was based on a history of working together and embedded in the rules and procedures. Responsibility was a collective and emergent property of the system; when things were done the way they had always been done responsibilities were also taken care of (cf. Rochlin, 1999a, p. 1554). The personnel could feel certain that the big picture would be taken into account when everybody did their part accordingly and in the same way as in the past.

The challenge for the organization in the future is to better acknowledge the demands of anticipating and monitoring, as well as those of the associated practices. The demand for reflecting was also hampered by low integration of the culture since information and the expertise of others was not utilized to the extent possible. On the other hand, the personnel were committed to safety and exercised a questioning attitude, both characteristics that are needed in a safety critical organization.

5.3.2 Olkiluoto NPP maintenance unit

Structure and organizing of work

Olkiluoto NPP is owned by Teollisuuden Voima Oy. The company was founded in 1969 by 16 Finnish industrial and power companies. The operating principle of the Company is to supply electricity to the shareholders at production costs to the maximum amount, as safely and economically as possible. Olkiluoto's two BWR type units each operate at a net capacity of 840 MW.

The case study concentrated on the two offices of the Production department in charge of the maintenance at Olkiluoto: The office of mechanical maintenance and the office of electrical and I&C maintenance. The offices consist of a number of groups with a group manager, foremen and technicians. The group manager also attends to the duties of the foremen. The groups work for both plant units. Approximately 120 employees work with issues related to maintenance in the Production department. The average tenure of the personnel was approximately 20 years.

Every morning there is a joint meeting arranged by the operations where the state of the plant and last night's events are reviewed. The foremen from maintenance usually attend the meeting. Foremen utilise the work order system (TTJ), from where they can check in the morning all the planned failure repairs and decide whether or not these belong to their area. In routine tasks, foremen handle the work planning. Two of the most important computer systems in terms of the daily work are TTJ and the system of preventive maintenance (ENKKU). The preventive maintenance tasks are stored in the ENKKU system as well as the information for the calculation of the schedules for preventive maintenance. Failure repairs account for approximately 5 percent of all the work.

At TVO, a system of equipment responsibility areas has been used to organize the work since the mid-90s. At the same time, a comprehensive new information system was taken into use to organize the work, store plant-related information and plan the maintenance activities on short and long term bases (TTJ and ENKKU). The system of equipment responsibility means that the foreman or the group manager "owns" the particular equipment group and plans e.g. the program of preventive maintenance and budget for the machinery. The owner of the equipment plans all the maintenance activities conducted for the corresponding equipment, irrespective of the type of maintenance (electrical, mechanical, instrumentation) required. The owner utilizes experts in the other fields to accomplish this. Plenty of small changes have been made to the plant organization and organizing of maintenance during the years of the plant's operation (Reiman et al., 2006), in contrast to the organization at Loviisa NPP.

Internal integration

Cohesiveness and employee wellbeing were considered as little valued in the maintenance organization. Values related to change and development were also quite low. Cost-effectiveness, safety and hierarchy were the most strongly endorsed values of the organization according to the personnel. The working climate within the groups was quite good on the average, though. Job satisfaction was also quite good. The organization was very solution-oriented; plenty of development initiatives had been carried out at the unit in the previous years, and if some issues worth attention were spotted, they were instantly developed. The personnel characterized their culture as *high in professional pride, development-oriented* and *conscientious*.

Feedback was considered mostly as a negative indication that something had been done poorly. Positive feedback was rare according to the personnel. On the one hand, the personnel emphasized that they themselves usually knew whether or not the particular job had been done well. On the other hand, some people felt that the culture is somewhat problematic in the sense that high quality performance is taken for granted. This leads to a practice in which high quality is a basic assumption and positive feedback is not given, but mistakes and poor quality immediately get attention from the managers. General criticism of leadership and communication practices within the maintenance was also expressed by the personnel.

The system of equipment responsibility had created a lot of debate. Many perceived the idea itself as good, but the system had been *collectively labelled* as bad. The effort it required was experienced as being extra to the regular work. As an idea the system could work as a tool for sharing knowledge and facilitating co-operation: even though the individual has the accountability / responsibility for a particular device, the work should be a shared activity, meaning shared cross-disciplinary and cross-departmental responsibility for the particular device.

Sense of control was mediocre on the average and work stress was quite low, but these differed a lot between the task groups. The foremen experienced significantly more job stress than the other workers did. They also felt that they do not always have enough time to do their job properly. The foremen experienced that most of the responsibility for proper work was on their hands, yet they had quite a lot of “paper work” and analyses which kept them from the field and from supervising their technicians. The perceived lack of sufficient resources and the unequal distribution of labour were experienced as lowering the sense of control and causing work stress. The low sense of control, the weak sense of solidarity and the perceived lack of positive feedback were experienced as the most negative aspects of the culture.

Conceptions concerning the work and the maintenance task

Most of the workers were very proud of their plant and their own proficiency. A central finding in terms of organizational reliability was that the maintenance personnel perceived little inherent uncertainty in the maintenance task itself.

This conception was widely shared, and it was thus not an emergent property (see Section 5.1) of the culture as it was at Loviisa NPP. The maintenance workers at TVO approached the work through the existing procedures and organizational routines. The maintenance work itself was experienced as quite routine-like and the personnel had difficulties in identifying any challenging aspects in their own tasks. It was pointed out that the plant is well-functioning and everybody has sufficient competence to get along with his daily tasks. Competence, sufficient resources, an overview of the plant, continuous improvement, appropriate routines, and adherence to procedures were considered as critical for fulfilling the maintenance core task, but these were mostly considered to be well taken care of (except for resources in some cases). Nevertheless, the functioning of the organization was considered to be strongly dependent on the long experience of the personnel.

"Responsibility" was an ambiguous concept for the personnel at TVO, even though responsibility was emphasised as the cornerstone of maintenance culture. The problem of responsibility is enlarged by the fact that certainty, competence and the ability to know and do well are emphasised as being very high at TVO. On the one hand, it is emphasised that in order to be responsible for something you have know it well and you have to be absolutely certain about it. On the other hand, the ability of the organization to be certain is explained by the responsible and well-knowing personnel.

Assessment

On the basis of the results it can be concluded that TVO has developed quite functional organizational structures and practices in order to respond to the critical demands of the maintenance task. Nevertheless, there are some issues in the culture that require consideration in order to maintain the effectiveness of the culture in the future as well.

The focus of the maintenance organization had for some time been in anticipating the plant condition and conducting preventive maintenance accordingly. This has both advantages and disadvantages. TVO has intensively developed organizational procedures and information systems to facilitate the anticipation and transparency of the activities. The personnel also saw the overall goals of the organization and their own contribution to them clearly, partly due to the well-developed information systems. Nevertheless, anticipating the plant condition was dependent more on the methodicalness of the current activity than on the critical reflection or questioning of the existing approaches. This works efficiently as long as the existing approaches are adequate and are seen as tools and not as mere aims. The tools and the practices do not facilitate the understanding of the functioning of the power plant as well as they could. Furthermore, the uncertainties inherent in the maintenance core task should be better acknowledged (reflected) in the culture.

The foremen considered their work as changed from being on the field to paper work and computer analyses. This did not fit their conception of motivating and good maintenance work. The role of the foremen should thus be clarified and the work load of the foremen balanced. The foremen should be able to better acknowledge how their (new) tasks contribute to the maintenance core task. Six main development issues were proposed to the maintenance unit at the development seminars and in the final report (Reiman & Oedewald, 2003). These were the system of equipment responsibility, working climate, division of labour and workload, leadership and feedback, personal competence and treating uncertainty, transfer of expertise and generation change. A follow-up project with TVO and VTT was started to address the issue of generation change and maintenance of competence. The development themes were also contemplated by the maintenance organization in group meetings after the study.

5.3.3 Forsmark NPP maintenance unit

Structure and organizing of work

The Forsmark NPP (FKA) is owned by Forsmarks Kraftgrupp AB. The company was founded in 1973 by Vattenfall AB and Mellansvensk Kraftgrupp AB. The present owners of the company are Vattenfall (66%), Mellansvensk Kraftgrupp (25.5%) and E.ON. Kärnkraft Sverige (8.5%). Forsmark’s three BWR reactors have a combined output of nearly 3090 MW. The maintenance unit at Forsmark NPP had approximately 180 full-time employees at the time of the case study in 2002–2003. The average tenure of the maintenance personnel was over 15 years.

The maintenance function at FKA was in the aftermath of a major reorganization at the time of the main data collection in the autumn 2002. Even though the main phases of the organizational changes were already implemented, many organizational issues were still under debate (the reorganization had been initiated approximately two years before the time of data collection). Before the reorganization, maintenance activities were distributed so that each of the reactor units had their own dedicated maintenance support-organisation. Within each unit-specific maintenance organization, control was previously exhibited in terms of a line organisation. In the new maintenance organization, the previous specific maintenance functions were centralised into a single maintenance unit and a matrix organization was introduced. Four "business areas" (Operative maintenance, Maintenance projects, Installation, and Analysis & development) controlled and implemented operative maintenance projects that were ordered from the stations at the site (in a much more "businesslike" flavour than previously was the case). In the new organization responsibility for the execution of various maintenance projects was separated from the responsibility for the maintenance resources (the matrix). As usual in matrix organizations, the operative personnel had several "bosses". A technician could conduct work to several business areas under the manager from that area. The line manager "sells" the technician to the particular business area that needs resources.

Internal integration

In the previous maintenance organization, the respective maintenance groups had a clear sense of belonging and ownership. Maintenance culture(s) was, then, associated with reactor units, which also presumably created a set of different maintenance cultures. In the new organization, personnel can be assumed to protect some of the values and norms that belonged to the previous cultures.

The current maintenance organization [at the time of data collection] evoked ambiguous feelings. Several interviewees complained about the matrix form and found it confusing. On the other hand, there were also signs that the new organization had led to a broader scope of work tasks and to positive challenges in one's work. On the downside were indications that the new maintenance organization had led to negative changes in the perceived ownership for the technology, since there had previously been separate maintenance organizations for each of the three reactor units. Several of the interviews included indications of a general cost pressure that affected the maintenance organization: ‘it is talk about costs all the time’ and ‘costs have got too high a focus’. On the other hand, several of the interviewees said that they personally were strong in their ambition to keep the power plant in a state of high quality. (see also Reiman et al., 2006)

The working climate, by large, was judged as good when perceived in the small group context but there were strong signs that the confusion with the organizational structure arrangements affected the working climate negatively in a larger sense. The most frequently mentioned development target was the need to “clarify” the maintenance organization. Comments were also made on the negative effects of the organizational change on climate, personnel wellbeing and trust in management.

Conceptions concerning the work and the maintenance task

At FKA, the uncertainties of the sociotechnical system were more apparent than at Loviisa or Olkiluoto maintenance unit. The personnel at FKA also emphasized the maintenance work as a learning and problem solving task. Reflectivity and learning were currently pointed out as being critical to achieving the goals of maintenance, as were also the attitudes, engagement and flexibility of the personnel. This may have been due to the fact that many workers had new responsibility areas that demanded attention and learning. Economic issues were emphasized as being an integral part of the maintenance core task. This also could have been due to the organizational change, where the cost issues received more attention than in the past. Problems in the internal integration embroidered the conceptions concerning the maintenance to a degree where many of the conceptions of the personnel can be considered as a remonstration against the “official” view.

Assessment

The current emphasis on reflectivity and learning may lead the personnel to question the practices and procedures previously taken for granted. Even some latent failures could be spotted with ‘new eyes’. Nevertheless, the prioritizing of tasks and managing of the increased workload were seen as demanding since the workers lacked the overall picture of the goals of the plant and of the organizational responsibilities. In order to manage the situation, the social aspects of the organization were emphasized by the personnel (e.g. good team spirit). In the long run, however, this kind of a situation is stressful and unmotivating to the personnel. Furthermore, gathering and interpreting systematic information of the entire plant condition is extremely demanding in the current situation. This may lead to increased events because the knowledge concerning the plant's state either does not exist or is not shared sufficiently.

The culture of the FKA was in transition. In practice, the organization was currently focusing on the reacting demand. The significance of the demand for reflecting was emphasized. Nevertheless, the change in the organizational structure also changed the means of reflecting more from formal to informal networks.

In Spring 2003 there was a change in the maintenance organization. The matrix type was abandoned in favour of a more traditional line organization but the centralisation of the maintenance into a single organization was still retained.

5.4 Similarities and differences in the organizational cultures

5.4.1 Cultural value profiles and maintenance core task

The prevalent values in all three organizations were safety and hierarchy, with personnel related values and development values receiving little attention according to the personnel (cf. Klein et al., 1995, p. 782; Skogstad & Einarsen, 1999, p. 298). Critical attitudes towards management and the values prevalent in the organization existed at all the plants. This can have an effect on the workers' perception of their work: For example, Kivimäki et al. (1995) found that critical attitudes towards the goals and values of management were positively related to higher perception of nuclear risk (cf. Harvey et al., 2002). The task groups within the units also differed in their perceptions of the organization. The "shop floor" workers were more critical in their attitudes toward the organization, a finding which is quite common in industrial organizations (see e.g. Cameron & Quinn, 1999; Harvey et al., 2002; McDonald et al., 2000, p. 164). Few indications were found that labour unions affected the employees' relation with management. There were thus subcultures in all the units based on organizational level (Hofstede et al., 1990), but these subcultures were overlapping in many senses and shared many features with each other, as well as had internal differences between individuals (cf. Martin, 2002; Parker, 2000; McDonald et al., 2000, p. 173).

Safety was highly valued at all three plants, and in that sense they all had strong safety cultures. Otherwise the cultural features were quite different, and thus it seems that the culturally accepted means of maintaining high safety differ. Still, even though safety was highly valued, some indications were found that the effect of maintenance on nuclear safety was sometimes poorly understood, and the mechanisms of nuclear safety were not clear to all the workers. Emphasis on safety thus seemed to be in some cases more attitudinal than knowledge-based of the principles of nuclear safety or the safety significance of one's own work (see also Oedewald & Reiman, 2005; Oedewald & Reiman, submitted). Combined with the emphasis on certainty and control prevalent at the maintenance units, the attitudinal safety emphasis can lead to either undue optimism due to an implied strong safety focus or to undue carefulness due to lack of understanding of the possible safety effects of one's own work.

It was common to all the three plants that at a general level the goal of the maintenance was considered to be very clear; maintenance is a prerequisite for reliable production of electricity. The personnel also saw their own work as highly important. Differences were found in the cultural conceptions concerning the maintenance core task at the three organizations. The conceptions of the personnel concerning the demanding aspects of their own job varied between the plants. Coping with uncertainty and sudden technical problems was emphasised at Loviisa NPP. This included technical problem solving as well as managing the complex social organization and the hierarchical rules. At TVO few demanding sides were recalled in the interviews. It was pointed out that the plant is well functioning and that everybody has sufficient competence to get along with his or her daily tasks. Special situations such as the annual outages and large modification projects were seen as demanding and motivating. At FKA prioritising the tasks and managing the lately increased workload was seen as demanding. At all the plants failure repairs and technical challenges were considered motivating.

The results of the three case studies reported in the present study imply that the maintenance units all emphasised some requirement of the maintenance core task (Figure 4) at the expense of the other demands. The emphasised demand also differed between the units. This is hypothesized to be due to interplay of differences in the market situation, technology and organizational culture prevalent at the units. Organizational changes in maintenance activities had also made some features of the task more salient (e.g. emphasis on learning at Forsmark) and put some on the background. A future challenge for all the plants is to organize the maintenance in a way that allows perceiving and fulfilling all the critical demands of the maintenance task. Otherwise the conceptions concerning the organizational core task change in a manner congruent with the prevalent emphasis. The other demands are then no longer considered critical for effective maintenance. Some implications were found that a *cultural drift* in the conceptions concerning the maintenance core task had already taken place at some cases.

5.4.2 Psychological characteristics of the maintenance work

Most of the maintenance workers were proud of their job. They saw maintenance work as very important for the plant safety. The maintenance work produced a feeling of meaningfulness, especially when there were technical problems to solve (cf. Orr, 1996, pp. 95–97). The motivating aspect of the problems and fault situations is a paradox in the sense that one of the goals of maintenance is to avoid problems and keep the technology running reliably. This conception of maintenance work is not optimal in terms of fulfilling the maintenance task, where preventive maintenance, condition monitoring and analysis of the maintenance history of the equipment are important for keeping the production safe and reliable in the long run. As stated in IAEA (2005, p. 6), "constant repairs tend to create a firefighter mentality among the workers, which is further bolstered by both the feeling of satisfaction after the repairs are successfully completed and 'rewards' or praise following a job well done. These feelings contrast starkly with the otherwise mundane and systematic approach of preventive maintenance." (cf. Carroll et al., 1998, p. 102; Thomas, 2005) In the case organizations, the handicraft nature of maintenance work was emphasized. The opportunity to work with the machines motivated the maintenance workers (cf. Cooke, 2002, p. 983). Some workers clearly saw the work as requiring more than manual labour, but they had trouble conceptualizing the nature of this knowledge. Safety was emphasized in the cultures and its importance was taken for granted, but the meaning of safety and the cultural norms concerning the appropriate means to guarantee it were little reflected.

The maintenance work in nuclear power plants is varied by its nature. It requires traditional craftsman skills as well as analytical understanding about the different failure mechanisms, the operating principles of the power plant and e.g. condition monitoring techniques. In many aspects maintenance work is similar to so called knowledge work. However, the maintenance personnel seem to carry a strong craftsman identity. Attending to the machinery, for example when conducting fault repairs, is a crucial source of job motivation. The motivating aspect of the fault repairs partly stems from the fact that they are directly (and visibly) related to the overall goal of the organization; maintaining the operability of the plant.

The importance of a sense of personal responsibility for effective maintenance was emphasized in the case plants. Still, the meaning and content of personal responsibility remained vague, as did the conditions necessary for obtaining the sense of personal responsibility in a complex sociotechnical system such as a NPP. In NPPs, the achievement of a sense of personal responsibility is complicated by strict rules, procedures, and a tendency to emphasize shared responsibility and collective action instead of individual initiative (cf. Rochlin, 1999a; Hackman & Oldham, 1980). Schulman (1993a, p. 43) argues that too localized a responsibility can be dangerous in NPPs, that “actions taken too soon, in too narrow a context, can jeopardize other parts of the system”. On the other hand, diffusion of responsibility can mean that everyone, and therefore no one, will be responsible for doing the job (Snook, 2000; Sagan, 2004). Furthermore, expressing safety concerns could be interpreted as a lack of confidence in co-workers or the system as a whole in organizations where collective responsibility is emphasised (Oedewald & Reiman, 2006a, p. 56).

Hackman and Oldham (1980, p. 75) point out that "[t]he irony is that in many such significant jobs [e.g. an aircraft brake assembler], precisely *because* the task is so important, management designs and supervises the work to ensure error-free performance, and destroys employee motivation ... in the process". The prescriptions guiding the personnel’s conduct (see Schlenker et al., 1994) were in some cases perceived to be so strong that the individual choice, which is needed for personal responsibility to be felt, was not perceived to be present (see also Hackman & Oldham, 1980, p. 75; Hirschhorn, 1993). On the other hand, the impossibility of proceduralizing all the aspects of the maintenance work and the inadequacy of the procedures to cope with the realities and surprises of daily work were acknowledged by many in the case organizations (cf. Hirschhorn, 1993, p. 140; Bourrier, 1996, p. 106; Carroll et al., 1998, p. 106; Dekker, 2003; Dien, 1998; Orr, 1996). A key part of one's professionalism in maintenance seems to be knowledge on how to interpret, apply and neglect the procedures in a manner that work can be carried out.

A cultural emphasis on certainty and control existed at the maintenance units (cf. Perin, 2005). In some of the units, this emphasis was emergent, which meant that it was a property of the social interaction patterns; you were supposed to act with the emphasis on certainty (cf. Ignatov, 1999). At some of the units certainty was a shared cultural feature and uncertainty was neglected or denied. Also individual differences in dealing with uncertainty were found (cf. Norros, 2004). One factor to consider is that all the case plants have been performing well in the past. Starbuck and Milliken (1988, p. 329) argue that "success breeds confidence and fantasy" (cf. Gagliardi, 1986, p. 123). Feeling safe is not, however, necessarily same as being safe (Rochlin, 1999b, p. 10). On the one hand, a certain level of a sense of control is needed in order to be able to act. On the other hand, illusion of control is an error provoking factor (Reason & Hobbs, 2003; Reason, 1990, 1997) as is a (real or perceived) lack of control (Clarke & Cooper, 2004; McLennan et al., 2005). The need to maintain a feeling of being in control over events is very strong (Langer, 1983; Fiske & Taylor, 1991, pp. 197–204; Clarke & Cooper, 2004, p. 9; Weick, 1995; Nuutinen, 2006) and thus probably has an effect on the cultural solutions of any organization (cf. Schein, 2004, p. 265). Low sense of control can lead to compensating mechanisms such as belittling the meaningfulness and importance of one's job, or to the narrowing of one's interest to some specific aspect of the work, such as following the instructions to the letter no matter what happens. Although on the average the sense of control among the maintenance workers was quite high, in some worker groups it was significantly lower. Especially foremen felt they had difficulties in managing their work (see also Oedewald & Reiman, 2005, 2006b).

A challenge for NPP maintenance is to be able to build organizational structures and practices (organizational culture) that would facilitate the following conditions: a sense of meaningfulness that is connected to the task itself, a possibility to see the results of one's own work, a realistic sense of control, and a sense of personal responsibility over the plant (see also Oedewald & Reiman, 2005, 2006a). Furthermore, the personnel should have up-to-date conceptions of the requirements of the maintenance task, and have the ability (competence, tools, procedures, resources) to carry out the task appropriately.

The fact that a large proportion of the work is routine preventive maintenance is a challenge for the safety and reliability of the maintenance. Routine work decreases motivation (Hackman & Oldham, 1980; Carroll et al., 1998, p. 117) and can lead to lower quality or increased slips and lapses due to inattention. Too much routine can be avoided by organizational practices e.g. by the division of the tasks and job rotation. More attention should be paid to offering learning opportunities and challenging jobs to all the workers. For example, modification projects and rare disturbance situations could be exploited better. In addition to their motivation enhancing effect the early acquiescence with the new equipment, for example, contributes to anticipating maintenance needs, including preventive and corrective maintenance (cf. Laakso et al., 1998, p. 33).

The results gave implications that the competence of the employees was by large taken for granted at the maintenance units due to long tenures and abundant training. However, long tenure and experience as such does not guarantee competence (cf. Norros, 1995; Klemola & Norros, 1997; Rogalski et al., 2002; Shanteau et al., 2002). Long tenure can also lead to routinisation. Experience is then no longer a benefit, but can actually be a source of errors when the work and its outcomes are not actively reflected upon (cf. Starbuck & Milliken, 1988, p. 323). Routine tasks are a major source of incidents (e.g. van Vuuren, 2000; Reason & Hobbs, 2003; Laakso, 2006). Furthermore, new technology, new job contents and working practices, and new demands placed on maintenance set new requirements, which means that some of the old habits and out-dated conceptions have to be unlearned.

5.4.3 Changes in maintenance work

The evidence from the case studies indicated that the content of the individual jobs is gradually changing in the maintenance work. The role of foremen has especially changed from participating in the field work to supervision of work on the computer, planning the work and analysing data concerning the maintenance and fault history of equipment (i.e. reflecting in Figure 4). This change evoked mixed feelings. Some foremen were afraid of losing touch with the field work, their workers and the machines. However, the enriched job content was perceived as challenging by some. Furthermore, the current focus on strategic optimization and new information technology can threaten the traditional conception of proficiency (based on handicraft skills and practical experience) among the personnel. The new expectations created by the new technology are not congruent with the old cultural conceptions of a skilled worker. The personnel do not want to see the machinery as merely numbers on a computer screen or data base, but as concrete objects to work and play with (cf. Orr, 1996; Zuboff, 1988).

Maintenance activities have been under various restructuring initiatives (see also Kecklund, 2004). These changes were perceived as stressful and causing uncertainty among the workers (see also Reiman et al., 2006). The personnel's experiences were not merely resistance to change; they were also genuine worry about the safety implications of the changes. This may have an effect on the commitment and trust of the personnel towards management. McDonald (2001, p. 223) warns that organizations that are based on unofficial practices are especially vulnerable to changes (in technology, organizations, personnel). Maintenance belongs to that category. The cultural emphasis on certainty prevalent in the case organization and the vagueness of personal responsibility make any change initiatives in the maintenance units demanding; they either have to be justified from a perspective that fits into the prevalent cultural conception of the work, or the conception of the work has to be changed (cf. Weeks, 2004, p. 104, p. 121). For example, financial goals that came with the privatization of Loviisa NPP did not fit into the personnel's cultural picture and were thus neglected by them. The *resistance to change* in the organization was actually at the same time *commitment to maintaining safety* and commitment to the practices that in their opinion were needed to guarantee safety.

In contrast to the prevalent cultural conceptions, the maintenance task modelling showed the knowledge intensive nature of the maintenance work. Maintenance has often been considered as mostly manual labour, which requires little or no mental work. This correlates also to maintenance quite often being at the bottom of the hierarchy (in comparison to e.g. technical support and operations) in terms of respect, influence and authority at the NPPs (Perin, 2005, p. 75; Mercier, 1988, p. 14; cf. Hopkins, 2005, p. 85). Mercier (1988, p. 14), for example, argues that NPP maintenance work suffers from a “dirty hands” image. Perin (2005, p. 262) states that “given the significance of maintenance activities to risk reduction in all high hazard industries, in this twenty-first century a “dirty hands” image marks a cultural lag of “gigantic” proportions”. The nature and significance of maintenance work should be better acknowledged by the maintenance workers themselves and by other parties (e.g. operations and technical groups). This study found some evidence of an image problem at the case plants. An emphasis on the manual labour requirement of maintenance instead of the knowledge-intensive aspects depicted in the core task model was also discovered (see Figure 4).

5.5 Assessing the organizational culture in complex sociotechnical systems

There are three main reasons for assessing organizational culture: First, the demands of the OCT are not always obvious to the personnel at every level of the organization or to the outside observer. This is especially so in complex sociotechnical systems where the uncertainty and ambiguity of information are prevalent and the effect of local changes to the entire system is difficult to notice (cf. Norros & Nuutinen, 2002; Rasmussen, 1997; Norros, 2004; Dörner, 1989). Second, the organizational culture influences the personnel's definition of the organizational core task (or, to phrase it more accurately, the personnel's definitions of the OCT are one element of the culture itself, see Figure 3). The personnel's conceptions of the organizational core task are thus historically constructed and rooted in the culture of the organization and as stated, they are not inevitably uniform. Third, the organizational core task is not static (cf. Nuutinen, 2005). For example, a nuclear power plant sets the same technical constraints (e.g. radiation, redundant safety systems, time lags on feedback of activities) to the activity but the environment might change (e.g. deregulation of the electricity markets, political pressure and regulations) and set new demands for organizational safety and effectiveness. The constraints and requirements that stem from the concrete object of the work might also change. For example the aging of the technical infrastructure generates new phenomena (e.g., corrosion or increase in the frequency of technical faults). Thus, the appropriate means to fulfil the OCT also change.

5.5.1 Extracting the criteria by modelling the organizational core task

Contrary to CTA (Norros, 2004), the focus in OCT modelling is on the organizational level and on the general demands of the work domain. The OCT frames the motive of the activity and the shared constraints and requirements that all the workers have to take into account in all their tasks (actions, see 5.4). The methodology strives to avoid a purely cognitivistic or error-focused approach in assessing the activity in complex work settings (cf. Hutchins, 1995; Norros & Nuutinen, 2002; Norros, 2004, p. 67). The focus is not on the specific tasks, single acts or individual cognitive processes but on the boundaries and requirements of the activity in the entire sociotechnical system.

The object of the work (e.g. particular power plant, manufacturing plant, or offshore platform) and society and environment (e.g. deregulated electricity market, harsh winter weather) set constraints and requirements for the fulfilment of the organizational core task (e.g. producing electricity safely and efficiently by light boiling water nuclear reactor to the electricity market at a competitive price). Certain constraints and requirements for the organizational activity follow from these components of the OCT (see Figure 3). Constraints refer to the boundaries of activity imposed by the environment, the object and the objective of work, irrespective of who is carrying out the task, and with what tools and division of labour (cf. Vicente, 1999). Requirements refer to the features of the core task that should be taken into account in the activity (cf. Norros, 2004, p. 67). Together these set demands for the organizational core task.

In the core task analysis, as in traditional task analysis, we first define the object, goals and subtasks of the activity in question. When modelling the OCT of a complex sociotechnical system it is not sufficient to decompose the task into sequential subtasks and single acts and determine the criteria for correct actions. Additional demands caused by coordinating the work in the entire system would be missed, as would the need for identifying the boundaries of safe activity in the entire system. In dynamic systems the work is never linear, predictable and perfectly rule bound. Situations are unique, but they share certain common constraints and requirements stemming from the overall goals and the characteristics of the object of work. Thus, it is necessary to model the boundaries of the organizational activity and not only the work activities themselves (Rasmussen, 1997, 2000; Vicente, 2000). Thus, the aim of CAOC is to model the shared demands applying to all activity in the organisation. As a first step toward conceptualising the shared demands the objective of the work and the characteristics of the object of work are extracted in an analysis of the research data. Characteristics of the object of work (e.g. age of components, design basis and technical specifications of the plant) and the objective of the work set constraints and requirements for the organizational core task. Furthermore, society and environment set requirements and constraints that have to be taken into account in the organization.

Rasmussen (1997, 2000) argues that modelling activity in terms of task sequences and errors is not effective in understanding behaviour in dynamic socio-technical systems. Rather, the focus should be on “the mechanisms generating behaviour in the actual, dynamic work context” (Rasmussen, 1997, p. 190). Rasmussen (1997, p. 191) writes that “rather than striving to control behaviour by *fighting deviations* from a particular pre-planned path, the focus should be on the control of behaviour by *making the boundaries explicit and known* and by giving opportunities to develop *coping skills at boundaries*.” The OCT represents the boundaries of safe and effective activity of the organization, and the “mechanisms generating behaviour” are made explicit in the cultural analysis.

Figure 5 illustrates the analysis framework that was used in the maintenance core task modelling. A simplified version of the framework was reported in Oedewald and Reiman (2002) and in *Article I*. A preliminary version of the framework was made by analysing the interviews and two group working session at Loviisa NPP where the characteristics of the object and the objectives of maintenance were modelled. The framework was then revised in one meeting with the project group and by reviewing the literature on characteristics of work in complex sociotechnical systems (e.g. Vicente, 1999; Perrow, 1984). It was later reviewed and slightly revised by working in a group with maintenance experts from TVO (see Table 2).

CHARACTERISTICS OF THE OBJECT	CONSTRAINS	REQUIRES	OBJECTIVES
Complexity with tight or loose couplings	-tasks with different degrees of complexity and coupling -unplanned incidents - tasks with different significance to safety and reliability	-tasks have to be planned and co-ordinated -documentation of committed operations -slack resources -understanding of the safety significance of different work tasks	The goal is to keep the plant in such a condition that it can be operated, and take all the boundaries (safety, economy, public acceptance) into account To maintain the value of the plant at the same good level at minimum.
Safety-critical nature -risk of core damage	-redundancy -process-related systems and safety-systems -unavailability times	-tasks have to be accomplished within pre-specified time limits -taking nuclear safety into account -deviations have to be reported and investigated	
Radiation	-closed spaces, time limits -risk of external release	-radiation protection and control -concentration of work to outage situations	
Ageing and physical changes	-information about plant condition becomes outdated -unplanned incidents	-continuous plant condition monitoring -equipment have to be renewed	
Loosely coupled social system	-distributed knowledge and skills -unplanned interactions	-co-operation and co-ordination load -shared goals and methods	
Mediated interaction with machinery	-uncertainty of information -time lags for feedback	-active information acquisition -active information management	
The amount of electricity produced	-minimum downtime	-planning of maintenance activities	

BOUNDARY CONDITIONS
-laws and regulations
-technical specifications of the plant
-the way of operating the plant (1 refueling outage/year)
-market economy
-public opinion
-infrastructure

Figure 5. The analysis framework that was used in the maintenance core task modelling.

After the requirements and constraints for activity have been extracted, the next stage of the core task analysis is to group the identified constraints into categories and name these categories as critical demands for the activity. Figure 6 depicts the critical demands of the maintenance core task and the associated constraints as identified in the core task modelling (*Article I)*.

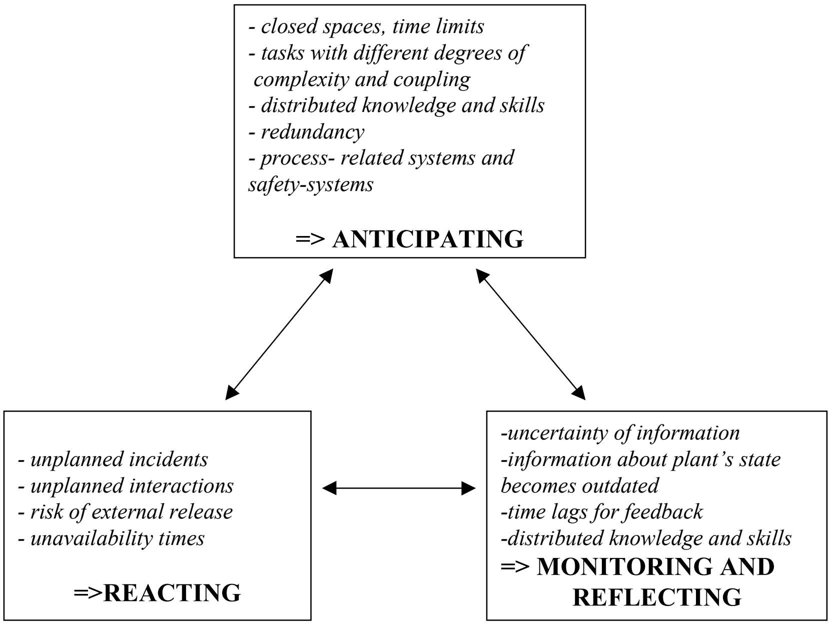

Figure 6. The critical demands of the maintenance core task and the associated constraints.

The need to balance the critical demands creates additional demands (cf. Reiman & Norros, 2002). We have called these demands instrumental demands, since they facilitate the fulfilment of the critical demands. The resulting model of the maintenance core task was presented in Figure 4 in Section 5.1. Working practice demands were abstracted from the requirements depicted in Figure 5 and grouped to corresponding critical and instrumental demands. Multiple and sometimes conflicting goals are a characteristic of complex sociotechnical system (Dörner, 1989; Rasmussen, 1997; Dekker, 2005). Conventional task analyses are not good at picking up these goal conflicts (Woods et al., 1994, p. 86). The critical demands can be considered as (potentially conflicting) subgoals of the system. Fulfilment of the OCT requires fulfilment of the critical demands as well as fulfilment of the instrumental demands that arise out of the inherent conflicts and discrepancies between the critical demands. OCT thus requires successful balancing of the critical demands. This sets requirements for the organizational culture.

5.5.2 Focusing the assessment on the cultural conceptions

As depicted in Appendix D, the CULTURE-questionnaire gives information on how the job characteristics are *experienced* by the employees and what the employees *perceive*. The cultural elements (Figure 3) of structure, integration and conceptions influence the psychological states of meaningfulness, knowledge of expectations, sense of personal responsibility and sense of control. Thus, by measuring the states we gain information on how the elements of the organizational culture are experienced subjectively. This means how the person perceives the space of the activities “allowed” by the organizational culture as depicted in *Article V*. The next phase is to contextualise the analysis and concentrate on the meaning of the cultural elements in terms of their effectiveness. This means firstly the modelling of the organizational core task as described in Section 5.5.1 and further analysis of the cultural conceptions concerning the organizational core task. The core task model provides an analytical tool with which to focus on the functionally relevant aspects of the organizational culture. The cultural conceptions are then inferred iteratively from the research data. Conceptions are abstracted in two different ways: (1) according to predefined dimensions, such as what is considered as demanding in work (see Appendix A) or how the meaningfulness of the work and organizational values are related (questionnaire, see Appendix D), and (2) emerging themes based on grounded theory analysis of the data, such as discourse on certainty or responsibility in the interviews, work groups and seminars, or surprising correlations between individual variables in the questionnaire. Emergent conceptions manifest in e.g. interviews (“everybody here says that, but I do not personally agree”) and by comparing questionnaire data to the “public opinion” at the seminars and the working groups.

The cultural assessment is made by qualitatively evaluating the characteristics of the organizational culture against the extracted demands of the work. The demands of the core task can be depicted graphically as illustrated in *Article I* or in a table format as illustrated in *Article IV*. Each element of the organizational culture and its corresponding characteristics are evaluated against each extracted demand. The assessment of all the cases was specified for the present study. An interpretation of the cultural conceptions embedded in the practices and tools was made by the author. The conceptions can be either reasons for the practices, or the practice or a tool has generated the conception in the culture. Both influences are present in organizations. It is often impossible to reason whether some conceptions existed before the current tools were taken into use or whether the tools helped to create (and embed) the conception into the organization.

The aim of the assessment is not on seeking causal relations to some objective measures. Instead, the aim is to anticipate the consequences of the current conceptions and practices in the organization for the fulfilment of the demands of the maintenance task, and to clarify the role of technical solutions (including tools) in embedding the conceptions concerning the work. Furthermore, we are interested in how the personnel take the constraints and requirements of the OCT into account (cf. Norros, 2004, p. 65) in their work. The conceptualization of the OCT helps to understand why certain situations and tasks are experienced as frustrating or stressful by the personnel. Furthermore, and importantly, it is also possible to show that certain practices and routines may either be based on a presently inadequate conception of the OCT, or they may in the long run lead to false conceptions. These flawed conceptions and underlying assumptions can lead to creation of artefacts (procedures, practices, rules) that maintain and recreate this imperfect mental representation of the OCT.

Organizational safety and effectiveness is achieved when the cultural way of responding to the core task demands is adequate and based on an accurate conception of the OCT (Figure 3). Furthermore, the organization needs to maintain reflectivity towards the possible changes in the requirements of its core task, and towards a "practical drift" (Snook, 2000) and “fine-tuning” (Starbuck & Milliken, 1988) of the practices and the organizational activity. Practical drift means a gradual local optimization of working practices that does not necessarily take the entire OCT into account (cf. Rasmussen, 1997; Leveson, 2004, p. 247; Dekker, 2005). Snook (2000, p. 194) writes: “Practical drift is the slow steady uncoupling of practice from written procedure ... After extended periods of time, locally practical actions within subgroups gradually drift away from originally established procedures ... Constant demands for local efficiency dictate the path of the drift.” Fine-tuning means multiple, incremental experiments to adjust the system and is thus more conscious and deliberate than drift. A *cultural drift* could also mean a gradual change in the norms of the entire organization.

A theory that would be able to anticipate and prevent accidents should be “sensitive to the creation of deficiencies, not just to their eventual presence”

(Dekker, 2005, p. 34). Inaccurate conceptions can gradually create deficiencies, direct the organizational adaptation in the daily work (drift), and create and maintain unsafe practices and associated tools. The organization and its members create and recreate the context in which future behaviour occurs. The conceptions concerning the OCT are of crucial importance in directing this process. Inaccurate conceptions of the OCT can lead to a selection of inappropriate criteria for the activity. Even "errorless" conduct by the personnel can thus lead to an accident if they are acting on the basis of flawed conceptions of the constraints and requirements of the organizational core task prevalent in the organizational culture (cf. Dekker, 2005; Vaughan, 1996). Furthermore, organizational culture is constantly changing, and these changes can affect the cultural conceptions. For example, when small changes in practices (drift) do not lead to an accident, the organization will "begin to believe that past success is a guarantee of future safety" (Dekker, 2005, p. 63; Starbuck & Milliken, 1988). Their conceptions of the OCT thus move closer to or cross the actual "boundary" (cf. Rasmussen, 1997) of safe and effective activity. Introduction of new information systems or other technology can also direct attention to certain aspects of the core task and gradually change the conception of what is critical in the work (cf. Zuboff, 1988; Hutchins, 1995). Unsafe or ineffective practices are thus made legitimate and seemingly safe in the culture.

The focus of organizational assessment as we define it should thus be on the OCT-related conceptions in the given organization. To simplify, poor formal organizational practices and tools combined with adequate conceptions of the OCT are better than currently functioning tools and practices combined with deficient or out-dated conceptions of the OCT. For example, this can mean a situation where current practices maintain a false conception of the OCT since they work well enough in the normal daily work, but some critical aspect of the OCT tends to be ignored because it does not manifests itself daily (e.g. bypassing a radiation check at a NPP in a room where there has never been radiation before), or its effects are long-term and difficult to perceive (e.g. monitoring the effect of corrosion on machinery), or it becomes relevant only in a case of exceptional conditions (e.g. simultaneous failure of redundant safety systems). The focus on conceptions gives us a better chance to predict (the direction of) a drift in the practices beforehand and to identify the practices and conceptions that are no longer adequate.

6. Discussion

The aim of the present study was to develop and test a methodology for the assessment of organizational culture in complex sociotechnical systems. Contextuality and interpretativeness were taken as the cornerstones of the methodology. The concepts of organizational culture and organizational core task were operationalized and tested in case studies. Three case studies of cultural assessment in NPP maintenance organizations were described along with the emerging cultural assessment methodology. The results indicated that organizational culture in complex sociotechnical systems can be characterized according to three qualitatively different elements. The three elements of organizational culture in complex sociotechnical systems are as follows: structure, internal integration, and conceptions (Section 5.1). On the basis of the organizational core task modelling in the case studies, three critical demands of the maintenance task were abstracted: anticipating the condition of the plant and conducting preventive maintenance accordingly, reacting to unexpected technical faults, and monitoring and reflecting on the effects of maintenance actions and the condition of the plant. The overall objective of the maintenance activity was defined as follows: maintaining the operational reliability and the economic value of the nuclear installation so that the power production can continue as long as planned (Section 5.2). The case plants differed on their emphasis on, on the interpretation of, and on the culturally accepted means of carrying out the demands of the maintenance task (Section 5.3). Despite this they shared similar conceptions about the goals of the maintenance and about the paramount importance of safety in the maintenance of a NPP, but sense of control, sense of personal responsibility and organizational changes emerged as psychologically challenging issues in all the plants (Section 5.4). Finally, it was illustrated how focusing on the cultural conceptions concerning the organizational core task allows an assessment of complex sociotechnical systems (Section 5.5).

The case studies and the theoretical work done in the present study provide evidence indicating that organizational cultural perspective to complex sociotechnical systems provides additional insight (both practical and theoretical) compared to human error, HRO and NAT perspectives. *Conceptions concerning the work and the organizational core task* were identified as the core element of organizational culture (Figure 3). The organizational core task (OCT) was defined as the shared objective of organizational activity. It was proposed that assessment of organizational culture in complex sociotechnical systems should focus on the cultural conceptions concerning especially the OCT. The conceptions can be shared among the personnel, emergent in the organizational culture or embedded in the tools and practices. It is postulated that organizational safety and effectiveness are achieved when the cultural way of responding to the core task demands is adequate and based on an accurate conception of the OCT (Figure 3).

Three elements of organizational culture were abstracted (Figure 3). The structure element of culture corresponds closely with Schein's (2004, p. 26) "artifact level" of culture. However, the two other elements of internal integration and conceptions do not correspond with Schein's (Ibid.) levels of "espoused values" and "basic assumptions". The elements of culture are not levels, from surface to deep. Rather they are qualitatively different elements of the organizational culture which in interaction influence organizational activity. Conceptions can be embedded in the structure and structure can create the preconditions for internal integration. Conceptions also differ from assumptions in that they evolve and change as the tools and practices change. Actually, in our conceptualization the basic assumptions in Schein's model (Ibid.) would belong to the internal integration element, since basic assumptions are by his definition *shared* ways of perceiving, thinking and feeling. Finally, contrary to Schein's model (1985, 2004), all three (Figure 3) are part of the organizational culture, not mere manifestations as the upper two levels of Schein's model are. Nevertheless, it is acknowledged that Schein's model served as a starting point (see Section 4.1) and a strong inspiration for the present framework (see Reiman & Oedewald, 2002a).

The concept of organizational core task differs from the older concept of primary task (Rice, 1958, 1965; Miller & Rice, 1967) in some important respects. Miller and Rice define the organization's primary task as a task the organization must perform in order to survive (Miller & Rice, 1967), or the task the organization was "created to perform" (Rice, 1958, p. 32). According to Hirschhorn the primary task "reflects people's practices, rather than their beliefs ... [and] it is useful to define the primary task as the ensemble of [the organization's] primary practices, that is, these practices which make manifest its actual goals" (Hirschhorn, 1999, p. 7). The concept of primary task is more descriptive than normative in nature. It seems to refer both to the culture of the organization (the task it is actually carrying out) and to the "objective" task the culture originally created itself to perform.

Several cultural phenomena that affect safety and effectiveness of the organization were discovered in the case studies. First, *collective labelling* (cf. Weeks, 2004) of certain issues as e.g. bad or insignificant created a bias for future interaction with these issues. Second, *emergent cultural conceptions* are norms which "have a life of their own", even though the individual persons might understand them to be counterproductive for the effectiveness of the culture. The self-reproducing nature of conceptions makes them difficult to challenge or change. Third, *embedding of the conceptions* in the artefacts and structure of the organizational culture makes it difficult to reflect on the meanings and alternative uses of the tools and practices in the culture (cf. Wright, 1994a; Hutchins, 1995). Fourth, *drift of working practices* or *cultural drift* of the norms or conceptions (cf. Vaughan, 1996; Snook, 2000; Dekker, 2005) might create unsafe practices or conceptions to the culture which are not actively reflected upon. Fifth, the *normalization of accuracy* leads to diminished reflection of working practices and conceptions, as well as to unrealistically high sense of control. Sixth, the *personal interpretation of the cultural elements* (cf. Martin, 2002) affects perceptions of one's own work, most importantly sense of control and sense of personal responsibility. Finally, the tendency to create *cultural distinctions* within the organization as a form of we-versus-them categorizations (cf. Parker, 2000; Haslam, 2004; Turner, 1991) overemphasises the differences in attitudes and values (internal integration) even when the groups share a similar view on e.g. the organizational core task. These phenomena necessitate the consideration of all three elements of organizational culture (Figure 3) when evaluating the effect of organizational culture on the effectiveness of the organization. For example, safety culture assessments often focus on the internal integration elements, whereas safety management systems concentrate on the structural elements of the culture (cf. Introduction). Both are needed, as is the consideration of the cultural conceptions embedded in the structural elements and (re)produced by the internal integration elements.

Next, we will discuss the general results concerning research on organizational culture in complex sociotechnical systems and the limitations of the study and future research needs.

6.1 Studying the organizational culture of complex sociotechnical systems

The cultural approach depicted in this dissertation has connections both to the HRO theories and to NAT (see Section 1.2). The study has contributed to these theories by clarifying the concept of organizational culture, by providing methods for assessing its features and by pointing out the dynamics of culture that either prevent or allow the organizations to function as HROs. However, the emphasis and aims of CAOC differs from that of HRO or NAT. The CAOC strives to be more contextual and evaluative than HRO and NAT research. The aim is not to seek generalizations and common characteristics of high reliability organizations but to assess an individual organization against relevant criteria and give recommendations for appropriate measures. This is due to the fact that when working with safety critical organizations we acknowledge, in addition to the advancement of scientific theory, the need of research to contribute to the practical development of safety and effectiveness at that particular organization. In CAOC, this is accomplished by facilitating dialogue in the organization during the research process, by providing development targets and "self-invalidating predictions" of future incidents on the basis of the assessment, and by contributing to the development and implementation of new tools and practices. Also the tradition of descriptive organizational culture research (see e.g. Smircich, 1983; Frost et al., 1985; Sackmann, 1991; Kunda, 1992; Schumacher, 1997; Parker, 2000; cf. Geertz, 1973; Smircich, 1983) might be more applicable in safety critical domains if it devoted attention more systematically to the demands of the work the organization is carrying out.

Recently, the term *resilience* has been introduced into safety science (Hollnagel et al., 2006). Dekker (2005, p. 45) writes: “Organizational resilience is not a property, it is a capability: A capability to recognise the boundaries of safe operations, a capability to steer back from them in a controlled manner, a capability to recover from a loss of control if it does occur.” In a book called “Resilience Engineering”, Woods and Hollnagel (2006, p. 3) argue, “safety is created through proactive resilient processes rather than reactive barriers and defences”. The present study provides concurrent evidence to this. Organizational culture and the cultural conceptions concerning a safe and effective way of working (the OCT) are crucial in creating and maintaining these “resilient processes”. Safety in complex sociotechnical systems cannot be understood or managed without understanding the demands of the organizational core task and managing the dynamics between the three elements of the organizational culture. Safety (or an accident) is an emergent property of this dynamics. Proactivity of the organization is dependent on the up-to-date cultural conceptions concerning the organizational core task and its demands ("the organization's model of how it creates safety" in Woods' [2006, p. 22] terms). Furthermore, the conceptions embedded in the tools, practices and daily routines of the work should be reflected. For example, outdated tools can maintain a false image of the present core task or its demands (cf. Hutchins, 1995). The current tools and technology both facilitate and constrain organizational performance (Orlikowski, 1992, p. 411). Unsuitable or outdated work practices or tools can also gradually change the conceptions concerning the OCT and thus legitimize activities that are (no longer) actually safe.

The most genuine and far-reaching idea in the safety culture concept is its preventive nature (IAEA, 1991). With (safety) cultural thinking, you do not wait until the organization is "sick", and then cure it by some form of intervention[15]. With (safety) cultural thinking, development initiatives can be made without any visible signs of degradation in the safety or effectiveness. The underlying assumption is that it is always possible to enhance safety and further that only by changing can a constant level of safety be maintained (cf. Feldman, 2000; Tsoukas & Chia, 2002). Hence the motive for assessing and developing the (safety) culture regularly.[16] Minding this, it is disadvantageous that the indicators currently used for safety culture research so often come from the number of accidents, and the criteria for good safety culture are the lack of accidents or incidents along a certain time span in the history of the organization. We have proposed that in complex sociotechnical systems it is both necessary and possible to analyze the safety and effectiveness of the organization by simultaneously assessing all three elements of the organizational culture.

The link between organizational culture and organizational effectiveness has been much debated starting from the seminal work by Peters and Waterman in 1982 praising the significance of culture for organizational excellence (Siehl & Martin, 1990; Alvesson, 2002, p. 68; Hofstede et al., 1990; Wilderom et al.,

[15] The "sick organization" metaphor is common in many consultancy approaches (cf. Levinson, 2002; Schein, 1985, 1999; Kets de Vries & Miller, 1986).
[16] For improving safety culture in NPP maintenance, see IAEA (2005).

2000; Sorensen, 2002). Wilderom et al. (2000) have examined the culture-performance link and they identified the published empirical research that had addressed the question. They found that in the studies both the operationalisation of the independent variable (organizational culture) and the dependent variable (organizational performance) varied greatly. They also note that many of the studies claim a link between cultural consistency (defined also as strength, intensity, or homogeneity) and short-term organizational performance. They conclude that the evidence of a link between the cultural strength and performance is "insufficient" (cf. Saffold, 1988; Alvesson, 2002). Furthermore, in most of the studies Wilderom et al. (2000) reviewed, culture and performance were measured simultaneously, so the question of causality remains unanswered. How does then cultural theory enhance the understanding of accidents and reliability? And what is the effect of organizational culture on safety? Considering the complex sociotechnical system as an organizational culture, the question becomes larger: what is safety and how is it accomplished in an organizational setting? Then one must no longer look for *the* effect of organizational culture on safety, but rather the effects of different elements and contents of the culture on safety (cf. Hale, 2000, p. 5). Organizational culture does not thus *cause* accidents (or safety), but the contents of the culture might contribute to accidents or safety (e.g. counter-productive conceptions or inadequate practices). The problem with this approach is that it makes the cultural theory more difficult to falsify (cf. Bacharach, 1989; Sayer, 1992). It should, however, enhance its utility in terms of its ability to make more accurate predictions. The falsifiability of these predictions is in turn hampered by the interventive nature of research, where some predictions are made in order to decrease the probability of them ever coming true. The need to balance scientific rigour with practical relevance leads us to the last section of the present study; limitations and future research needs.

6.2 Limitations of the study and future research needs

The basic premise of this dissertation is that the cultural conceptions influence organizational performance and thus safety and effectiveness of the organization in the long run. Performance, however, was not measured in this study. The premise has thus not been validated in this study, and we have to rely on the evidence of other researchers (e.g. Sandberg, 2000; Norros & Klemola, 1999;

Klemola & Norros, 1997; Carroll et al., 1998; Norros, 2004). The CAOC methodology emphasizes subjective measures such as perceptions and conceptions. In the future, more objective measures and indicators could be incorporated into the assessment method for validation purposes. The central challenge in terms of validity of the cultural assessment is how to conceptualize the objective demands of the organizational core task and the prevailing subjective cultural features in such a manner that the researcher is able to reliably assess their "fit". The results are always incomplete and remain as hypotheses (cf. Sayer, 1992, p. 67), a fact, which has to be taken into account when using the results in the development work and when reporting the results to the scientific community. On the other hand, in CAOC it is made explicit that some features of the task might be cultural artefacts and even though they are a part of the current work culture, they do not necessarily contribute to the OCT. Thus, the methodology promotes critical reflection of the current organizational practices and their premises.

Even though the cultural approach to the organization is a holistic approach, it cannot – and should not – cover everything. By concentrating on the cultural conceptions concerning the organizational core task we are able to concentrate on a critical element of organizational culture affecting safety and effectiveness. Nevertheless, by highlighting some aspects of the organization, we are clouding others. For example, individual human errors due to inattention, violations made by frustrated or mentally unstable workers, mistakes, mishaps, slips and lapses might still occur that have nothing to do with organizational culture or cultural conceptions. They might affect them afterwards, of course, when the significance of the event is being debated in the culture. Sagan (2004, p. 17), when discussing the influence of Normal Accidents theory, writes that "many of the most well-known catastrophes … may have been normal accidents, produced by baffling complexity and by tight coupling, but others were caused by more traditional, prosaic problems such as single component failures, sloppy operations, drinking on the job, or failure to invest in even the most simple of precautionary safety systems in some developing countries". Clearly these organizations were not High Reliability Organizations either. What these organizations did have were organizational cultures with structural elements, integration elements and cultural conceptions concerning the work and the organization. It is impossible to say whether an analysis of these might have prevented the accidents. Simple human error barriers or safety audits by e.g. the regulator might have sufficed in some cases.

The above-mentioned limitation of the methodology brings us to an important specification. The methods and methodologies that seek to enhance safety of already high-performing organizations (such as the case organizations in question) are not intended to replace, but rather complement, the methods already in use in these organizations. Safety barriers (such as checklists, redundant systems, and work permit procedure) and human error analyses help to prevent and mitigate errors of omission and commission in various tasks. Safety culture training seeks to promote values of safety and deliberation among workers. Safety management and safety management systems direct attention to issues relating to safety performance and offer systematic ways of setting and monitoring safety indicators. These methods help to enhance the overall safety of the complex sociotechnical system, *up to a point*. As has been debated by e.g. Rasmussen (1997), Amalberti (2001) and Dekker (2005), additional improvements in safety are very difficult to come by with traditional methods once the system is already "almost totally safe". We have argued that by concentrating on the OCT conceptions, it is possible to detect the practices and conceptions that are not adequate for the fulfilment of the OCT before any series incidents happen. Furthermore, discussion of the organizational core task requirements in the organization facilitates dialogue and critical reflection of the basis of the current tools and practices. Cultural assessment can also act as a starting point for the development of incident reporting systems, human error barriers, safety culture training courses etc. The assessment provides an overview of the challenges of the organizations, as well as ideas for the best way to introduce new concepts and tools. In some cases, introducing new tools to an "old" culture does not provide the benefit that is sought by them, since they are used according to the old conceptions.

Due to practical reasons (mainly access to the NPPs and their schedule) the data collection methods and their execution (e.g. the number of interviews) had to be planned well in advance. Thus, the emerging themes and questions (cf. Charmaz, 1995, p. 31) could only be addressed within the constraints of the data collection plan, and the nature and extent of the data already collected. Group working and the development groups formed later acted as an important place for testing of the emerging themes and raising questions for discussion. Furthermore, some of the emergent themes from the Loviisa NPP case study (such as sense of personal responsibility and emphasis on certainty) could be tested and elaborated in the TVO and FKA case studies. Still, not all the principles of iterative data collection could be satisfied in this case study. Also the predictive validity of the extracted criteria of the maintenance work could not be tested in the case studies. Some of the emerged topics are listed as possible research questions for future studies at the end of this section. The use of interview material might have also in some cases been subject to the holistic and elitist biases of qualitative analysis (Miles & Huberman, 1994). This means that some verbally expressive individuals might have influenced the analysis unduly. On the other hand, it can be hypothesized that these individuals also have a stronger influence on the organizational culture than others.

The specific methods comprising the CAOC methodology and the assessment procedure require more theoretical as well as empirical work. For example, the question of generalizing from the interviews into the case population (cf. Sayer, 1992, p. 240) is not adequately solved in the current methodology as introduced in the present study. The criteria for generalization are researcher-dependent and based mostly on implicit criteria and rules-of-thumb (such as more than half of the interviewees raising the same issue). Another issue concerns the use of surveys to measure organizational culture. The discussion on the use of surveys to measure organizational culture is abundant (see Denison, 1996; Glendon & Stanton, 2000; Guldenmund, 2000; Rousseau, 1990; Schein, 2004, pp. 206–207). Method triangulation has been proposed by many to compensate the limitations and biases of any one method. With the survey method we can get information on the perceptions and conceptions of the personnel concerning the given issues that are measured, in this case about how the elements of the organizational culture are perceived. Interviews are needed to deepen the understanding of the cultural conceptions concerning safety, work and the organizational core task prevalent in the organization. The way of tailoring the survey after the interviews also helps to focus some of the questions on the specific aspects of interest in the given organization. CULTURE-questionnaire has been internally validated in numerous case studies in the nuclear and other domains (see Appendix D). A need to add in the future more specific questions about the safety significance of one's own work and about the need for situation awareness in the work to the interview themes (Appendix A) was discovered during the course of the study. Still, the validity and reliability of the specific measures that have been developed within the CAOC framework require further testing.

In terms of methodological development the biggest limitation of the current study is its focus on only one work domain, namely NPP maintenance. The applicability of the proposed CAOC methodology in other domains has to be tested before firm conclusions about the validity of the methodology can be made. The CAOC methodology has subsequently been applied in e.g. metal manufacturing (Oedewald et al., 2005a, 2005b), health care (Oedewald & Reiman, 2006b) and NPP engineering.

The present study has identified some potential future research questions related to maintenance work and organizational assessment in complex sociotechnical systems:

1. What are the causes and consequences of a low/high sense of control in maintenance work or in safety critical organizations in general (cf. Norros & Nuutinen, 2005; Nuutinen, 2006)? Is sense of control a dimension of job motivation (cf. Hackman & Oldham, 1980) in complex sociotechnical systems, or is it a mediating variable?

2. What are the unique and general features of organizational culture in safety critical organizations (cf. Klein et al., 1995; Schulman, 1993a) and what are the unique and general features of NPP maintenance culture compared to the maintenance of some other safety critical organization, e.g. aviation maintenance (see McDonald, 2006)?

3. What is the meaning and significance of personal responsibility in safety critical organizations and what is its relation to the felt accountability as operationalized by e.g. Hochwarter et al. (2005)?

4. What is the relation between the scores on the dimensions of the CULTURE-questionnaire and actual (safety) performance? What is the concurrent and predictive validity of the questionnaire?

5. What is the relation between conceptions concerning the work and the organizational core task and the actual work performance (cf. Sandberg, 2000; Norros & Klemola, 1999; Norros, 2004)?

6. What are the influences of organizational and technological changes on the cultural conceptions concerning the OCT and maintenance practices of the given organization?

7. How good is the maintenance personnel's degree of theoretical understanding of the principles of nuclear safety and of the effect of one's own work on nuclear safety, and what consequences for the plant safety does this have? How good theoretical understanding is needed in the maintenance work (cf. Leppänen, 1993; Samurçay & Vidal-Gomel, 2002)?

8. How smooth is the cooperation of maintenance with operations and engineering departments in concrete tasks, and what consequences for the plant safety and reliability can problems in cooperation have?

9. How should the change of generation and the upkeep of motivation and competence of both newcomers and the experienced workers be handled (cf. Isobe et al., 1999; Kuronen & Rintala, 2005), and what are the potential safety consequences of different approaches to the change of generation at maintenance (cf. Walter, 2000)?

10. How should the embedded conceptions in the currently used tools and procedures be identified and assessed (cf. Hutchins, 1995; Salo & Svenson, 2003)?

11. How can the cultural conceptions in a safety critical organization be changed? How to move from assessment of complex sociotechnical systems to development of complex sociotechnical systems?

12. How do maintenance workers take the demands of the maintenance task into account in their actions (cf. Norros, 2004)? How are the demands constructed in action, and how do they manifest in the concrete work tasks?

In some of the questions, tentative work has already been done, e.g. on question 1 see Oedewald and Reiman (2006b) on question 2 see Oedewald and Reiman (2006a, in press), on question 6 see Reiman et al. (2006) and Oedewald and Reiman (2006b), on question 7 see Oedewald and Reiman (submitted).

References

ACSNI. (1993). *Organising for safety*. Third report of the Human Factors Study Group of the Advisory Committee on Safety in the Nuclear Industry. Health & Safety Commission. London: HMSO.

Alvesson, M. (2002). *Understanding organizational culture*. London: Sage.

Alvesson, M. & Berg, P.O. (1992). *Corporate culture and organizational symbolism*. Berlin: Walter de Gruyter.

Amalberti, R. (2001). The paradoxes of almost totally safe transportation systems. *Safety Science,* 37, 109–126.

Apostolakis, G.E. (1999). Organizational factors and nuclear power plant safety. In J. Misumi, B. Wilpert & R. Miller (Eds.), *Nuclear safety: A human factors perspective*. London: Taylor & Francis.

ATSB. (2001). *ATSB survey of licenced aircraft maintenance engineers in Australia*. Department of Transport and Regional Services. Australian Transport Safety Bureau.

Bacharach, S.B. (1989). Organizational theories: Some criteria for evaluation. *Academy of Management Review,* 14, 496–515.

Baker, E. (1980). Managing organizational culture. *Management Review,* 69, 8–13.

Barley, S.R. (1996). Technicians in the workplace: Ethnographic evidence for bringing work into organization studies. *Administrative Science Quarterly,* 41, 404–441.

Barley, S.R. & Kunda, G. (2001). Bringing work back in. *Organization Science,* 12, 76–95.

Barney, J. (1986). Organizational culture: Can it be a source of sustained competitive advantage? *Academy of Management Review,* 11, 656–665.

Barriere, R., Luckas, W., Whitehead, D., & Ramey-Smith, A. (1994). *An analysis of operational experience during low power and shutdown and a plan for addressing human reliability assessment issues* (NUREG/CR-6093). Washington DC: U.S. Nuclear Regulatory Commission.

Berger, P. L. & Luckmann, T. (1966). *The social construction of reality: A treatise in the sociology of knowledge*. London: Penguin Books.

Bier, V.M., Joosten, J.K., Glyer, J.D., Tracey, J.A. & Welch, M.P. (2001). *Effects of deregulation on safety: Implications drawn from the aviation, rail, and United Kingdom nuclear power industries* (NUREG/CR-6735). Washington DC: U.S. Nuclear Regulatory Commission.

Bourrier, M. (1996). Organizing maintenance work at two American nuclear power plants. *Journal of Contingencies and Crisis Management,* 4, 104–112.

Bourrier, M. (1998). Elements for designing a self-correcting organisation: Examples from nuclear power plants. In A.R. Hale & M. Baram (Eds.), *Safety management*. *The challenge of change*. Oxford: Pergamon.

Bourrier, M. (1999). Constructing organisational reliability: the problem of embeddedness and duality. In J. Misumi, B. Wilpert, R. Miller (Eds.), *Nuclear safety: A human factors perspective*. London: Taylor & Francis.

Bourrier, M. (2002). Bridging research and practice: The challenge of 'normal operations' studies. *Journal of Contingencies and Crisis Management,* 10, 173–180.

Brown, A.D. (1995). *Organisational culture*. London: Pitman.

Brunsson, N. & Olsen, J.P. (1993). *The reforming organization*. London: Routledge.

Burrell, G. & Morgan, G. (1979). *Sociological paradigms and organizational analysis*. London: Heinemann.

Cacciabue, P.C., Mauri, C. & Owen, D. (2003). The development of a model and simulation of an aviation maintenance technician task performance. *Cognition, Technology & Work,* 5, 229–247.

Cameron, K. S. (1986). Effectiveness as paradox: Consensus and conflict in conceptions of organizational effectiveness. *Management Science,* 32, 539–553.

Cameron, K.S. & Quinn, R.E. (1988). Organizational paradox and transformation. In R.E. Quinn & K.S. Cameron (Eds.), *Paradox and transformation. Toward a theory of change in organization and management*. Massachusetts: Ballinger.

Cameron, K.S. & Quinn, R.E. (1999). *Diagnosing and changing organisational culture: Based on the competing values framework*. Massachusetts: Addison-Wesley.

Carroll, J.S., Perin, C. & Marcus, A.A. (1993). *Management research on outages and maintenance*. Report of the second panel meeting. Nuclear power industry executives advisory panel. MIT Sloan School of Management. Cambridge, Massachusetts.

Carroll, J.S., Sterman, J. & Marcus, A.A. (1998). Playing the maintenance game: How mental models drive organizational decisions. In J.J. Halpern & R.N. Stern (Eds.), *Debating rationality. Nonrational aspects of organizational decision making*. Ithaca: Cornell University Press.

Charmaz, K. (1995). Grounded theory. In J.A. Smith, R. Harré, L. V. Langenhove (eds.), *Rethinking Methods in Psychology*. London: Sage.

Chatman, J.A. & Jehn, K.A. (1994). Assessing the relationship between industry characteristics and organizational culture: how different can you be? *Academy of Management Journal,* 37, 522–553.

Cheyne, A., Cox, S., Oliver, A. & Tomás, J.M. (1998). Modelling safety climate in the prediction of levels of safety activity. *Work & Stress,* 12, 255–271.

Chmiel, N. (2000). (ed.), *Introduction to work and organizational psychology. A European perspective*. Oxford: Blackwell.

Choppin, G., Liljenzin, J.-O. & Rydberg, J. (2002). *Radiochemistry and nuclear chemistry*, 3rd Edition. Butterworth–Heinemann.

Clarke, L. (1989). *Acceptable risk? Making decisions in a toxic environment*. Berkeley: University of California Press.

Clarke, L. (1993). "Drs. Pangloss and Strangelove meet organizational theory: High reliability organizations and nuclear weapons accidents. *Sociological Forum,* 8, 675–689.

Clarke, S. (1998). Safety culture on the UK railway network. *Work & Stress,* 12, 285–292.

Clarke, S. (1999). Perceptions of organizational safety: Implications for the development of safety culture. *Journal of Organizational Behavior,* 20, 185–198.

Clarke, S. & Cooper, C.L. (2004). *Managing the risk of workplace stress*. London: Routledge.

Cohen, M.D., March, J.G. & Olsen, J.P. (1972). A garbage can model of organizational choice. *Administrative Science Quarterly,* 17, 1–25.

Cohen, M.D., March, J.G. & Olsen, J.P. (1988). A garbage can model of organizational choice. In J.G. March (Ed.), *Decisions and organizations*. Oxford: Basil Blackwell.

Cooke, F.L. (2002). The important role of the maintenance workforce in technological change: A much neglected aspect. *Human Relations,* 55, 963–988.

Cooper, M.D. & Phillips, R.A. (2004). Exploratory analysis of the safety climate and safety behavior relationship. *Journal of Safety Research,* 35, 497–512.

Cooper, R. & Foster, M. (1971). Sociotechnical systems. *American Psychologist,* 26, 467–474.

Corley, K.G. (2004). Defined by our strategy or our culture? Hierarchical differences in perceptions of organizational identity and change. *Human Relations,* 57, 1145–1177.

Cox, S. & Cox, T. (1991). The structure of employee attitudes to safety: a European example. *Work & Stress,* 5, 93–106.

Cox, S. & Flin, R. (1998). Safety culture: Philosopher's stone or man of straw? *Work & Stress,* 12, 189–201.

Cox, S.J. & Cheyne, A.J.T. (2000). Assessing safety culture in offshore environments. *Safety Science,* 34, 111–129.

Czarniawska-Joerges, B. (1992). *Exploring complex organizations. A cultural approach*. Newbury Park, CA: Sage.

Dahlgren, K. & Skånberg, L. (1993). *Felaktigt utförd provning av rörböjar I system 321*. Stockholm: Statens Kärnkraftinspektion. Rapport no. 8.13-930477. [In Swedish.]

De Witte, K. & Van Muijen, J. (1994). *Organizational climate and culture in Europe. A theoretical and practical introduction to the Focus Questionnaire*. Amsterdam: K.U.Leuven & V.U. Unpublished working paper.

Dedobbeleer, N. & Beland, F. (1998). Is risk perception one of the dimensions of safety climate? In A. Feyer & A. Williamson (Eds.), *Occupational injury: Risk prevention and intervention*. London: Taylor & Francis.

Dekker, S. (2003). Failure to adapt or adaptations that fail: Contrasting models on procedures and safety. *Applied Ergonomics,* 34, 233–238.

Dekker, S.W.A. (2005). *Ten questions about human error. A new view of human factors and system safety*. New Jersey: Lawrence Erlbaum.

Denison, D.R. (1996). What *is* the difference between organizational culture and organizational climate? A native's point of view on a decade of paradigm wars. *Academy of Management Review,* 21, 619–654.

Denzin, N. (1970). *The research act in sociology*. London: Butterworth.

Department of Transport. (1989). *Investigation into the Clapham junction railway accident*. London: Her Majesty's Stationery Office.

Dien, Y. (1998). Safety and application of procedures, or ‘how do ‘they’ have to use operating procedures in nuclear power plants?’ *Safety Science,* 29, 179–187.

Donald, I. & Canter, D. (1994). Employee attitudes and safety in the chemical industry. *Journal of Loss Prevention in the Process Industries,* 7, 203–208.

Doniol-Shaw, G. (1997). Industrial maintenance, organizational design and workers´ health. The example of nuclear power plants. In IEA 1997, *FROM Experience to Innovation*. The 13th Trienial Congress of the International Ergonomics Association. Tampere, Finland.

Durkheim, E. (1982). *The rules of sociological method*. New York: Free Press. First published in 1895.

Dörner, D. (1989). *The logic of failure. Recognising and avoiding error in complex situations*. New York: Basic Books.

Enkvist, J. (2003). *A human factors perspective on non-destructive testing (NDT). Detection and identification of cracks*. Doctoral dissertation. Stockholm University: Department of Psychology.

Enkvist, J., Edland, A. & Svenson, O. (1999). *Human factors aspects of non-destructive testing in the nuclear power context: A review of research in the field*. SKI Report 99:8.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors,* 37, 32–64.

Endsley, M.R. & Robertson, M.M. (2000). Situation awareness in aircraft maintenance teams. *International Journal of Industrial Ergonomics,* 26, 301–325.

Engeström, Y. (1999). Activity theory and individual and social transformation. In Y. Engeström, R. Miettinen & R.-L. Punamäki (Eds.), *Perspectives in activity theory*. Cambridge: Cambridge University Press.

Etzioni, A. (1964). *Modern organizations*. Englewood Cliffs, NJ: Prentice-Hall.

Farrington-Darby, T., Pickup, L. & Wilson, J.R. (2005). Safety culture in railway maintenance. *Safety Science,* 43, 39–60.

Feldman, M.S. (2000). Organizational routines as a source of continuous change. *Organization Science,* 11, 611–629.

Feldman, M.S. & Rafaeli, A. (2002). Organizational routines as sources of connections and understandings. *Journal of Management Studies,* 39, 309–331.

Fiske, S.T. & Taylor, S.E. (1991). *Social cognition*. 2nd edition. McGraw–Hill.

Fleishman, E.A. & Buffardi, L. (1999). Predicting human error probabilities from the ability requirements of jobs in nuclear power plants. In J. Misumi, B. Wilpert, R. Miller (Eds.), *Nuclear safety: A human factors perspective*. London: Taylor & Francis.

Flink, A.-L. (2004). *Turvallisuuskulttuurin kehittäminen puolustusvoimissa – turvallisuuskulttuurin pilottitutkimus*. Opinnäytetyö. Laurea-ammattikorkea-koulu, Espoo. ['The development of safety culture of the Finnish defence forces – a pilot study']

Fried, Y. & Ferris, G.R. (1987). The validity of the job characteristics model: a review and meta-analysis. *Personnel Psychology,* 40, 287–322.

Frost, P.J., Moore, L.F., Louis, M.R., Lundberg, C.C. & Martin, J., eds. (1985). *Organizational culture*. Newbury Park: Sage.

Gagliardi, P. (1986). The creation and change of organizational cultures: A conceptual framework. *Organization Studies*, 7, 117–134.

Gauthereau, V. (2003). *Work practice, safety and heedfulness: Studies of organisational reliability in hospitals and nuclear power plants*. Linköping: Linköping Studies in Science and Technology, Dissertation #842.

Gauthereau, V. (2004). Emergent structures in drug dispensing to inpatients: implications for patient safety. *Cognition, Technology & Work*, 6, 223–238.

Geertz, C. (1973). Thick description: Toward an interpretative theory of culture. In C. Geertz (Ed.), *The interpretation of cultures*. New York: Basic Books.

Geller, E.S. (1994). Ten principles for achieving a total safety culture. *Professional Safety,* 39, 18–24.

Gephart, R.P.Jr. (1984). Making sense of organizationally based environmental disasters. *Journal of Management,* 10, 205–225.

Gherardi, S. & Nicolini, D. (2002). Learning the trade: A culture of safety in practice. *Organization,* 9, 191–223.

Ghiselli, E.E., Campbell, J.P. & Zedeck, S. (1981). *Measurement theory for the behavioral sciences*. San Francisco: W.H. Freeman and Company.

Ghosh, S.T. & Apostolakis, G.E. (2005). Organizational contributions to nuclear power plant safety. *Nuclear Engineering and Technology,* 37, 207–220.

Giddens, A. (1984). *The Constitution of society: Outline of the theory of structure*. Berkeley, CA: University of California Press.

Glendon, A.I. & Stanton, N.A. (2000). Perspectives on safety culture. *Safety Science,* 34, 193–214.

Gregory, K. (1983). Native-view paradigms: Multiple cultures and culture conflicts in organizations. *Administrative Science Quarterly,* 28, 359–376.

Guldenmund, F.W. (2000). The nature of safety culture: A review of theory and research. *Safety Science,* 34, 215–257.

Haber, S., Barriere, M. & Roberts, K. (1992). Outage management: A Case Study. In E. Hagen (Ed.), *IEEE Fifth Conference on Human Factors and Power Plants*, Monterey, California, June 7–11, 1992. New York: Institute of Electrical and Electronics Engineers. Pp. 134–137.

Hackman, J.R. & Lawler, E.E. (1971). Employee reactions to job characteristics. *Journal of Applied Psychology Monograph,* 55, 259–286.

Hackman, J.R. & Oldham, G.R. (1975). Development of the job diagnostic survey. *Journal of Applied Psychology,* 60, 159–170.

Hackman, J.R. & Oldham, G.R. (1980). *Work redesign*. Reading, Mass: Addison-Wesley.

Hale, A.R. (2000). Editorial. Culture's confusions. *Safety Science,* 34, 1–14.

Hale, A.R., Heming, B.H.J., Smit, K., Rodenburg, F.G.Th. & van Leeuwen, N.D. (1998). Evaluating safety in the management of maintenance activities in the chemical process industry. *Safety Science,* 28, 21–44.

Hale, A. R. & Hovden, J. (1998). Management and culture: The third age of safety. A review of approaches to organizational aspects of safety, health and environment. In A.-M. Feyer & A. Williamson (Eds.), *Occupational injury. Risk, prevention and intervention*. London: Taylor & Francis.

Hammersley, M. (1990). *Reading ethnographic research: A critical guide*. London: Longmans.

Hammersley, M. (1996). The Relationship between qualitative and quantitative research: Paradigm loyalty versus methodological eclecticism. In J.T.E. Richardson, (ed.), *Handbook of qualitative research methods for psychology and the social sciences*. Leicester: The British Psychological Society.

Harvey, J., Bolam, H., Gregory, D. & Erdos, D. (2001). The effectiveness of training to change safety culture and attitudes within a highly regulated environment. *Personnel Review*, 30, 615–636.

Harvey, J., Erdos, G., Bolam, H., Cox, M.A.A., Kennedy, J.N.P. & Gregory, D.T. (2002). An analysis of safety culture attitudes in a highly regulated environment. *Work & Stress,* 16, 18–36.

Haslam, S.A. (2004). *Psychology in organizations. The social identity approach*. Second edition. London: Sage.

Hatch, M.J. (1993). The dynamics of organizational culture. *Academy of Management Review,* 18, 657–693.

Hatch, M.J. (1997). *Organization theory. Modern, symbolic, and postmodern perspectives*. New York: Oxford.

Hawkins, P. (1997). Organizational culture: Sailing between evangelism and complexity. *Human Relations,* 50, 417–440.

Hempel, C.G. (1965). *Aspects of scientific explanation*. New York: Free Press.

Hernes, T. & Bakken, T. (2003). Implications of self-reference: Niklas Luhmann's autopoiesis and organization theory. *Organization Studies,* 24, 1511–1535.

Hirschhorn, L. (1993). Hierarchy versus bureaucracy: The case of a nuclear reactor. In K.H. Roberts (Ed.), *New challenges to understanding organizations*. New York: Macmillan.

Hirschhorn, L. (1999). The primary risk. *Human Relations,* 52, 5–23.

Hobbs, A. & Williamson, A. (2002a). Skills, rules and knowledge in aircraft maintenance: errors in context. *Ergonomics,* 45, 290–308.

Hobbs, A. & Williamson, A. (2002b). Unsafe acts and unsafe outcomes in aircraft maintenance. *Ergonomics,* 45, 866–882.

Hobbs, A. & Williamson, A. (2003). Associations between errors and contributing factors in aircraft maintenance. *Human Factors,* 45, 186–201.

Hochwarter, W.A., Perrewé, P.L., Hall, A.T. & Ferris, G.R. (2005). Negative affectivity as a moderator of the form and magnitude of the relationship between felt accountability and job tension. *Journal of Organizational Behavior*, 26, 517–534.

Hofstede, G., Neuijen, B., Ohayv, D.D. & Sanders, G. (1990). Measuring organizational cultures: A qualitative and quantitative study across twenty cases. *Administrative Science Quarterly,* 35, 286–316.

Hollnagel, E. (2002). Understanding accidents – From root causes to performance variability. In Proceedings of the IEEE 7th Conference on Human Factors and Power Plants. Scottsdale, Arizona, USA, September 2002.

Hollnagel, E. (2003). *Handbook of cognitive task design*. (Ed.), New Jersey: Lawrence Erlbaum.

Hollnagel, E. (2004). *Barriers and accident prevention*. Aldershot: Ashgate.

Hollnagel, E. (2006). Resilience – the challenge of the unstable. In E. Hollnagel, D.D. Woods & N. Leveson (Eds.), *Resilience engineering. Concepts and precepts*. Aldeshot: Ashgate

Hollnagel, E., Woods, D.D. & Leveson, N. (2006). *Resilience engineering. Concepts and precepts*. Aldershot: Ashgate.

Hollnagel, E. & Gauthereau, V. (2001). *Operational readiness verification: A study of safety during outage and restart of nuclear power plants.* SKI Report 2001:47.

Hollnagel, E. & Gauthereau, V. (2003). *Operational readiness verification, phase 2: A field study at a Swedish NPP during a productive-outage*. SKI Report 2003:09.

Hopkins, A. (2005). *Safety, culture and risk. The organisational causes of disasters*. Sydney: CCH.

HSE. (1997). Successful health and safety management. Health and Safety Executive, London: HMSO.

Hukki, K. & Norros, L. (1998). Subject-centered and systemic conceptualization as a tool of simulator training. *Le Travail Humain,* 61, 313–331.

Hutchins, E. (1995). *Cognition in the wild*. Massachusetts: MIT press.

IAEA, Safety Series No. 75-INSAG-4. (1991). *Safety culture*. Vienna: International Atomic Energy Agency.

IAEA, TECDOC-860. (1996a). *ASCOT guidelines. Revised 1996 edition*. Guidelines for organizational self-assessment of safety culture and for reviews by the assessment of safety culture in organizations team. Vienna: International Atomic Energy Agency.

IAEA, INSAG-10. (1996b). *Defence in depth in nuclear safety*. Vienna: International Atomic Energy Agency.

IAEA. (1998). *Modernization of instrumentation and control in nuclear power plants* (IAEA-TECDOC-1016). Vienna: International Atomic Energy Agency.

IAEA. (2001). *Managing change in nuclear utilities*. IAEA-TECDOC-1226. Vienna: International Atomic Energy Agency.

IAEA. (2003). *Managing change in the nuclear industry: The effects on safety*. INSAG-18. Vienna: International Atomic Energy Agency.

IAEA, Safety Reports Series No. 42. (2005). *Safety culture in the maintenance of nuclear power plants*. Vienna: International Atomic Energy Agency.

Ignatov, M. (1999). Implicit social norms in reactor control rooms. In J. Misumi, B. Wilpert, R. Miller (Eds.), *Nuclear safety: A human factors perspective*. London: Taylor & Francis.

Isobe, K., Shibuya, S. & Tabata, N. (1999). Human factors in nuclear power plant maintenance – an empirical study. In J. Misumi, B. Wilpert, R. Miller (Eds.), *Nuclear safety: A human factors perspective*. London: Taylor & Francis.

Jacobs, R. & Haber, S. (1994). Organizational processes and nuclear power plant safety. *Reliability Engineering and Systems Safety,* 45, 75–83.

Jacobsson Kecklund, L. (1998). *Studies of safety and critical work situations in nuclear power plants: A human factors perspective*. Doctoral dissertation. Department of Psychology. Stockholm University. Edsbruk: Akademitryck AB.

Jacobsson, L. & Svenson, O. (1991). *Psychosocial work strain of maintenance personnel during annual outage and normal operation in a nuclear power plant*. Proceedings of the Human Factors Society 35th annual meeting 1991.

Kalliath, T.J., Bluedorn, A.C. & Gillespie, D.F. (1999). A confirmatory factor analysis of the competing values instrument. *Educational and Psychological Measurement,* 59, 143–158

Karasek, R.A. & Theorell, T. (1990). *Healthy work: Stress, productivity, and the reconstruction of working life*. New York: Basic Books.

Katz, D. & Kahn, R.L. (1966). *The social psychology of organizations*. New York: John Wiley.

Kecklund, L. (2004). *Underhållsstrategier och säkerhet på en avreglerad elmarknad*. SKI Rapport 2004:40. [In Swedish with an English abstract.]

Kets de Vries, M.F.R & Miller, D. (1986). Personality, culture, and organization. *Academy of Management Review,* 11, 266–279.

Kettunen, J. (1997). *Uskomuksia ydinvoimalaitoksissa suoritettavien tarkastusten luotettavuudesta*. [‘Beliefs concerning the reliability of inspections in the nuclear power plants’] STUK-YTO-TR 121. Helsinki: STUK.

Kettunen, J., Mikkola, M. & Reiman, T. (2004). *When availability counts – Key concepts, constraints and challenges of outsourcing in the nuclear power* *industry*. The 9th International Symposium on Logistics. Logistics and Global Outsourcing. Bangalore, India. 11–14 July 2004.

Kettunen, J., Reiman, T. & Wahlström, B. (2006). Analysis of challenges to nuclear power plant safety management: Finland, Sweden, and the European context. In O. Svenson, I. Salo, A.B. Skjerve, T. Reiman & P. Oedewald (Eds.), *Nordic perspectives on safety management in high reliability organizations: Theory and applications*. Valdemarsvik: Akademitryck.

Kettunen, J., Reiman, T. & Wahlström, B. (submitted). Analysis of management challenges in the European nuclear power industry: Implications for management theory and practice.

Kilmann, R.H. (1985). Five steps to close the culture gap. In R.H. Kilmann, M. Saxton, R. Serpa, et al. (Eds.), *Gaining control of corporate culture*. San Francisco: Jossey–Bass.

Kirwan, B. & Ainsworth, L.K. (1992). *A guide to task analysis*. London: Taylor & Francis.

Kivimäki, M., Kalimo, R. & Salminen, S. (1995). Perceived nuclear risk, organizational commitment, and appraisals of management: A study of nuclear power plant personnel. *Risk Analysis*, 15, 391–396.

Klein, R.L., Bigley, G.A. & Roberts, K.H. (1995). Organizational culture in high reliability organizations: An extension. *Human Relations,* 48, 771–793.

Klemola, U.-M. & Norros L. (1997). Analysis of the clinical behaviour of the anaesthetics: recognition of uncertainty as a basis for practice. *Medical Education,* 31, 449–456.

Koch, B.A. (1993). Differentiating reliability seeking organizations from other organizations: Development and validation of an assessment device. In K.H. Roberts (Ed.), *New challenges to understanding organizations*. New York: Macmillan Publishing.

Kovan, D. (2000). Building a modern maintenance service at British Energy. *Nuclear News*, October 2000.

Kraus, D.C. & Gramopadhye, A.K. (2001). Effect of team training on aircraft maintenance technicians: computer-based training versus instructor-based training. *International Journal of Industrial Ergonomics,* 27, 141–157.

Kunda, G. (1992). *Engineering culture: Control and commitment in a High-Tech corporation*. Philadelphia: Temple University Press.

Kuronen, T. & Rintala, N. (2005). The prerequisites for successful knowledge sharing in nuclear power plants. *CSNI Workshop on Better Nuclear Plant Maintenance: Improving Human and Organizational Performance*, 3–5 October, Ottawa, Canada.

Kurtti, R. & Reiman, T. (2006). *Organisaatiokulttuuri logistiikkapalvelu-organisaatioissa. Tutkimus viidessä palveluvarastossa* [Organizational culture at logistics service organizations] Espoo: VTT. VTT Working Papers 47. 30 p.

La Porte, T.R. (1994). A strawman speaks up: Comments on The Limits of Safety. *Journal of Contingencies and Crisis Management,* 2, 207–211.

La Porte, T.R. (1996). High reliability organizations: Unlikely, demanding and at risk. *Journal of Contingencies and Crisis Management,* 4, 60–71.

La Porte, T.R. & Rochlin, G. (1994). A rejoinder to Perrow. *Journal of Contingencies and Crisis Management,* 2, 221–227.

La Porte, T.R. & Consolini, P.M. (1991). Working in practice but not in theory: Theoretical challenges of ´High Reliability Organizations´. *Journal of Public Administration Research and Theory,* 1, 19–47.

Laakso, K., Pyy, P. & Reiman, L. (1998). *Human errors related to maintenance and modifications*. Helsinki: STUK. STUK-YTO-TR 139.

Laakso, K. (2005). Systematic analysis and prevention of human errors and common cause failures in relation to maintenance. *CSNI Workshop on Better*

Nuclear Plant Maintenance: Improving Human and Organisational Performance. Ottawa, 3 – 5 Oct. 2005.

Laakso K. (2006). *Systematic analysis and prevention of human originated common cause failures in relation to maintenance activities at Finnish nuclear power plants.* Helsinki: STUK. STUK-YTO-TR 217.

Langer, E.J. (1983). *The psychology of control*. Beverly Hills: Sage.

Latorella, K.A. & Prabhu, P.V. (2000). A review of human error in aviation maintenance and inspection. *International Journal of Industrial Ergonomics,* 26, 133–161.

Lawton, R. (1998). Not working to rule: Understanding procedural violations at work. *Safety Science,* 28, 77–95.

Lazarus, R.S. & Folkman, S. (1984). *Stress, appraisal, and coping*. New York: Springer Publishing.

Lee, T. (1998). Assessment of safety culture at a nuclear reprocessing plant. *Work & Stress,* 12, 217–237.

Lee, T. & Harrison, K. (2000). Assessing safety culture in nuclear power stations. *Safety Science,* 34, 61–97.

Leontiev, A.N. (1975). *Dejatel'nost. Coznanie. Litšnost.* [Activity. Consciousness. Personality.] Kuopio: KOY. A Finnish Translation.

Leppänen, A. (1993). *Työn käsitteellisen hallinnan ja hyvinvoinnin yhteydet ja kehittyminen paperinvalmistuksessa työskentelevillä*. [‘Relationship between and development of conceptual mastery and well-being among personnel in paper production’] Väitöskirja, Helsingin yliopisto. Työ ja ihminen, työympäristö-tutkimuksen aikakausikirja, lisänumero 6/93.

Leveson, N. (2004). A new accident model for engineering safer systems. *Safety Science,* 42, 237–270.

Levinson, H. (2002). *Organizational assessment. A step-by-step guide to effective consulting*. Washington: American Psychological Association.

Linstead, S. & Grafton-Small, R. (1992). On reading organizational culture. *Organization Studies,* 13, 331–355.

Marone, J.G. & Woodhouse, E.J. (1986). *Averting catastrophe: Strategies for regulating risky technologies*. Berkeley: University of California Press.

Martin, J. (1992). *Cultures in organizations: Three perspectives*. New York: Oxford University Press.

Martin, J. (2002). *Organizational culture. Mapping the terrain*. Thousand Oaks: Sage.

Marx, D.A. & Graeber, R.C. (1994). Human error in aircraft maintenance. In N. Johnston, N. McDonald & R. Fuller (Eds.), *Aviation psychology in practice*. Aldershot: Ashgate.

McDonald, N. (2001). Human systems and aircraft maintenance. *Air & Space Europe,* 3, 221–224.

McDonald, N. (2006). Organisational resilience and industrial risk. In E. Hollnagel, D.D. Woods & N. Leveson (Eds.), *Resilience engineering. Concepts and precepts.* Aldershot: Ashgate.

McDonald, N., Corrigan, S., Daly, C. & Cromie, S. (2000). Safety management systems and safety culture in aircraft maintenance organisations. *Safety Science,* 34, 151–176.

McLennan, J., Pavlou, O. & Omodei, M.M. (2005). Cognitive control processes discriminate between better versus poorer performance by fire ground commanders. In H. Montgomery, R. Lipshitz & B. Brehmer (Eds.), *How professionals make decisions*. Mahwah, NJ: Lawrence Erlbaum.

Mearns, K., Flin, R., Gordon, R. & Fleming, M. (1998). Measuring safety climate on offshore installations. *Work & Stress,* 12, 238–254.

Mearns, K., Whitaker, S.M. & Flin, R. (2003). Safety climate, safety management practice and safety performance in offshore environments. *Safety Science,* 41, 641–680.

Meek, V.L. (1988). Organizational culture: Origins and weaknesses. *Organization Studies,* 9, 453–473.

Mengolini, A. & Debarberis, L. (2007). Safety culture enhancement through the implementation of IAEA guidelines. *Reliability Engineering & System Safety,* 92, 520–529 .

Mercier, J.-P. (1988). *Nuclear power plant maintenance*. English adaptation of "La maintenance des centralés nucleaires" published for Electricité de France 1987. 2nd edition. Paris: Editions Kirk.

Miles, M.B. & Huberman, A.M. (1994). *Qualitative data analysis: An expanded sourcebook*. Second edition. Sage.

Miller, E. & Rice, A.K. (1967). *Systems of organization: Task and sentient systems and their boundary control*. London: Tavistock.

Mintzberg, H. (1983). *Structure in fives. Designing effective organizations*. New Jersey: Prentice–Hall.

Morgan, G. (1997). *Images of organization*. (2nd ed.). Thousand Oaks, CA: Sage.

Morgeson, F.P. & Humphrey, S.E. (2006). The Work Design Questionnaire (WDQ): Developing and validating a comprehensive measure for assessing job design and the nature of work. *Journal of Applied Psychology*, 91, 1321–1339.

Moubray, J. (1992). *Reliability-centered maintenance*. New York: Industrial Press.

Norros, L. (1995). An orientation-based approach to expertise. In J.-M. Hoc, P.C. Cacciabue & E. Hollnagel (Eds.), *Cognition and human-computer co-operation*. Hillsdale, NJ: Lawrence Erlbaum.

Norros, L. (1998). Evaluation and development of process operator's working practices. In T. Vanttola (Ed.), *RETU. The Finnish Research Programme on Reactor Safety, 1995–1998, Final Symposium*. Espoo: VTT. VTT Symposium 189. Pp. 187–198.

Norros, L. (2004). *Acting under uncertainty. The core-task analysis in ecological study of work*. Espoo: VTT. VTT Publications 546. 241 p.

Norros, L. (2005). The concept of habit in the analysis of situated actions. *Theoretical Issues in Ergonomics Science,* 6, 385–407

Norros, L. & Kettunen, J. (1998). *NDT-tarkastajien toimintatavat ammattitaitoa ja tarkastustehtävää koskevien käsitysten perusteella*. ['The working practices of NDT inspectors on the basis of their conceptions concerning expertise and the inspection task'] Helsinki: STUK. STUK-YTO-TR 147.

Norros, L. & Klemola, U.-M. (1999). Methodological considerations in analysing anaesthetists' habits of action in clinical situations. *Ergonomics,* 42, 1521–1530.

Norros, L. & Nuutinen, M. (2002). The concept of the core-task and the analysis of working practices. In N. Boreham, R. Samurcay & M. Fischer (Eds.), *Work process knowledge*. London: Routledge.

Norros, L. & Nuutinen, M. (2005). Performance-based usability evaluation of a safety information and alarm system. *International Journal of Human-Computer Studies,* 63, 328–361.

Norros, L., Hukki, K., Haapio, A. & Hellevaara, M. (1998). *Päätöksenteko komentosillalla luotsaustilanteessa* [Decision making on bridge in piloting situations]. Espoo: VTT. VTT Julkaisuja – Publikationer 833. 77 p. + app. 7 p.

NRC. (1986). *Human reliability impact on inservice inspection*. NUREG / CR 4436. U.S. Nuclear Regulatory Commission.

NRC. (1998). Nuclear Regulatory Commission. Office of the Inspector General. NRC Safety Culture and Climate Survey. Executive Summary. June 1998. http://www.nrc.gov/NRC/OIG/SURVEY/index.html. 20.7.1998.

Nuutinen, M. (2005). Contextual assessment of working practices in changing work. *International Journal of Industrial Ergonomics,* 35, 905–930.

Nuutinen, M. (2006). *Expert identity in development of core-task-oriented working practices for mastering demanding situations*. Dissertation. Espoo: VTT. VTT Publications 604. 113 p. + app. 141 p.

Nuutinen, M. & Norros, L. (2001). *Co-operation on bridge in piloting situations. Analysis of 13 accidents on Finnish fairways*. Paper presented at CSAPC'01 8th Conference on Cognitive Science Approaches to Process Control. 24–26 September 2001, Neubiberg, Germany.

Nuutinen, M. & Norros, L. (in press). Core task analysis in accident investigation – analysis of maritime accidents in piloting situations. *Cognition, Technology & Work.*

Nuutinen, M., Reiman, T. & Oedewald, P. (2003). *Osaamisen hallinta ydinvoimalaitoksessa operaattoreiden sukupolvenvaihdostilanteessa*. [Management of competence at nuclear power plant operations during generation turnover] Espoo: VTT. VTT Publications 496. 82 p.

OECD/NEA. (1999). *Identification and assessment of organizational factors related to the safety of NPPs.* (NEA/CSNI/R(99)21). Issy-les-Moulineaux: OECD Nuclear Energy Agency.

OECD/NEA. (2000). *Nuclear power plant life management in a changing business world.* Workshop proceedings, Washington DC, USA, 26–27 June 2000. Issy-les-Moulineaux: OECD Nuclear Energy Agency.

OECD/NEA. (2001). *Assuring future nuclear safety competencies*. *Specific actions*. Issy-les-Moulineaux: OECD Nuclear Energy Agency.

OECD/NEA. (2002). *Regulatory aspects of management of change* (NEA/CSNI/R(2002)20). OECD/CSNI workshop 10–12 September 2001, Chester, UK. Issy-les-Moulineaux: OECD Nuclear Energy Agency.

OECD/NEA. (In preparation). *Better nuclear plant maintenance: Improving human and organisational performance*.

Oedewald, P. & Reiman, T. (2002). *Organisaatiokulttuurin arvioiminen. FINNUS/WOPS/CULTURE-projektin loppuraportti*. ['Assessment of organizational culture. Final report of the FINNUS/WOPS/CULTURE-project'] Julkinen tutkimusraportti BTUO64-021065. VTT Tuotteet ja tuotanto.

Oedewald, P. & Reiman, T. (2005). Enhancing maintenance personnel's job motivation and organizational effectiveness. *CSNI workshop on Better Nuclear Plant Maintenance: Improving Human and Organisational Performance*. Ottawa, Canada. 3–5 October 2005.

Oedewald, P. & Reiman, T. (2006a). *Turvallisuuskriittisten organisaatioiden toiminnan erityispiirteet*. [Characteristics of safety critical organizations. Work psychological perspective] Espoo: VTT. VTT Publications 593. 108 p. + app. 20 p.

Oedewald, P. & Reiman, T. (2006b). Using subjective measures to monitor the systems' capability to manage complexity – evidence from the nuclear industry and health care. In *proceedings of the Second Symposium on Resilience Engineering*. Juan-Les-Pins, France, 8–10 November 2006.

Oedewald, P. & Reiman. T. (submitted). Measuring *conceptual knowledge* among NPP maintenance personnel – a tool for knowledge management.

Oedewald, P., Reiman, T. & Kurtti, R. (2005a). Organisational culture in Finnish SME manufacturing companies – Quality as a means of survival? *Presentation held at 12th EAWOP Congress in Turkey*, Istanbul, May 2005.

Oedewald, P., Reiman, T. & Kurtti, R. (2005b). *Organisaatiokulttuuri ja toiminnan laatu metalliteollisuudessa. 11 tapaustutkimusta suomalaisissa pk-yrityksissä*. [Organizational culture and quality in metal industry. 11 case studies in Finnish SME companies] Espoo: VTT. VTT Tiedotteita – Research Notes 2316. 81 p. + app. 4 p.

Orlikowski, W.J. (1992). The duality of technology: Rethinking the concept of technology in organizations. *Organization Science,* 3, 398–427.

Orr, J.E. (1996). *Talking about machines: An ethnography of a modern job*. Ithaca, NY: ILR press.

Ostrom, L., Wilhelmsen, C. & Kaplan, B. (1993). Assessing safety culture. *Nuclear Safety* 2. April–June.

Ouchi, W.G. (1980). Markets, bureaucracies and clans. *Administrative Science Quarterly*, 25, 129–141.

Parker, M. (2000). *Organizational culture and identity*. London: Sage.

Parsons, T. (1951). *The social system*. London: Routledge & Kegan Paul.

Paté-Cornell, M.E. (1993). Learning from the Piper Alpha accident: A post mortem analysis of technical and organizational factors. *Risk Analysis,* 13, 215–232.

Perin, C. (2005). *Shouldering risks. The culture of control in the nuclear power industry*. New Jersey: Princeton University Press.

Perrow, C. (1984). *Normal accidents: Living with high-risk technologies*. New York: Basic Books.

Perrow, C. (1986). *Complex organizations*. 3rd edition. New York: Random House.

Perrow, C. (1994a). The limits of safety: The enhancement of a theory of accidents. *Journal of Contingencies and Crisis Management,* 2, 212–220.

Perrow, C. (1994b). Accidents in high-risk systems. *Technology Studies,* 1, 1–20.

Perrow, C. (1999). Organizing to reduce the vulnerabilities of complexity. *Journal of Contingencies and Crisis Management,* 7, 150–155.

Peters, T.J. & Waterman, R.H. (1982). *In search of excellence: Lessons from America's best-run companies.* New York: Harper & Row.

Pettigrew, A.M. (1979). On studying organizational cultures. *Administrative Science Quarterly*, 24, 570–581.

Pidgeon, N. (1998). Safety culture: Key theoretical issues. *Work & Stress,* 12, 202–216.

Pidgeon, N. & O'Leary, M. (2000). Man-made disasters: why technology and organizations (sometimes) fail. *Safety Science,* 34, 15–30.

Pronovost, P.J., Weast, B., Holzmueller, C.G., Rosenstein, B.J., Kidwell, R.P., Haller, K.B., Feroli, E.R., Sexton, J.B. & Rubin, H.R. (2003). Evaluation of the culture of safety: Survey of clinicians and managers in an academic medical center. *Quality and Safety in Health Care,* 12, 405–410.

Pyy, P. (2000). *Human reliability analysis methods for probabilistic safety assessment*. Espoo: VTT. VTT Publications 422. 63 p. + app. 64 p.

Pyy, P. (2001). An analysis of maintenance failures at a nuclear power plant. *Reliability Engineering and System Safety,* 72, 293–302

Quinn, R.E. & Rohrbaugh, J. (1983). A spatial model of effectiveness criteria: towards a competing values approach to organizational effectiveness. *Management Science,* 29, 363–377.

Radcliffe-Brown, A.R. (1958). *Method in social anthropology*. Chicago: University of Chicago Press.

Rasmussen, J. (1982). Human errors: A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents*, 4, 311–335.

Rasmussen, J. (1997). Risk management in a dynamic society: A modelling problem. *Safety Science,* 27, 183–213.

Rasmussen, J. (2000). Human factors in a dynamic information society: where are we heading? *Ergonomics,* 43, 869–879.

Rasmussen, J. & Jensen, A. (1974). Mental procedures in real-life tasks: A case study of electronic trouble shooting. *Ergonomics*, 17, 293–307.

Reason, J. (1990). *Human error*. Cambridge: Cambridge University Press.

Reason, J. (1993). Managing the management risk: New approaches to organisational safety. In B. Wilpert & T. Qvale (Eds.), *Reliability and safety in hazardous work systems. Approaches to analysis and design*. Lawrence Erlbaum.

Reason, J. (1997). *Managing the risks of organizational accidents*. Aldershot: Ashgate.

Reason, J. & Hobbs, A. (2003). *Managing maintenance error. A practical guide*. Hampshire: Ashgate.

Reiman, T. (2001). *Organisaatiokulttuuri Säteilyturvakeskuksen Ydinvoima-laitosten valvonta -osastolla*. [Organizational culture at the Radiation and Nuclear Safety Authority of Finland's Nuclear Reactor Regulation department]. Espoo: VTT. VTT Julkaisuja – Publikationer 853. 89 p. + app. 6 p. [In Finnish with an English abstract.]

Reiman, T. & Norros, L. (2002). Regulatory culture: Balancing the different demands of regulatory practice in the nuclear industry. In B. Kirwan, A.R. Hale & A. Hopkins (Eds.), *Changing regulation – Controlling risks in society*. Oxford: Pergamon.

Reiman, T. & Oedewald, P. (2002a). *The Assessment of organisational culture. A methodological study*. Espoo: VTT. VTT Tiedotteita – Research Notes 2140. 39 p.

Reiman, T. & Oedewald, P. (2002b). Working practices and safety culture in nuclear power plant operations (WOPS): Contextual Assessment of Organisational Culture – methodological development in two case studies. In R. Kyrki-Rajamäki & E.-K. Puska (Eds.), *FINNUS. The Finnish Research Programme on Nuclear Power Plant Safety, 1999–2002. Final Report.* Espoo: VTT. VTT Tiedotteita – Research Notes 2164. Pp. 251–260.

Reiman, T. & Oedewald, P. (2003). *Kunnossapitokulttuurin arvioiminen TVO:lla. CAOC-metodologiaan perustuva tapaustutkimus Olkiluodon ydin-voimalaitoksen kunnossapito-organisaatiossa*. Julkinen tutkimusraportti BTUO64-031176. [‘Assessment of maintenance culture at TVO. Case study based on CAOC methodology at Olkiluoto NPP maintenance organization’]

Reiman, T. & Oedewald, P. (2004). *Kunnossapidon organisaatiokulttuuri. Tapaustutkimus Olkiluodon ydinvoimalaitoksessa*. [Organizational culture in maintenance. A case study at Olkiluoto NPP]. Espoo: VTT. VTT Publications 527. 62 p. + app. 8 p.

Reiman, T. & Oedewald, P. (2005). Exploring the effect of organizational changes on the safety and reliability of maintenance. CSNI workshop on Better Nuclear Plant Maintenance: Improving Human and Organisational Performance. Ottawa, Canada. 3–5 October 2005.

Reiman, T. & Oedewald, P. (2006a). Organizational culture and social construction of safety in industrial organizations. In O. Svenson, I. Salo, A.B. Skjerve, T. Reiman & P. Oedewald (Eds.), *Nordic perspectives on safety management in high reliability organizations: Theory and applications*. Valdemarsvik: Akademitryck.

Reiman, T. & Oedewald, P. (2006b). Contextual assessment of organizational culture in complex sociotechnical systems. In Proceedings of the Ninth International Symposium of the ISSA Research Section, 1–3 March 2006, Nice, France.

Reiman, T., Oedewald, P., Rollenhagen, C. & Eriksson, I. (2004a). *Contextual assessment of maintenance culture at Olkiluoto and Forsmark*. NKS-94. http://130.226.56.167/nordisk/publikationer/1994_2004/NKS-94.pdf

Reiman, T., Oedewald, P. & Rollenhagen, C. (2004b). Comparison of organisational cultures at two NPP maintenance units. When is maintenance work motivating and meaningful? In C. Spitzer, U. Schmocher & V.N. Dang (Eds.), *Probabilistic Safety Assessment and Management*. PSAM7 – ESREL '04. Volume 2. London: Springer.

Reiman, T., Oedewald, P., Rollenhagen, C. & Kahlbom, U. (2006). Management of change in the nuclear industry. Evidence from maintenance reorganizations. MainCulture Final Report. NKS-119. Roskilde: Nordic nuclear safety research. Available from www.nks.org

Rice, A.K. (1958). *Productivity and social organisation: The Ahmedebad Experiment*. London: Tavistock Publications.

Rice, A.K. (1965). *Learning for leadership*. London: Tavistock Publications.

Richter, A. & Koch, C. (2004). Integration, differentiation and ambiguity in safety cultures. *Safety Science,* 42, 703–722.

Rijpma, J.A. (1997). Complexity, tight-coupling and reliability: Connecting normal accident theory and high reliability theory. *Journal of Contingencies and Crisis Management,* 5, 15–23.

Roberts K. (1989). New challenges in organizational research: high reliability organizations. *Industrial Crisis Quarterly,* 3, 111–125.

Roberts, K.H. (1990). Some characteristics of one type of high reliability organization. *Organization Science,* 1, 160–176.

Roberts, K.H. (1993). Some aspects of organizational culture and strategies to manage them in reliability enhancing organizations. *Journal of Managerial Issues,* 5, 165–181

Roberts, K.H. & Rousseau, D.M. (1989). Research in nearly failure-free, high reliability organizations: Having the bubble. *IEEE Transactions on Engineering Management,* 36, 132–139.

Roberts, K.H., Rousseau, D.M. & La Porte, T. (1994a). The culture of high reliability: quantitative and qualitative assessment aboard nuclear powered aircraft carriers. *Journal of High Technology Management Research,* 5, 141–61

Roberts, K.H., Stout, S.K. & Halpern, J.J. (1994b). Decision dynamics in two high reliability military organizations. *Management Science,* 40, 614–624.

Rochlin, G.I. (1996). Reliable organizations: Present research and future directions. *Journal of Contingencies and Crisis Management,* 4, 55–59.

Rochlin, G.I. (1999a). Safe operation as a social construct. *Ergonomics,* 42, 1549–1560.

Rochlin, G.I. (1999b). The social construction of safety. In J. Misumi, B. Wilpert & R. Miller (Eds.), *Nuclear safety: A human factors perspective*. London: Taylor & Francis.

Rogalski, J., Plat, M. & Antolin-Glenn, P. (2002). Training for collective competence in rare and unpredictable situations. In N. Boreham, R. Samurcay & M. Fischer (Eds.), *Work process knowledge*. London: Routledge.

Rokeach, M. (1973). *The nature of human values*. New York: Free Press.

Rollenhagen, C. (2006). Safety management of nuclear power plants – values and balance of attention. In O. Svenson, I. Salo, A.B. Skjerve, T. Reiman & P. Oedewald (Eds.), *Nordic perspectives on safety management in high reliability organizations: Theory and applications*. Valdemarsvik: Akademitryck.

Roth, E.M., Multer, J. & Raslear, T. (2006). Shared situation awareness as a contributor to high reliability performance in railroad operations. *Organization Studies,* 27, 967–987.

Roughton, J.E. & Mercurio, J.J. (2002). *Developing an effective safety culture. A leadership approach*. Woburn, MA: Butterworth–Heinemann.

Rouse, W.B. (1979). Problem solving performance of maintenance trainees in a fault diagnosis task. *Human Factors*, 21, 195–203.

Rousseau, D.M. (1990). Assessing organizational culture: The case for multiple methods. In B. Schneider (Ed.), *Organizational climate and culture*. San Francisco: Jossey-Bass.

Sackmann, S.A. (1991). Uncovering culture in organizations. *Journal of Applied Behavioral Science,* 27, 295–317.

Saffold, G.S. (1988). Culture traits, strength, and organizational performance: Moving beyond 'strong' culture. *Academy of Management Review*, 13, 546–558.

Sagan, S.D. (1993). *The limits of safety. Organizations, accidents, and nuclear weapons*. New Jersey: Princeton University Press.

Sagan, S.D. (1994). Towards a political theory of organizational reliability. *Journal of Contingencies and Crisis Management,* 2, 228–240.

Sagan, S.D. (2004). Learning from *normal accidents*. *Organization & Environment,* 17, 15–19

Salo, I. & Svenson, O. (2001). *Human factors in maintenance: Development and research in Swedish nuclear power plants*. SKI Report 01:40.

Salo, I. & Svenson, O. (2003). Mental causal models of incidents communicated in licensee event reports in a process industry. *Cognition, Technology & Work,* 5, 211–217.

Samurçay, R. & Vidal-Gomel, C. (2002). The contribution of work process knowledge to competence in electrical maintenance. In N. Boreham, R. Samurcay & M. Fischer (Eds.), *Work process knowledge*. London: Routledge.

Sandberg, J. (2000). Understanding human competence at work: An interpretative approach. *Academy of Management Journal,* 43, 9–25.

Sandberg, J. (2004). *Ydinturvallisuus*. (Ed.) ['Nuclear safety'] Hämeenlinna: Karisto.

Sandelands, L. & Drazin, R. (1989). On the language of organization theory. *Organization Studies,* 10, 457–478.

Sayer, A. (1992). *Method in social science. A realist approach*. 2nd ed. London: Routledge.

Schein, E.H. (1985). *Organizational culture and leadership*. San Francisco: Jossey–Bass.

Schein, E.H. (1990). Organizational culture. *American Psychologist,* 45, 109–119.

Schein, E.H. (1999). *Process consultation revisited. Building the helping relationship*. Reading, Massachusetts: Addison–Wesley.

Schein, E.H. (2004). *Organizational culture and leadership* (3rd ed.). San Francisco: Jossey–Bass.

Schlenker, B.R., Britt, T.W., Pennington, J., Murphy, R. & Doherty, K. (1994). The triangle model of responsibility. *Psychological Review,* 101, 632–652.

Schraagen, J.M., Chipman, S.F. & Shalin, V.L. (2000). *Cognitive task analysis*. (Eds.), Mahwah: Lawrence Erlbaum.

Schulman, P.R. (1993a). The analysis of high reliability organizations: A comparative framework. In K.H. Roberts (Ed.), *New challenges to understanding organizations*. New York: Macmillan.

Schulman, P.R. (1993b). The negotiated order of organizational reliability. *Administration & Society,* 25, 353–372.

Schulman, P.R. (1996). Heroes, organizations and high reliability. *Journal of Contingencies and Crisis Management,* 4, 72–82.

Schultz, M. (1995). On studying organizational cultures. Diagnosis and understanding. Berlin: Walter de Gruyter.

Schultz, M. & Hatch, M.J. (1996). Living with multiple paradigms: The case of paradigm interplay in organizational culture studies. *Academy of Management Review,* 21, 529–557.

Schumacher, T. (1997). West Coast Camelot. The rise and fall of an organizational culture. In S.A. Sackmann (ed.), *Cultural complexity in organizations. Inherent contrasts and contradictions*. Thousand Oaks: Sage.

Scott, W.R. (1995). *Institutions and organizations*. Thousand Oaks: Sage.

Scott, W.R. (2003). *Organizations. Rational, natural, and open systems*. Fifth edition. New Jersey: Prentice Hall.

Shanteau, J., Weiss, D.J., Thomas, R.P. & Pounds, J.C. (2002) Performance-based assessment of expertise: How to decide it someone is an expert or not. *European Journal of Operations Research,* 136, 253–263.

Siehl, C. & Martin, J. (1990). Organizational culture: A key to financial performance? In B. Schneider (Ed.), *Organizational culture and climate*. San Francisco: Jossey–Bass.

Selznick, P. (1948). Foundations of the theory of organization. *American Sociological Review,* 13, 25–35.

Seminara, J.L. & Parsons, S.O. (1982). Nuclear power plant maintainability. *Applied Ergonomics,* 13, 177–189.

Shepherd, A. (1992). Maintenance training. In B. Kirwan & L.K. Ainsworth (Eds.), *A guide to task analysis*. London: Taylor & Francis.

Simon, H.A. (1957). *Administrative behavior: A study of decision making processes in administrative organisation*. New York: Macmillan.

Silverman, D. (1971). *The theory of organizations: A sociological framework*. New York: Basic Books.

Silverman, D. (1993). *Interpreting qualitative data. Methods for analysing talk, text and interaction*. London: Sage.

Simon, H.A. (1957). *Administrative behavior: A study of decision making processes in administrative organisation*. New York: Macmillan.

Singer, S.J., Gaba, D.M., Geppert, J.J. Sinaiko, A.D., Howard, S.K. & Park, K.C. (2003). The culture of safety: Results of an organization-wide survey in 15 California hospitals. *Quality and Safety in Health Care,* 12, 112–118.

SKI. (2005). *Safety and radiation protection at Swedish nuclear power plants 2004.* SKI rapport 2005:32.

Skogstad, A. & Einarsen, S. (1999). The importance of a change-centred leadership style in four organizational cultures. *Scandinavian Journal of Management,* 15, 289–306.

Slovic, P. (1987). Perception of risk. *Science*, 236, 280–285.

Smircich, L. (1983). Concepts of culture and organizational analysis. *Administrative Science Quarterly,* 28, 339–358.

Smircich, L. (1985). Is the concept of culture a paradigm for understanding organizations and ourselves? In P.J. Frost, L.F. Moore, M.R. Louis, C.C. Lundberg & J. Martin (Eds.), *Organizational culture*. Newbury Park: Sage.

Smith, J.A. (1995). Semi-structured interviewing and qualitative analysis. In J.A. Smith, R. Harré & L.V. Langenhove (Eds.), *Rethinking methods in psychology*. London: Sage.

Snook, S. A. (2000). *Friendly fire. The accidental shootdown of U.S. Black Hawks over Northern Iraq*. New Jersey: Princeton University Press.

Sorensen, J. N. (2002). Safety culture: A survey of the State-of-the-Art. *Reliability Engineering and System Safety,* 76, 189–204.

Stake, R.E. (2000). Case studies. In N. K. Denzin & Y.S. Lincoln (Eds.), *Handbook of qualitative research*. Second Edition. Thousand Oaks: Sage.

Starbuck, W.H. & Milliken, F.J. (1988). Challenger: Fine-tuning the odds until something breaks. *Journal of Management Studies,* 25, 319–340.

Strauss, A. & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. (2^{nd} ed). Thousand Oaks: Sage.

Svedung, I. & Rasmussen, J. (1998). Organisational decision making and risk management under pressure from fast technological change. In A.R. Hale & M. Baram (Eds.), *Safety management. The challenge of change*. Oxford: Pergamon.

Svenson, O. & Salo, I. (2001). Latency and mode of error detection in a process industry. *Reliability Engineering and System Safety,* 73, 83–90.

Swain, A. & Guttmann, H. (1983). *Handbook of human reliability analysis with emphasis on nuclear power plant applications.* NUREG/CR-1278, U.S. Nuclear Regulatory Commission.

Tabachnick, B.G. & Fidell, L.S. (2001). *Using multivariate statistics*. 4th Edition. Boston: Allyn & Bacon.

Thomas, S.J. (2005). *Improving maintenance and reliability through cultural change*. New York: Industrial Press.

Toriizuka, T. (2001). Application of performance shaping factor (PSF) for work improvement in industrial plant maintenance tasks. *International Journal of Industrial Ergonomics,* 28, 225–236.

Tossavainen, K. (ed.). (2005). *Regulatory control of nuclear safety in Finland*. Annual report 2004. STUK-B-YTO 241. Helsinki: STUK.

Trice, H.M. & Beyer, J.M. (1993). *The cultures of work organizations*. New Jersey: Prentice Hall.

Tsoukas, H. (2001). Re-viewing organization. *Human Relations,* 54, 7–12.

Tsoukas, H. & Hatch, M.J. (2001). Complex thinking, complex practice: The case for a narrative approach to organizational complexity. *Human Relations,* 54, 979–1014.

Tsoukas, H. & Chia, R. (2002). On organizational becoming: rethinking organizational change. *Organization Science,* 13, 567–582.

Turner, B.A. (1971). *Exploring the industrial subculture*. London: Macmillan.

Turner, B. (1976). The organizational and interorganizational development of disasters. *Administrative Science Quarterly*, 21, 378–397.

Turner, B. (1978). *Man-made disasters*. London: Wykeham.

Turner, B.A. & Pidgeon, N.F. (1997). *Man-made disasters. Second edition*. Butterworth-Heinemann, Oxford.

Turner, J.C. (1991). *Social influence*. Milton Keynes: Open University Press.

van Maanen, J. & Barley, S.R. (1985). Cultural organization. Fragments of a theory. In Frost, P.J., Moore, L.F., Louis, M.R., Lundberg, C.C. & Martin, J. (Eds.), *Organizational culture*. Newbury Park: Sage.

Vaughan, D. (1996). *The Challenger launch decision*. Chicago: University of Chicago Press.

Vaughan, D. (1999). The dark side of organizations: Mistake, misconduct, and disaster. *Annual Review of Sociology,* 25, 271–305.

Verkasalo, M. & Lindeman, M. (1994). Personal ideals and socially desirable responding. *European Journal of Personality,* 8, 385 – 393.

Vicente, K. (1999). *Cognitive work analysis. Toward safe, productive, and healthy computer-based work*. London: Lawrence Erlbaum.

Vicente, K. (2000). Work domain analysis and task analysis: a difference that matters. In Schraagen, J.M., Chipman, S.F. & Shalin, V.L. (Eds.), *Cognitive task analysis*. Mahwah: Lawrence Erlbaum.

van Vuuren, W. (2000). Cultural influences on risks and risk management: six case studies. *Safety Science,* 34, 31–45.

Wahlström, B. & Kettunen, J. (2000). *An international benchmark on safety review practices at nuclear power plants*. Espoo: VTT. VTT Tiedotteita – Research Notes 2015. 54 p. + app. 19 p.

Walter, D. (2000). Competency-based on-the-job training for aviation maintenance and inspection – a human factors approach. *International Journal of Industrial Ergonomics,* 26, 249–259.

Waring, A. (1996). *Safety management systems*. London: Chapman & Hall.

Waring, A.E. & Glendon, A.I. (1998). *Managing risk*. Thomson.

Weber, M. (1978). *Economy and society.* Berkeley CA: University of California Press.

Weeks, J. (2004). *Unpopular culture. The ritual of complaint in a British bank.* Chicago: University of Chicago Press.

Weeks, J. & Galunic, C. (2003). A theory of the cultural evolution of the firm: The intra-organizational ecology of memes. *Organization Studies,* 24, 1309–1352.

Weick, K.E. (1979). *The social psychology of organizing. 2nd ed*. Reading, MA: Addison–Wesley.

Weick, K.E. (1987). Organizational culture as a source of high reliability. *California Management Review,* 29, 112–127.

Weick, K.E. (1993a). Sensemaking in organizations: Small structures with large consequences. In J.K. Murnigham (Ed.), *Social psychology in organizations: Advances in theory and research*. Englewood Cliffs, NJ: Prentice Hall.

Weick, K.E. (1993b). Organizational redesign as improvisation. In G.P. Huber & W.H. Glick (Eds.), *Organizational change and redesign: Ideas and insights for improving performance*. Oxford: Oxford University Press.

Weick. K.E. (1995). *Sensemaking in organizations*. Thousand Oaks: Sage.

Weick. K.E. (1998). Foresights of failure: an appreciation of Barry Turner. *Journal of Contingencies and Crisis Management,* 6, 72–75.

Weick, K.E & Roberts, K.H. (1993). Collective mind in organizations: Heedful interrelating on flight decks. *Administrative Science Quarterly,* 38, 357–381.

Weick, K.E. & Sutcliffe, K.M. (2001). *Managing the unexpected. Assuring high performance in an age of complexity*. San Francisco: Jossey–Bass.

Weick, K.E., Sutcliffe, K.M., Obstfeld, D. (1999). Organising for high reliability: processes of collective mindfulness. *Research in Organisational Behaviour,* 21, 81–123

Weick, K. E., Sutcliffe, K. M. & Obstfeld, D. (2005). Organizing and the process of sensemaking. *Organization Science,* 16, 409–421.

Wickens, C.D., Lee, J.D., Liu, Y. & Becker, S.E.G. (2004). *An introduction to human factors engineering*. Second Edition. New Jersey: Prentice Hall.

Wiener, Y. (1988). Forms of value systems: A focus on organizational effectiveness and cultural change and maintenance. *Academy of Management Review*, 13, 534–545.

Wildavsky, A. (1988). *Searching for safety*. New Brunswick, N.J.: Transaction Books.

Wilderom, C.P.M., Glunk, U. & Maslowski, R. (2000). Organizational culture as a predictor of organizational performance. In N.M. Ashkanasy, C.P.M. Wilderom & M.F. Peterson (Eds.), *Handbook of organizational culture & climate*. Thousand Oaks: Sage.

Wilkins, A.L. & Ouchi, W.G. (1983). Efficient cultures: Exploring the relationship between culture and organizational performance. *Administrative Science Quarterly*, 28, 468–481.

Williamson, O.E. (1975). *Markets and hierarchies: Analysis and antitrust implications*. New York: Free Press.

Williamson, A.M., Feyer, A.-M., Cairns, D. & Biancotti, D. (1997). The development of a measure of safety climate: The role of safety perceptions and attitudes. *Safety Science*, 25, 15-27.

Woods, D.D. (2006). Essential characteristics of resilience. In E. Hollnagel, D.D. Woods & N. Leveson (Eds.), *Resilience engineering. Concepts and precepts*. Aldeshot: Ashgate.

Woods, D.D. & Hollnagel, E. (2006). Prologue: Resilience engineering concepts. In E. Hollnagel, D.D. Woods & N. Leveson (Eds.), *Resilience engineering. Concepts and precepts*. Aldeshot: Ashgate.

Woods, D.D., Johannesen, L.J., Cook, R.I. & Sarter, N.B. (1994). *Behind human error: Cognitive systems, computers, and hindsight*. State-of-the-Art Report. SOAR CSERIAC 94-01. Ohio, Columbus: The Ohio State University.

Wright, C. (1994a). A fallible safety system: institutionalised irrationality in the offshore oil and gas industry. *The Sociological Review,* 38, 79–103.

Wright, S. (1994b). 'Culture' in anthropology and organizational studies. In S. Wright (Ed.), *Anthropology of organizations*. London: Routledge.

Yauch, C.A. & Steudel, H.J. (2003). Complementary use of qualitative and quantitative cultural assessment methods. *Organizational Research Methods,* 6, 465–481.

Yin, R.K. (1994). *Case study research. Design and methods*. 2nd edition. Thousand Oaks: Sage.

Young, E. (1989). On the naming of the rose: interests and multiple meanings as elements of organizational culture. *Organization Studies,* 10, 187–206.

YVL 1.0. Safety criteria for design of nuclear power plants. Issued 12 Jan 1996. Regulatory Guides on nuclear safety (YVL), STUK.

Zuboff, S. (1988). *In the age of the smart machine: The future of work and power*. USA: Basic Books.

Appendix A: The interview questions utilised in the case studies

ONE'S OWN WORK

1. Tell us about your work. What is the central content of your work? What are your daily tasks and responsibilities?
2. What are the most demanding of difficult things in your work?
    - How do the difficulties manifest themselves?
    - Are there uncertainties in your tasks?
    - How do you cope with difficulties / uncertainties?
3. What motivates you in your job?
    - What is interesting in your job? What is dull?
    - Do you enjoy challenges in your work or do you prefer predictability and stability?
4. Tell us some event from your work that has been significant in some way (You have learned something, realised something etc.)
5. Has your job changed? How?
    - have the tools you are utilizing changed? what computer systems do you utilise in your work?
6. How do you know you have done your job well? (What does 'good quality' mean in your work)
    - How can you ensure it?
7. How can you tell that somebody is expert in your work?
8. How does one achieve expertise in this work?
9. What is the role of rules and instructions in your work?

MAINTENANCE TASK

Introduction: Think about the maintenance of a nuclear power plant in general

10. What is the goal or the core task of maintenance?
11. What is critical in achieving it?
    - What uncertainties are connected to its achievement? (On what it is dependent?)
    - *How do you know how well the maintenance is functioning (department heads)*

12. Do you have an overview of the condition of the plant? Should you have? How do you achieve it? [Not asked at the Loviisa case study]
13. How you are personally able to influence that maintenance fulfils its goals?

ORGANIZATION / ORGANIZING OF WORK

Introduction: think about your own power plant.

14. Is the organizing of the maintenance activities currently optimal?
    - If there are problems, how do they manifest themselves in practice?
15. Are the interfaces between different branches clear?
16. How do the different branches perceive you / how do you perceive them? (electrical, mechanical, operations, planning)
    - appreciation, attitudes towards each other
    - cooperation, communication, information exchange

ORGANIZATIONAL CULTURE

17. How would you describe the organizational culture of [the plant]?
    - Are there subcultures? (different branches, age, occupational groups)
    - What kind of climate there is
18. In every organization there are plenty of stories or legends, e.g. about some heroic deeds, bad mistakes, the "good old times" or something that are e.g. told to newcomers. Do you remember one that is told here?
19. Final question, what are currently the most important targets for development in the maintenance activities at [the plant]?

Do you have something in mind that you would like to add or ask us?

Appendix B: The CULTURE02-questionnaire as used at Olkiluoto NPP in 2002

Maintenance culture at TVO
(NKS/MainCulture)

This survey is part of the Nordic nuclear safety research program (NKS) and its project MainCulture. The aim of the project is to assess and develop maintenance activities in Finnish and Swedish power plants. A further aim of the research is to develop the maintenance culture at the participating power plants. In connection to the project personnel interviews were carried out at TVO in 5–6.9. In this survey everyone has an opportunity to tell his/her view on the culture of maintenance, one's own work, and how these could be developed.

The research is carried out by Teemu Reiman and Pia Oedewald (VTT) in Finland, and Carl Rollenhagen and Irene Eriksson (Mälardalen University) in Sweden.

The questionnaire is confidential and the responses will be treated in a manner where individual persons are not recognisable. Results will be presented in feedback and development seminars at TVO and in a joint research report to the NKS.

Please return the questionnaire in the enclosed envelope by September 30, 2002 to VTT.

Teemu Reiman, project manager
teemu.reiman@vtt.fi

VTT Industrial Systems
PL 1301, 02044 Espoo

PART 1

PLEASE READ THESE INSTRUCTIONS BEFORE ANSWERING.

In this page there are 35 statements. Rate to what extent you perceive that the following statements are **valued at your office** and circle the corresponding number. Your response should indicate your **personal feeling** of whether or not the given issue is valued at your office.

		Not at all					Very high degree
1	Initiative	1	2	3	4	5	6
2	Well-defined tasks	1	2	3	4	5	6
3	Avoidance of all risks	1	2	3	4	5	6
4	Financial objectives	1	2	3	4	5	6
5	Systematic way of work	1	2	3	4	5	6
6	Open communication	1	2	3	4	5	6
7	Feedback	1	2	3	4	5	6
8	Personnel development	1	2	3	4	5	6
9	Goal setting	1	2	3	4	5	6
10	Collective responsibility	1	2	3	4	5	6
11	Rule following	1	2	3	4	5	6
12	Questioning old beliefs and practices	1	2	3	4	5	6
13	Centralised decision making	1	2	3	4	5	6
14	Mutual trust	1	2	3	4	5	6
15	Independent decision making	1	2	3	4	5	6
16	Flexibility	1	2	3	4	5	6
17	Proficiency in work	1	2	3	4	5	6
18	To reach the goals we set	1	2	3	4	5	6
19	Continuous development	1	2	3	4	5	6
20	Cost-effectiveness	1	2	3	4	5	6
21	Not giving up / Persistence	1	2	3	4	5	6
22	Possibilities offered by new technology	1	2	3	4	5	6
23	Autonomy from the parent company	1	2	3	4	5	6
24	Occupational safety	1	2	3	4	5	6
25	Admitting one's own mistakes	1	2	3	4	5	6
26	Openness for new ideas / techniques	1	2	3	4	5	6
27	Learning	1	2	3	4	5	6
28	Carefulness	1	2	3	4	5	6
29	Individual responsibility	1	2	3	4	5	6
30	Wellbeing of the personnel	1	2	3	4	5	6
31	Cooperation	1	2	3	4	5	6
32	Efficient work tasks	1	2	3	4	5	6
33	Questioning new ideas	1	2	3	4	5	6
34	Determined leading	1	2	3	4	5	6
35	Group autonomy	1	2	3	4	5	6

PART 2

PLEASE READ THESE INSTRUCTIONS BEFORE ANSWERING.

In this part there are short statements about your organisation and your job. Think of yourself as a worker and a member of Olkiluoto NPP. Mark how well the statements describe your job and your organisation by circling the corresponding number.

		Not at all	Very little	Little	Some	Much	Very high degree
1	I do my job exactly according to instructions	1	2	3	4	5	6
2	I have a clear picture of my responsibilities and powers	1	2	3	4	5	6
3	My work tasks are clearly defined	1	2	3	4	5	6
4	The content of my job is interesting	1	2	3	4	5	6
5	The content of my job is motivating	1	2	3	4	5	6
6	My superior gives me constructive feedback	1	2	3	4	5	6
7	I have clear goals for my work	1	2	3	4	5	6
8	I feel that the work I am doing is important	1	2	3	4	5	6
9	As a whole, my job is stressful	1	2	3	4	5	6
10	I have a demanding work	1	2	3	4	5	6
11	The working climate in my branch is good	1	2	3	4	5	6
12	I am able to perceive the outcome of my work	1	2	3	4	5	6
13	I have a clear picture of how my work contributes to the overall goals of this organisation	1	2	3	4	5	6
14	I think it is important to reflect my working practices	1	2	3	4	5	6
15	When I have come across maladies in my work I have been able to bring them to open discussion at my branch	1	2	3	4	5	6
16	I am on good terms with my colleagues	1	2	3	4	5	6
17	I know on what basis my work is assessed	1	2	3	4	5	6
18	I actively develop my skills	1	2	3	4	5	6
19	I can cope with my tasks	1	2	3	4	5	6
20	I strive to work more efficiently	1	2	3	4	5	6
21	I make sure that my tasks lead to the desired outcome	1	2	3	4	5	6
22	The amount of bureaucracy in my organisation affects my job motivation negatively	1	2	3	4	5	6
23	It is difficult to find the needed resources in unexpected situations	1	2	3	4	5	6
24	It is better NOT to admit one's mistakes	1	2	3	4	5	6
25	I generally enjoy challenges in my work	1	2	3	4	5	6
26	Considering all things, I am generally satisfied with my job	1	2	3	4	5	6
27	My job tasks are varied	1	2	3	4	5	6
28	I would hope to get more responsibility	1	2	3	4	5	6
29	I am able to have an influence on the way I carry out my work	1	2	3	4	5	6
30	I always have enough time to do my job carefully	1	2	3	4	5	6
31	In my work, safety and efficiency are often in conflict	1	2	3	4	5	6
32	I am able to have an influence on the quality of my work	1	2	3	4	5	6

PART 3

PLEASE READ THESE INSTRUCTIONS BEFORE ANSWERING.

In this part there are short statements about maintenance work. Think of nuclear power plant maintenance in general. Mark how well the statements describe the demands of maintenance task by circling the corresponding number.

		Not at all agree	Not agree	Some-what not agree	Some-what agree	Agree	Totally agree
1	The outcome of the work has to be ascertained by oneself	1	2	3	4	5	6
2	It is possible to go beside bureaucracy without affecting the safety of the plant	1	2	3	4	5	6
3	Everybody has to take economy into account	1	2	3	4	5	6
4	One has to work with incomplete information about the task	1	2	3	4	5	6
5	Knowledge sharing is imperative to effective maintenance	1	2	3	4	5	6
6	By following the rules, one is relieved of personal responsibility	1	2	3	4	5	6
7	Assessment of the effects and results of actions is essential requirement of maintenance	1	2	3	4	5	6
8	One has to have excess resources in order to be able to take care of sudden incidents	1	2	3	4	5	6
9	Economy contradicts to safety	1	2	3	4	5	6
10	If one is uncertain, one should not do anything	1	2	3	4	5	6
11	One should never deviate from the plans	1	2	3	4	5	6
12	It is possible to predict the effects of work tasks that are carried out	1	2	3	4	5	6
13	In order to carry out work tasks, close cooperation between different fields is required	1	2	3	4	5	6
14	Unexpected things always happen	1	2	3	4	5	6
15	It is everyone's responsibility to develop the plant	1	2	3	4	5	6
16	It is essential for everybody to know the reasons behind the rules	1	2	3	4	5	6
17	Bureaucracy is needed in order to guarantee safety	1	2	3	4	5	6
18	Careful planning does not contradict with efficiency	1	2	3	4	5	6
19	Getting along with people is paramount to working in maintenance	1	2	3	4	5	6
20	Anticipating and planning are essential requirements of maintenance	1	2	3	4	5	6
21	Working according to the detailed instructions hinders expertise	1	2	3	4	5	6
22	Reacting to unanticipated events is most essential in maintenance	1	2	3	4	5	6
23	Rules have to be interpreted depending on the unique situations	1	2	3	4	5	6
24	Everybody has to know a little about each others' specialities	1	2	3	4	5	6
25	In situations that require quick reacting it is enough to simply follow the rules	1	2	3	4	5	6
26	Strict documentation of committed operations contributes to learning	1	2	3	4	5	6
27	Maintenance functions most effectively when one is given a change to concentrate purely on one's own special field	1	2	3	4	5	6

PART 4

PLEASE READ THESE INSTRUCTIONS BEFORE ANSWERING.

Now that you have responded to the values as perceived in your department, to questions about your own job, and about the core task of maintenance, we ask you to mark **how much**, in your opinion, these values **should be endorsed** in your office. Try to use the whole scale.

		Not at all					Very high degree
1	Initiative	1	2	3	4	5	6
2	Well-defined tasks	1	2	3	4	5	6
3	Avoidance of all risks	1	2	3	4	5	6
4	Financial objectives	1	2	3	4	5	6
5	Systematic way of work	1	2	3	4	5	6
6	Open communication	1	2	3	4	5	6
7	Feedback	1	2	3	4	5	6
8	Personnel development	1	2	3	4	5	6
9	Goal setting	1	2	3	4	5	6
10	Collective responsibility	1	2	3	4	5	6
11	Rule following	1	2	3	4	5	6
12	Questioning old beliefs and practices	1	2	3	4	5	6
13	Centralised decision making	1	2	3	4	5	6
14	Mutual trust	1	2	3	4	5	6
15	Independent decision making	1	2	3	4	5	6
16	Flexibility	1	2	3	4	5	6
17	Proficiency in work	1	2	3	4	5	6
18	To reach the goals we set	1	2	3	4	5	6
19	Continuous development	1	2	3	4	5	6
20	Cost-effectiveness	1	2	3	4	5	6
21	Not giving up / Persistence	1	2	3	4	5	6
22	Possibilities offered by new technology	1	2	3	4	5	6
23	Autonomy from the parent company	1	2	3	4	5	6
24	Occupational safety	1	2	3	4	5	6
25	Admitting one's own mistakes	1	2	3	4	5	6
26	Openness for new ideas / techniques	1	2	3	4	5	6
27	Learning	1	2	3	4	5	6
28	Carefulness	1	2	3	4	5	6
29	Individual responsibility	1	2	3	4	5	6
30	Wellbeing of the personnel	1	2	3	4	5	6
31	Cooperation	1	2	3	4	5	6
32	Efficient work tasks	1	2	3	4	5	6
33	Questioning new ideas	1	2	3	4	5	6
34	Determined leading	1	2	3	4	5	6
35	Group autonomy	1	2	3	4	5	6

What are the main strengths of the maintenance activities at your plant Olkiluoto NPP:

____
____
____
____
____

What are the main weaknesses of the maintenance activities at Olkiluoto NPP:

____
____
____
____
____

BACKGROUND INFORMATION

At next section there are some questions about you and your organisation. Circle the corresponding choice or write your answer.

1. Age
    1. Under 25
    2. 25–35
    3. 36–45
    4. 46–55
    5. over 55

2. Education ____

3. Period of employment (same tasks) ______ years

4. Period of employment at Olkiluoto ______ years

Work task: ____

Office and group: ____

THANK YOU!

RESPONSES WILL BE HANDLED CONFIDENTIALLY!

Appendix C: The CULTURE06-questionnaire as used at Olkiluoto NPP in 2006

Organizational culture in TVO maintenance

This questionnaire is part of the national nuclear safety research programme SAFIR and its project CULMA. The questionnaire is a continuation of a survey of the maintenance culture conducted in 2002. In this survey everyone has an opportunity to tell his/her view on the culture of maintenance, one's own work, and how these could be developed.

The project is carried out by Teemu Reiman and Pia Oedewald (VTT).

The questionnaire is confidential and the responses will be treated in a manner where individual persons are not recognisable.

Please return the questionnaire in the enclosed envelope by February 10, 2006 to VTT.

Teemu Reiman and Pia Oedewald

VTT Industrial Systems
PL 1000, 02044 Espoo

Section A. PLEASE READ THESE INSTRUCTIONS BEFORE ANSWERING.

In this page there are 36 statements. Rate **to what extent** you perceive that the following statements are **valued** at your organization. Circle the corresponding number. Your response should indicate your **personal feeling** of whether or not the given statement is considered important in your organization.

		Not at all					Very much
1	Initiative	1	2	3	4	5	6
2	Definition of clear responsibility areas	1	2	3	4	5	6
3	Avoidance of all risks	1	2	3	4	5	6
4	Financial goals	1	2	3	4	5	6
5	Systematic way of working	1	2	3	4	5	6
6	Open communication	1	2	3	4	5	6
7	Personnel development	1	2	3	4	5	6
8	Goal setting	1	2	3	4	5	6
9	Shared/collective responsibility	1	2	3	4	5	6
10	Prescription	1	2	3	4	5	6
11	Questioning of old routines	1	2	3	4	5	6
12	Centralized decision making	1	2	3	4	5	6
13	Mutual trust	1	2	3	4	5	6
14	Feedback	1	2	3	4	5	6
15	Autonomous/independent decision making	1	2	3	4	5	6
16	Flexibility	1	2	3	4	5	6
17	Personal proficiency	1	2	3	4	5	6
18	Goal achievement	1	2	3	4	5	6
19	Continuous development	1	2	3	4	5	6
20	Cost-effectiveness	1	2	3	4	5	6
21	Methodicalness	1	2	3	4	5	6
22	The possibilities of new technology	1	2	3	4	5	6
23	Personal responsibility	1	2	3	4	5	6
24	Occupational safety	1	2	3	4	5	6
25	Admitting one's own mistakes	1	2	3	4	5	6
26	Openness towards new ideas and techniques	1	2	3	4	5	6
27	Learning	1	2	3	4	5	6
28	Deliberation	1	2	3	4	5	6
29	Productivity / profitability	1	2	3	4	5	6
30	Personnel wellbeing	1	2	3	4	5	6
31	Individual	1	2	3	4	5	6
32	Efficient working	1	2	3	4	5	6
33	Quality	1	2	3	4	5	6
34	Co-operation	1	2	3	4	5	6
35	Goal-oriented leading/management	1	2	3	4	5	6
36	Nuclear safety	1	2	3	4	5	6

<u>Section B. PLEASE READ THESE INSTRUCTIONS BEFORE ANSWERING.</u>

In this part there are short statements about your organization and your job. Mark how well the statements describe **you and your job** by circling the corresponding number.

		Not at all					Very well
1	The work is organized smoothly	1	2	3	4	5	6
2	My work is interesting	1	2	3	4	5	6
3	My superior gives me constructive feedback	1	2	3	4	5	6
4	The goals of my work are clear	1	2	3	4	5	6
5	I feel that my work is important	1	2	3	4	5	6
6	My job is demanding	1	2	3	4	5	6
7	The working climate at my work community is good	1	2	3	4	5	6
8	I am able to perceive the outcome of my work	1	2	3	4	5	6
9	I have a clear picture of how my work contributes to the general goals of the organization	1	2	3	4	5	6
10	If things do not work out as intended at my work, I have a bad conscience	1	2	3	4	5	6
11	The flow of information at my organizations is sufficient	1	2	3	4	5	6
12	On the whole, my work is stressful	1	2	3	4	5	6
13	I know on what basis my work performance is assessed	1	2	3	4	5	6
14	I am on good terms with my colleagues	1	2	3	4	5	6
15	I can cope with my tasks	1	2	3	4	5	6
16	I always strive to do my work the best I can	1	2	3	4	5	6
17	I make certain that my work leads to the desired outcome	1	2	3	4	5	6
18	My work tasks are clearly defined	1	2	3	4	5	6
19	My workload is suitable	1	2	3	4	5	6
20	I bring out the errors I have made in my work myself	1	2	3	4	5	6
21	Considering all things, I am generally satisfied with my job	1	2	3	4	5	6
22	My job tasks are varied	1	2	3	4	5	6
23	It is mainly my responsibility that my work leads to the desired outcomes	1	2	3	4	5	6
24	I am always able to do my work thoroughly/with care	1	2	3	4	5	6
25	My co-workers are committed to taking care of safety	1	2	3	4	5	6
26	I am able to influence the quality of my work	1	2	3	4	5	6
27	My work is motivating	1	2	3	4	5	6
28	I often have rush in my work	1	2	3	4	5	6
29	It is mainly my supervisor's responsibility that my work leads to the desired outcomes	1	2	3	4	5	6
30	I am satisfied with my wages	1	2	3	4	5	6

SECTION B. CONTINUES

Mark how well the statements describe **you and your job** by circling the corresponding number.

		Not at all					Very well
31	My work has an effect on nuclear safety	1	2	3	4	5	6
32	It is only a matter of time before my work leads to an incident/accident	1	2	3	4	5	6
33	The probability of accidents is quite high at my workplace	1	2	3	4	5	6
34	I am rarely worried about accidents at my job	1	2	3	4	5	6
35	I am clear about what my responsibilities are concerning health and safety	1	2	3	4	5	6
36	If I worried about safety I would never get my job done	1	2	3	4	5	6
37	All accidents are not preventable	1	2	3	4	5	6
38	In my opinion [the organization] has a clear and long term safety policy	1	2	3	4	5	6
39	The safety of the plant has worried me often recently	1	2	3	4	5	6

SECTION C. PLEASE READ THESE INSTRUCTIONS BEFORE ANSWERING.

In this part there are short statements about Olkiluoto NPP maintenance. Think of maintenance work in general. Mark how well the statements hold true by circling the corresponding number.

		Completely disagree					Completely agree
1	By following procedures/rules one is relieved of personal responsibility	1	2	3	4	5	6
2	Everybody has to take the financial issues of the work into account	1	2	3	4	5	6
3	Every employee should have a good general view of the functioning of the plant	1	2	3	4	5	6
4	The effects/consequences of the work activities are known in advance	1	2	3	4	5	6
5	Surprising things happen often in the daily work.	1	2	3	4	5	6
6	It is everyone's responsibility to develop one’s own work and the organization	1	2	3	4	5	6
7	Work functions most effectively when one is given a change to concentrate purely on one's own special field	1	2	3	4	5	6
8	The work involves things/phenomena, of which new information is continually discovered	1	2	3	4	5	6
9	It is better to be too careful than too hasty at this work	1	2	3	4	5	6
10	The work contribution of a single person affects substantially the performance of the entire organization	1	2	3	4	5	6
11	The nature of the work and the tasks include plenty of uncertainties and unknown things	1	2	3	4	5	6
12	It is essential that everybody knows the reasons on which the rules and procedures are based on	1	2	3	4	5	6
13	Economy contradicts with safety	1	2	3	4	5	6
14	Rules and procedures have to be interpreted according to the situation at hand	1	2	3	4	5	6
15	Maintenance is appreciated at TVO	1	2	3	4	5	6
	The central requirement of maintenance is:						
16	to react quickly to unanticipated faults	1	2	3	4	5	6
17	to monitor the condition of the equipment and inspect the causes of failures	1	2	3	4	5	6
18	to anticipate the condition of the equipment and plan the needed measures	1	2	3	4	5	6
	Maintenance work requires especially:						
19	ability to work rapidly	1	2	3	4	5	6
20	theoretical knowledge	1	2	3	4	5	6
21	ability to endure pressure/strain	1	2	3	4	5	6
22	ability to prioritize tasks and issues	1	2	3	4	5	6
23	carefulness/deliberation	1	2	3	4	5	6
24	ability to understand complex phenomena	1	2	3	4	5	6
25	problem solving ability	1	2	3	4	5	6
26	courage to make decisions	1	2	3	4	5	6
	At the organization the following should be valued especially:						
27	personnel wellbeing and cooperation	1	2	3	4	5	6
28	financial issues and cost-effectiveness	1	2	3	4	5	6
29	development and innovation	1	2	3	4	5	6
30	efficiency	1	2	3	4	5	6
31	safety and deliberation	1	2	3	4	5	6
32	methodicalness and systematicalness	1	2	3	4	5	6
33	autonomony and initiative	1	2	3	4	5	6

In your opinion, what are the main strengths of the maintenance activities at TVO:

____
____
____
____
____

In your opinion, what are the main development targets / weaknesses of the maintenance activities at TVO:

____
____
____
____
____

What issues in maintenance have particularly developed during the past two or three years:

____
____
____
____

BACKGROUND INFORMATION

At next section there are some questions about You and Your organisation. Circle the corresponding choice or write your answer.

1. Age 1. under 25 2. 25–35 3. 36–45 4. 46–55 5. over 55

2. Education ____

3. Time spent in the same task ______ years

4. Tenure at TVO ______ years

Task: ____

Office and group: ____

THANK YOU!

THE RESPONSES WILL BE DEALT WITH CONFIDENTIALLY!

Appendix D: Development of the CULTURE-questionnaire

Pilot study at the Radiation and Nuclear Safety Authority of Finland

The CULTURE-questionnaire is based in part on the experiences of the assessment of organizational culture in the department of Nuclear Reactor Regulation (YTO) at the Radiation and Nuclear Safety Authority of Finland (STUK) in 1999 (Reiman, 2001). In the assessment, the First Organizational Cultural Unified Search (FOCUS) questionnaire by De Witte and Van Muijen (1994) was used[17] together with additional questions generated specifically for the purposes of the current study.

Interviews, document analysis, survey and development seminars were used to characterise the organizational culture at YTO (Reiman, 2001). The results of the interviews and document analysis were used for tailoring the FOCUS questionnaire to better fit the safety-critical domain in question. Some context-specific questions were also added. The FOCUS-questionnaire was based on Cameron and Quinn's (1988, 1999) competing values model (see below). After modifications, the extended FOCUS-questionnaire was distributed to the entire staff of YTO (Reiman, 2001; Reiman & Norros, 2002).

In order to characterise different organizational cultures, Cameron and Quinn (1988, 1999; see also Quinn & Rohrbaugh, 1983; Cameron, 1986) have proposed an approach called the competing values framework. The framework has been developed through empirical research on organizational effectiveness and on the relation between the various criteria used to evaluate effectiveness.

[17] We are grateful for Prof. Eila Järvenpää for providing us the opportunity to utilize the FOCUS-questionnaire.

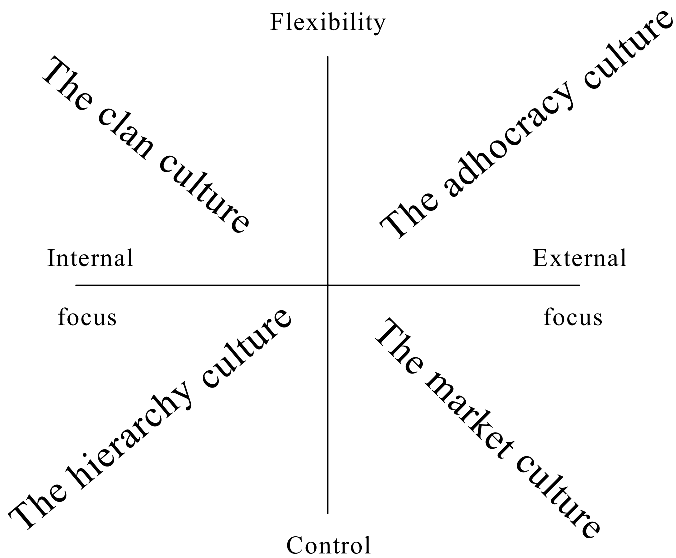

Figure D1. Cameron and Quinn's (1988, 1999) competing values framework.

According to this theory, organizations can be viewed along two dimensions (see Figure D1): focus on internal processes versus focus on external processes and focus on control versus focus on flexibility. Together, these two dimensions form four quadrants from which four dominant culture types emerge. In a culture where hierarchy values are dominant, procedures govern what people do and stability, predictability and efficiency are considered to be long-term concerns of the organization. An organization with a dominant market culture values productivity and competitiveness by strongly emphasising external positioning and control. The workplace is highly result-oriented. A clan culture values cohesion, participativeness, teamwork and commitment. An adhocracy culture has the fostering of adaptability, flexibility and creativity as a major goal. Readiness for change is advocated. (Cameron & Quinn, 1999)

In the first part of the FOCUS-questionnaire ("descriptive" part), the respondent was asked to answer descriptive ”how many" and "how often" questions (e.g. how often tasks are conducted according to specified procedures). The second part ("value" part) had statements about organizational characteristics (such as risk taking, openness to criticism) and the respondent was asked how characteristic of his/her organization they were. Additional, more "focused" questions/statements were included into both parts of the FOCUS-questionnaire, such as the values of “initiative”, “collective responsibility”, “safety” and “centralized decision making”. Response scale in all the questions was from 1 to 6.

In addition to the two measures of FOCUS-questionnaire, a third measure dealing with perception of one’s own work was constructed for the purposes of the study (Reiman, 2001). FOCUS lacked an individual dimension; how the work and the culture are experienced on a subjective level. Three dimensions were included to that measure; job satisfaction, personal sense of control and feeling of competence (based on the ideas of Lazarus and Folkman [1984] and Karasek and Theorell [1990]) and role clarity (see e.g. Koch, 1993; Jacobs & Haber, 1994; NRC, 1998). Interviews at the target organization (YTO) and the above mentioned literature was used in constructing the measure. The measure included 13 questions and an instruction (”Do you agree with the following statements?”):

1. I have a clear picture of my responsibility areas and my authority concerning issues related to my work.
2. My work is interesting and motivating in content.
3. I know exactly the responsibility areas of my closest coworkers.
4. My superior gives me clear and constructive feedback.
5. I feel that my work also has a societal significance.
6. Overall, my work is very stressful.
7. My work tasks are sometimes too demanding.
8. The fact that decisions have to be made on the basis of insufficient information especially increases the strenuousness of my work.
9. I am able to perceive the outcome of my work.
10. I have a clear picture of how my work contributes to the overall goals of my organization.
11. My superior knows my competence areas.
12. All things considered, I am satisfied with my job and my work place.
13. I find it difficult to assess the level of my competence and need for training.

Based on the analysis of the data (n=36), two factors emerged from the third measure; “meaningfulness of the work” (questions 1, 2, 4, 5, 9, 10, 11, 12) and “lack of control” (questions 6, 7, 8, 13), with alphas of 0.88 and 0.74, respectively (Reiman, 2001).

Of the third measure, nine questions (1, 2, 4, 5, 6, 7, 9, 10, 12) were used in CULTURE01, with some of them slightly revised, and all but the first question still exist in some form in the CULTURE06-questionnaire. Thus, almost all of the questions measuring meaningfulness, and half of the questions measuring lack of control were selected for the CULTURE01-questionnaire.

CULTURE01-questionnaire

On the basis of the STUK case study, it was concluded that in a survey the respondents should be explicitly asked to think about the values prevalent in his/her organization (Reiman, 2001, p. 71). These perceived values could then be compared to the characteristics of one’s own work and to the perceived requirements the maintenance task. Furthermore, it was not clear what aspects of organizational culture the two parts of the FOCUS-questionnaire were actually measuring.

Three measures were constructed: perceived values, characteristics of one’s own work and perceptions of the maintenance task. The pilot version of the CULTURE-questionnaire thus consisted of measures for:

- (A) Perceived values in one’s own organizational group (32 statements)
- (B) Conceptions concerning one's own work (40 questions), which was broken down into two measures in the analysis; measure of psychological characteristics related to work and measure of individual perceptions and conceptions
- (C) Conceptions of the maintenance core task (23 statements).

The competing values framework of Cameron and Quinn (1999) was taken as a theoretical background for the measure. It was chosen for three main reasons: (1) it was general enough to grasp the different features of organizational culture, (2) it describes culture as including tensions between different values, which is one of the challenges in safety critical organizations, and (3) the framework has been validated in a number of studies (Cameron & Quinn, 1988, 1999; Kalliath et al., 1999) including the pilot study (Reiman, 2001). Value statements were also supplemented with statements from the previous studies of safety critical organizations (Reiman, 2001; Koch, 1993; NRC, 1998), and on the basis of the results of the preliminary interviews and focus group work at Loviisa NPP (see Table 2 and Section 4.2).

Ideal values were measured by asking each respondent to circle five values from the perceived values section that they considered to be most important to their organizational group. However, the data on the five ideal values were found quite useless in the analysis, except as a heuristic tool in a few conversations with the personnel. It was clear that in the next version a different measure was needed to grasp the ideal values of the workplace. The questionnaire also included one open question: "In your opinion, what are the main development targets / weaknesses of the maintenance activities at X?"

In the B section, the questions measuring psychological characteristics related to work (16) were formed on the basis of the theoretical Job Characteristics Model (JCM) (see Hackman & Lawler, 1971), Job Diagnostic Survey (Hackman & Oldham, 1975, 1980) and the results of the previous studies (e.g. Reiman, 2001; Reiman & Norros, 2002; Koch, 1993) in safety critical organizations. The JCM was found to fit the results from a grounded theory based analysis of the motivating aspects of the maintenance personnel's work in the interviews (see Table 2). Thus, questions measuring the psychological states were added to the questionnaire. Some of the existing questions (see above) already measured similar characteristics and for that reason only a few extra questions were needed.

According to Hackman's et al. (Hackman & Lawler, 1971; Hackman & Oldham, 1975, 1980) Job Characteristics Model (JCM), high job satisfaction, motivation and high quality of work performance can be acquired if the worker can achieve three psychological states:

- the work must be experienced as meaningful
- the worker must experience that he is personally responsible for the work outcome
- the worker must be able to determine what the outcome of his efforts are, what results are achieved and whether they are satisfactory.

The Job Characteristics Model (JCM) argues that five core job characteristics (skill variety, task identity, task significance, autonomy and feedback) influence the three critical psychological states (Hackman & Lawler, 1971). Since no objective data about the characteristics of the respondents' jobs could be collected, it was plausible to measure the psychological states directly. Furthermore, Hackman and Lawler (1971) emphasise that it is not the objective state of the job characteristics that is essential to employee attitudes and behaviour but how they are *experienced* by the employees and what the employees *perceive*. Also, substantial corroboration for the linkage between the psychological states and job satisfaction exists, but not so much for the linkage between the objective job characteristics and job satisfaction (see Fried & Ferris, 1987). The cultural elements (Figure 3) of structure, integration and conceptions influence the psychological states. Thus, by measuring the psychological states we gain information on how the elements of the organizational culture are experienced subjectively.

The questions measuring individual perceptions and conceptions (23) were formed on the basis of previous studies (Reiman & Norros, 2002; see also Koch, 1993) and Cameron and Quinn's (1999) model. The questions were initially designed to measure each of the four competing values sectors (Cameron & Quinn, 1999), as they would actualise in the respondent's own work.

Twenty three items, each rated on a six-point Likert-type scale, were related to the general and particular demands of the maintenance work at a nuclear power plant. In the core task modelling (Table 2 and *Article I*) we identified tensions between the different demands of the maintenance core task. The questions of the core task instrument were constructed on the basis of these tensions. For example, we identified a tension between relying on plans and acting in unanticipated situations. This was measured with questions such as "unexpected things happen unavoidably" and "the effects of actions are known in advance".

Results of a grounded-theory-based (see e.g. Charmaz, 1995) analysis of the interviews (see Table 2) were utilised in wording the questions. A pilot study was conducted by forming a "focus" group with the maintenance experts from the target organisation and by going through the questionnaire question by question. Obscure questions were revised. The validity and reliability of the CULTURE01-questionnaire is inspected in *Article II* (see also Table D1).

Table D1. Reliabilities (coefficient alphas), mean scores and standard deviations of the summated scales of the CULTURE01-questionnaire (n = 135).

Variables	Items	α	Mean	SD
Value instrument				
Financial and efficiency	4	0,75	3,87	0,98
Safety and deliberation	5	0,80	4,13	0,87
Change and development	4	0,81	2,77	0,93
Hierarchy	3	0,63	3,68	0,96
Autonomy and proficiency	6	0,88	3,48	0,96
Cohesiveness	7	0,90	2,98	0,92
Psychological characteristics				
Feedback	4	0,75	3,47	0,96
Meaningfulness	3	0,73	4,35	0,94
Personal responsibility	4	0,62	4,42	0,71
Sense of control	4	0,52	4,28	0,74
Individual perceptions				
Management	5	0,72	2,77	0,82
Climate	5	0,59	4,10	0,70
Development orientation	5	0,61	4,15	0,63

α = Cronbach's alpha coefficient; SD = standard deviation.

Internal consistency of the measures was inspected by calculating a reliability coefficient (Cronbach's alpha coefficient, see e.g. Ghiselli et al., 1981, p. 256) for every summated scale (Table D1).

Four summated scales instead of three as Hackman and Lawler's model (1971) predicted were formed from the psychological characteristics related to work. A sense of control scale was formed that did not correspond with the measurement model. This scale measures the perception that one is in control of one's work and oneself as a worker. The scale was composed of four questions, "I always have enough time to do my job carefully" and "My job tasks are too demanding" (reverse scoring), “my work is stressful“ (reverse scoring), and “it is better not to admit one’s mistakes“ (reverse scoring). Questions initially hypothesised to measure meaningfulness or sense of personal responsibility loaded this factor.

The summated scales that were formed from the A-section factor loadings corresponded in some aspects with Cameron and Quinn's (1999) model, especially in the clan and market dimensions. The hierarchy focus was split into two scales, a measure of the bureaucracy and rules and a measure of the safety values and safety regulations. The adhocracy scale was also split into two scales; a measure of the developmental and questioning attitude and a measure of the individual expertise and initiative (see Table D1).

CULTURE02-questionnaire

After the pilot study changes were made to the questionnaire. At a kick-off seminar of the Olkiluoto NPP maintenance culture study at TVO, one of the maintenance personnel questioned why everybody always asks only for targets for improvement, and not the strengths and the things that should not be altered. A significant weakness in the CULTURE01 was thus revealed: contrary to the basic premises of the emerging theoretical framework (CAOC), the survey was made more from the point of view of spotting weaknesses in the given culture than spotting strengths. A second open question was thus added: "in your opinion, what are the main strengths of the maintenance activities at X".

A new measure was also added, a measure of the ideal values of the organization. This was done since the five ideal values of CULTURE01 were found quite useless. The measure included the same statements as the perceived values section but with an instruction to select how much the statements should be valued (see Appendix B).

One obscure question was removed from the A-section (the value statement “shared values of the maintenance unit”). Some questions were slightly modified (such as value statements “results”, “economic efficiency”, “innovativeness” to “reach the goals we set”, “cost-effectiveness”, “Openness for new ideas / techniques”, correspondingly). Four value statements – “learning”, “questioning new ideas”, “determined leading”, “group autonomy” – were added to the A-section.

The two measures of Section B of the pilot questionnaire were combined. Of the 40 questions in CULTURE01, 30 were used in the summated scales and 4 as control variables (see above). Eight questions – including one control question and one that was used in a summated scale – were removed from CULTURE02. Most of the removed questions were specific questions of interest to the project group tailoring the CULTURE01 questionnaire dealing with e.g. teamwork and socialisation of the newcomers. The questions were supposed to measure three psychological states; meaningfulness, sense of personal responsibility and feedback (see Hackman & Lawler, 1971; Hackman & Oldham, 1975, 1980). The pilot study identified a fourth psychological "state", sense of control (cf. Karasek & Theorell, 1990; Lazarus & Folkman, 1984). Two new questions measuring this concept were included in the B-section ("I can cope with my tasks", "Safety and efficiency are often in conflict in my work"). This was also an attempt to differentiate it better from the sense of personal responsibility dimension. Three personal work-related scales were identified in the pilot study: perception of the working climate, attitudes toward the management and personal development orientation. The questions related to these scales were included in the B-section of the CULTURE02-questionnaire. A total of 32 questions addressed the conceptions concerning one's own work and the organization.

The questionnaire had thus four measures:

- perceived values (35 statements)
- conceptions concerning one's own work (32 questions)
- conceptions of the maintenance core task (27 statements)
- ideal values (35 statements).

This version of the questionnaire was used at the assessment of maintenance culture at TVO and FKA (see Reiman et al., 2004a, *Article III* and Table D2).

Table D2. Reliabilities (coefficient alphas), mean scores and standard deviations of the summated scales of the CULTURE02-questionnaire (n = 84), from Reiman and Oedewald (2004).

	No. of items	alpha	Mean	SD
VALUES				
Efficiency	6	0,72	4,14	0,72
Hierarchy	7	0,68	4,10	0,60
Cohesiveness	5	0,90	3,38	1,07
Development	4	0,82	3,62	0,94
Flexibility	5	0,79	3,95	0,87
Safety	3	0,79	4,43	0,92
ONE'S OWN WORK				
Meaningfulness	4	0,79	4,52	0,72
Knowledge of expectations	5	0,83	4,32	0,77
Sense of control	4	0,62	3,71	0,80
Sense of personal resp.	4	0,63	4,83	0,47
Climate	4	0,64	4,58	0,66
Development orientation	5	0,75	4,40	0,61
IDEAL VALUES				
Efficiency	6	0,80	4,19	0,73
Hierarchy	7	0,73	3,98	0,74
Cohesiveness	5	0,61	5,10	0,47
Development	4	0,65	4,62	0,66
Flexibility	5	0,67	4,59	0,61
Safety	3	0,61	5,11	0,50

Depicted in Table D2 are the summated scales and their reliabilities, mean scores and standard deviations from the separate analysis of the TVO sample (Reiman & Oedewald, 2004). Summated scales in the ideal values section (Section D) were created on the basis of the factors loadings of the perceived values sections (A section). This was done in order to be able to compare the “gap” between perceived and ideal values.

Some notes about the three maintenance samples

The factor solution for the Section A seems to vary a bit between the samples, but the nature of the measured concept (perceptions of organizational values) means that one should not look for a universal model of how values are perceived. Rather the factor structure as such tells about the particular organizational culture and its value dimensions. Actually, a uniform value structure across organizations would be more an evidence against the functioning of the instrument than validation (cf. Hale, 2000, p. 8). This is due to the fact that it is hypothesized that the organizational culture has an influence on how organizational effectiveness is perceived and how different values or end-states (Rokeach, 1973) relate to each other, and what modes of conduct are socially preferable. This “consensus” is not necessarily even organization-wide and factor analysis can delimit the analysis to integration aspects of the sample (see Martin, 2002, p. 233).

Four to six factors seem to emerge from the case studies. At the Loviisa case study with CULTURE01, a six-factor structure was created where the financial values were clearly separated from the safety and hierarchy values (*Article II*). At the Olkiluoto case study (Reiman & Oedewald, 2004), a six-factor structure was created where the efficiency values were separated from the safety and hierarchy values. In the Forsmark sample, five factors emerged (Reiman et al., 2004a) with safety and hierarchy (rules) forming a common factor. Combined data from FKA and TVO produced four factors (*Article III*). This is not the most valid way of analysing the value section, as described above. The combined analysis was done in order to be able to compare the value scores of the organizations. Separate analyses of the samples are reported in Reiman et al. (2004a, see also Table D2 and Reiman and Oedewald [2004]) and the factor structure differs from that of the combined sample, as was expected (cf. Hale, 2000, p. 8).

The logic of analysis differed from that of Cameron and Quinn’s (1999). We did not aim at finding a dominant culture type (it would have been a “safety culture” in all the three case studies). Instead, we inspected the mean scores on all the value dimensions and the interrelation of the dimensions to the conceptions concerning one’s own work. Furthermore, we were interested in differences in the mean scores (or value perceptions) between different age groups, different tasks, or sections.

CULTURE03-questionnaire

Some minor changes were made to this version. They were mostly linguistic adjustment of the questions that were difficult to interpret by the respondents, or that did not seem to correlate with other questions (i.e. they were not used in the summated scales in the earlier version). A couple of obscure questions were removed from the A-section (value statements “persistence”, “questioning new ideas”, “group autonomy”, “autonomy from the owners of [parent company]”). Three value statements – “quality”, “individual”, and “nuclear safety” – were added to the A-section. Values of “quality” and “individual” were added to the questionnaire on the basis of group discussion with managers and experts of Finnish SME metal manufacturing firms (see Oedewald et al., 2005b). Nuclear safety was considered as being too obvious a value when the first version of the CULTURE-questionnaire was made. However, the case studies provided indications that it is not necessarily always an obvious value in NPP maintenance (see Section 5.3). One question was also added to the B-section (“If there are sudden technical problems in my area of responsibility, I feel that I have failed personally”). The measures were as follows:

- perceived values (36 statements)
- conceptions concerning one's own work (33 questions)
- conceptions of the maintenance core task (30 statements)
- ideal values (36 statements).

The 03-version of the questionnaire was used only for two case studies. Firstly, for the remeasure of Loviisa maintenance unit's culture (n = 100, see Reiman et al., 2006), and secondly, the B-section of the survey was used for a measure of the safety culture at the Helsinki anti-aircraft regiment by Flink (2004). The N of the sample was 51 of which 48 answered the B-section. In that study (ibid.), the factor structure of the B-section was very similar to that of the maintenance organizations studied in the present study: four factors emerged, meaningfulness of the work (alpha .88), feedback and the knowledge of expectations (.87), sense of control (.78), and development orientation (.69). Some interesting relations were found between the B-section and the questions directly related to the safety culture in the particular regiment. For example, the meaningfulness of work (which had the highest mean score of the four summated scales) was negatively associated (r = -.389, p = .006) with the question “during the last 12 months there has been an accident or accidents in my own work”. Feedback, on the other hand, was not associated with the accident statement, but it was negatively associated (r = -.351, p = .015) with the statement “during the last 12 months there has been a near-by miss or misses in my own work”. The meaningfulness dimension did not correlate statistically significantly with the “near-by miss” question. (Flink, 2004, p. 43)

CULTURE04-questionnaire

The fourth version of the questionnaire is almost identical to the third one. This version includes a couple of additional questions to B-section (“in my present job, I am motivated mainly by my wages“, “I am proud of the company I work in“, “the continuation of my work is uncertain”). These questions were formulated on the basis of a preliminary analysis of 55 CAOC-interviews conducted in a metal manufacturing sector of the Finnish SME-industry. This version was not used in NPP maintenance, but it has been used e.g. in 11 Finnish SME metal manufacturing companies (Oedewald et al., 2005a, 2005b). In the metal industry sample (n = 301), the C-section of the survey was constructed anew according to the principles of CAOC and the value statement “nuclear safety” was changed to “customer”.

CULTURE05 and CULTURE06 -questionnaires

Significant changes were made to the B- and C-sections of the questionnaire on the basis of accumulated data from various domains (see above). All the questions that had proved to have no discriminative validity or were for some other reasons not used in the summated scales were removed from the B-section. For example, the three questions added to the B-section of the fourth version of the questionnaire were removed.

The D-section was removed from the questionnaire and seven statements measuring the ideal values were included in the C-section. The statements were formulated on the basis of the A-section factor loadings of the previous versions of the questionnaire and the revised measurement model formed on the basis of the loadings.

The idea behind the C-section was changed so that it now included questions that would be used across domains and questions that would be tailored to the particular domain. This was done in order to be able to accumulate data also on the common characteristics and demands of the work in safety critical organizations across domains.

The measures were as follows:

- perceived values (36 statements)
- conceptions concerning one's own work (30 questions)
- conceptions of the organizational core task (26 general statements).

The CULTURE05 –questionnaire was used only in two logistics service organizations (n = 65), see Kurtti and Reiman (2006). The CULTURE06 – questionnaire has been used in the remeasure of TVO maintenance organization (n = 72, see Table D3), in TVO Power Plant Engineering (n = 50), in two hospital organizations (n = 440 and 176) and one private medical counselling call centre company (n = 52) (see also Oedewald & Reiman, 2006b). For the CULTURE06-questionnaire, some specific safety-related questions were added based on Cox and Cox (1991), Cox and Cheyne (2000), and Torsne and Rollenhagen (personal correspondence). Table D3 depicts the reliability coefficients (Cronbach's alpha coefficients) of the perceived values measure and the measure of conceptions concerning one's own work at the TVO maintenance culture 2006 sample.

Table D3. Alphas of the perceived values and conceptions concerning one's own work at the TVO maintenance culture 2006 sample (n = 72).

Variables	Items	α	Mean	SD
Value instrument				
Financial and efficiency	4	0,76	4,26	0,79
Safety and deliberation	3	0,68	5,12	0,65
Change and development	6	0,86	4,05	0,81
Systematicalness	6	0,73	4,43	0,60
Autonomy and proficiency	5	0,80	4,17	0,84
Cohesiveness	6	0,89	4,04	0,96
Psychological characteristics				
Meaningfulness	4	0,80	4,60	0,75
Knowledge of expectations	5	0,83	4,30	0,85
Personal responsibility	6	0,69	4,91	0,57
Sense of control	5	0,69	4,00	0,71
Climate	4	0,71	4,29	0,76

α = Cronbach's alpha efficient; SD = standard deviation.

It can be observed from Table D3 that all the alphas exceed 0.6 and only two of the eleven measures have an alpha slightly lower than 0.7.

The measurement model for the questionnaire is shown in Table D4. The reliability coefficient from the combined sample of three health care organizations is also shown in the table in order to indicate the functioning of the instrument in other domains. Alphas in the B-section are slightly lower than in the maintenance measure (Table D3), but still all alphas exceed 0.6.

Table D4. The measurement model of the CULTURE06-questionnaire. Question numbers refer to the questionnaire as depicted in Appendix C.

Measurement model A-section

Dimension	Questions	Alpha in combined health care sample (n = 668)
Cohesiveness and employee wellbeing	6,9,13,14,30,34	0,89
Financial values and efficiency	4,20,29,32	0,81
Development and change	7,11,19,22,26,27	0,85
Safety	3,24,28	0,70
Systematicalness and methodicalness	2,5,8,10,12,21	0,76
Autonomy and personal proficiency	1,15,16,17,23	0,85

Measurement model B-section

Dimension	Questions	Alpha in combined health care sample (n = 668)
Meaningfulness	2,5,6,22	0,78
Knowledge of expectations	4,8,9,13,18	0,74
Sense of personal responsibility	10,16,17,20,23,26	0,61
Sense of control	15,19,24,12[rev],28[rev]	0,67
Communication climate	3,7,11,14	0,66

In addition to using summated scales it is always beneficial to inspect the correlation matrix between different individual value statements in order to clarify how the relation of different values is perceived in the particular culture. For example, is collective responsibility seen to be linked with personnel wellbeing and co-operation or with prescription and systematic way of working? And with what value statements does “nuclear safety” (or patient safety in the health care sector) correlate?

Further development of the questionnaire

There is a clear response tendency is some of the questions, especially in the A-measure. Verkasalo and Lindeman (1994) state that instead of being a threat to validity, this "socially desirable responding" might indicate something about the respondents' personalities. In the same vein, it could be postulated that the response tendency of the personnel indicates something about the culture of the organization. Thus, the response tendency should not be removed by statistical means. It also interesting to note that more socially (or culturally) desirable responding seems to occur at the values measure when the personnel are instructed to think about their organization than when they are instructed to think about their own work.

Validation of the CULTURE-instrument focused firstly on its discriminant validity (e.g. statistical differences in scale scores by age or tenure in the organization, or by task or position in the organization and differences between the organizations). The CULTURE-instrument found differences within as well as between organizations. Cooper and Phillips (2004, p. 498) argue, in relation to measuring safety climate, that “any between sub-group differences merely inform about the degree to which the measure has reached its initial design goals” since “psychometric instruments are deliberately designed to discriminate people on various demographic dimensions”. Thus “they do not inform about the ability of the measure to assess or predict actual ongoing safety performance”. The discriminant validity of the questionnaire should only act as a starting point in deciding the validity of the instrument. The discriminant validity of the CULTURE01-survey has been described in depth in *Article II*.

The validity of the instrument has been inspected by different means. One means of validation is the usefulness of the obtained results in the development work. Although traditionally considered a criterion for qualitative research, the plausibility and credibility of the results to the personnel (Hammersley, 1990) can be considered an indication of the validity of the results, since the aim is also to change the culture. On the other hand, results deemed as unplausible by the personnel cannot be rejected outright, since the central aspects of the culture are taken for granted and sometimes responded to in a denying manner at first (see e.g. Schein, 1985). The research did not aim at finding performance indicators or other objective characteristics to validate the connection of the results to the operational reliability of the plant.

Some safety specific questions were added to the CULTURE06 questionnaire. A future research question is the relation of these questions to the other measures of the questionnaire. Also, a measure of felt accountability (Hochwarter et al., 2005) was added. The relation of this measure to other measures and especially to the sense of personal responsibility dimension remains to be tested. The new measure should also provide more evidence on the functioning of the sense of personal responsibility dimension. A measure of risk perceptions (cf. Slovic, 1987; Dedobbeleer & Beland, 1998) might also provide interesting information on the organizational culture to corroborate the already measured dimensions. Furthermore, measures from Morgeson and Humphrey's (2006) Work Design Questionnaire concerning especially the "knowledge characteristics" of the work might supplement the current measures of CULTURE-questionnaire.

Appendix E: Characteristics of the nuclear industry

Nuclear power plant (NPP) is a steam power plant that uses a nuclear reaction to generate the heat that is needed for boiling water, producing steam, and ultimately driving the steam turbine. In order to maintain a stable operating temperature in the reactor and transfer the heat from the reactor it is necessary to provide a coolant. The coolant material, which is water in Light Water Reactors (LWRs)[18], enters the core from below, is heated while passing upwards along the fuel rods and leaves the core at the top as either hot water at high pressure (in the pressurized water reactor, PWR) or as high pressure high temperature steam – water mixture (in the boiling water reactor, BWR). The steam drives one or more turbines connected to electric generators. In the PWR steam is generated at lower pressure on the secondary side of separate heat exchanger, steam generators. (Choppin et al., 2002; Sandberg, 2004)

The two nuclear power units of Loviisa are owned by Fortum Power and Heat and they are located on the island of Hästholmen by the Gulf of Finland. The first unit was commissioned and connected to the electricity net in 1977 and the second unit in 1980. Both units have VVER type pressurized water reactors (PWR) and the net electric power of each unit is 488 MWe. The two currently operating units of Olkiluoto are BWR types, and the third unit under construction will be a PWR. They are owned by Teollisuuden Voima Oy (TVO). Electricity generation at Olkiluoto 1 (OL1) started in September 1978. Olkiluoto 2 (OL2) was connected to the national grid in February 1980. At present, both units operate at a net capacity of 840 MW. In Sweden, the three reactors of Forsmark and the three reactors of Oskarshamn are all BWRs by type. Of the four reactors of Ringhals, three are PWRs and one is a BWR. (www.stuk.fi, www.tvo.fi, www.ski.se)

Nuclear power plants are technically complex and operationally demanding entities. They usually incorporate divergent technologies, hazardous substances

[18] All Nordic nuclear power plants are LWRs. In LWRs light water acts as both a moderator and a coolant. A moderator is used to slow the neutrons down to the termic energy level in order to ease their absorbtion by the atomic nuclei in the fuel. Other typical moderators include heavy water and graphite. Other coolants include gas (carbon dioxide or helium), heavy water, and liquid molten metal.

and many interrelated subsystems. For example, in many plants both analogue and digital technologies are used side by side in the control and instrumentation systems, adding to the system integration, maintenance and modification challenges (IAEA, 1998). Managing the nuclear fuel cycle calls for impeccable safety and security procedures in all parts of the chain, including enrichment, fuel fabrication, reloading, use, interim storage, transportation, reprocessing and final disposal. During plant outages more than one thousand employees representing both the plant organization and its contractors may work on various assignments on the same site, which creates demanding work planning, co-ordination and management challenges and also increases risk levels (Pyy, 2000, Barriere et al., 1994). Plant outages are intentionally planned as short as possible to minimise revenue losses, while the scope of assignments to be completed is usually huge, ranging from reactor refuelling to turbine works and from trial runs of pumps and valves to software updates. Especially modifications create additional demands for safety analyses and for maintaining the integrity of plant documentation (Wahlström & Kettunen, 2000).

A key prerequisite for reactor safety is appropriate cooling of the fuel. Due to the radioactive decay of the fission products the reactor produces excess heat even after shutdown. The removal of this heat in all conditions is one the cornerstones of nuclear safety. In the NPPs, safety is managed by several principles, the most important of which is the defence-in-depth principle including prevention, protection and mitigation of accidents. The principle means that the plant has multiple independent levels of protection against a severe release of radioactive material. This includes the fuel itself, the fuel cladding, the pressure-bearing primary system of the reactor, and the reactor containment. In addition to these physical barriers, the principle assumes that the plant has a good safety management and culture, as well as sufficient financial resources, competent personnel and adequate tools and procedures. Several design principles related to the defence-in-depth principle exist for safety systems. These principles are meant to prevent and control abnormal operating occurrences and failures. First, all functions that are critical to safety are provided with several redundant systems and equipment (redundancy principle), and all the equipment and systems are designed to meet high quality requirements and sufficient safety margins. Second, safety systems that back up each other as well as parallel parts of safety systems shall be separated from each other so that their failure due to an external common cause failure is unlikely (separation principle). Third, systems based on diverse principles of operation shall be used to the extent possible for ensuring the most important safety functions (diversity principle). (YVL 1.0; Sandberg, 2004; SKI, 2005; IAEA, 1996b; www.tvo.fi, www.iaea.org)

Due to the complexity of the plant and the possibility of a major accident, there exists an absolute demand for safety in the nuclear industry. The operating organizations are responsible for the safety of nuclear power plants. In Finland, nuclear safety regulation is based on the Nuclear Energy Act (990/1987). The Radiation and Nuclear Safety Authority (STUK) formulates the detailed safety requirements concerning the use of nuclear energy. As an independent regulator STUK ascertains that the nuclear power plants produce energy according to the requirements. STUK produces regulatory guides called YVL –guides. There are currently about 70 YVL guides in the following eight series: general guides, systems, pressure equipment, building and structures, other structures and components, nuclear materials, radiation protection and radioactive waste management. The power companies must follow the rules set in the regulatory guides unless they can prove they can achieve the same level of safety with other methods. STUK operates under the administrative control of the Ministry of Social Affairs and Health. (www.stuk.fi)

Appendix F: Original publications I–V

ARTICLE I

Core task modelling in cultural assessment: A case study in nuclear power plant maintenance

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Core task modelling in cultural assessment: A case study in nuclear power plant maintenance

Pia Oedewald & Teemu Reiman

Abstract

This article aims at illustrating the use of core task modelling on a system level and attempts to show its relevance to cultural assessment. The methodology that was used in a case study consists of an iterative process of core task modelling, organisational culture research and organisational assessment. The case study was conducted in a NPP's maintenance department. The maintenance task, its goals, critical demands and the demands for the working practices were conceptualised by core task analysis. The organisational culture of the maintenance department was explored with interviews, a survey and workgroups. The results show three critical demands and three instrumental demands to be controlled on all levels in the organisation. The maintenance culture must support the activity of balancing between these distinct requirements. The core task model was used in assessing the characteristics of the maintenance culture. This was done through analysing the unity of the personnel's conceptions concerning the organisation, its task, goals and values. The relevance of this approach to organisational development is discussed.

Key words

Assessment, Human Factors, Maintenance, Modelling, Organisational Culture, Task Analysis.

1. Introduction

A nuclear power plant (NPP) is a complex socio-technical system, characterised by many coupled subsystems, uncertainty in the data available to workers, mediated interaction via various tools and potentially high hazards (Vicente 1999, p. 14–17, see also Perrow 1984). The aim of the maintenance of a power plant can be defined as that of guaranteeing safe, reliable and cost-effective production of electricity. This includes planned outages, preventive maintenance, modifications and fault repairs. Maintenance consists of different technical fields (e.g. electrical, mechanical, instrumentation & control), various work tasks (technician, foreman, work planning, etc.), and the personnel interact with complex technology. The maintenance of a power plant is thus a complex activity requiring different skills and multiple co-operating parties.

According to Moubray (1992), maintenance issues in general have recently received increasing attention, which stems from a "rapidly growing awareness of the extent to which equipment failure affects safety and the environment, a growing awareness of the connection between maintenance and product quality and increasing pressure to achieve high plant availability and to contain costs." (Moubray 1992, p. 1). In addition to the inherent complexities of maintenance, recent changes in society (changes in the age structure and values concerning work, utilisation of new technologies, deregulation of electricity markets, emphasis on outsourcing noncritical functions, etc.) have set new demands for nuclear power production (Wahlström et al. 2002). The present working practices, ideas, and conceptions might no longer be suitable for the new environment.

Due to the safety-critical nature of maintenance in NPPs, human factors studies have mostly aimed at classifying, predicting and preventing human errors (Laakso et al. 1998, Pyy 2001, Svenson and Salo 2001). These studies have been useful in designing different barriers against errors that have already been made at least once. Also some specific tasks such as NDT (non-destructive testing) have been studied extensively from the psychological point of view (NRC 1986). The psychological demands of the daily work or the nature of the maintenance task itself have seldom been considered.

Mathilde Bourrier, who has studied organisational reliability in nuclear power plants during the annual outages, points out that "Organisational reliability … is a result of a complex compromise between resource allocation and actors' strategies *within* the organisation." (Bourrier 1999). She concludes that organisational reliability should be investigated and seen as a property of the social systems embedded in the reliability-seeking organisations. She also states that this social construction of reliability can be best approached with systemic analysis. (Bourrier 1999, see also Rochlin 1999.) Weick (1987) conceptualises organisational reliability as a dynamic non-event and emphasises the need to see reliability as an ongoing condition where small changes can lead to unanticipated outcomes. This requires constant attention to small cues and enough common knowledge to anticipate the activities of other parties. Weick emphasises the role of organisational culture in fulfilling these demands. (Weick 1987.)

We propose a methodology called Contextual Assessment of Organisational Culture (CAOC) (Reiman and Oedewald 2002), which applies two basic concepts, *core task* and *organisational culture,* to capture the systemic and complex nature of maintenance work. According to Edgar Schein's (1985, 1999a) theory, organisational culture is defined as "A pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid and, therefore, to be taught to new members as a correct way to perceive, think and feel in relation to those problems." (Schein 1985, p. 12, italics altered). The term "group" can refer to the whole organisation in question or to some part of it. Schein (1990) writes: "Within any given unit, the tendency for integration and consistency will be assumed to be present, but it is perfectly possible for coexisting units of a larger system to have cultures that are independent and even in conflict with each other" (Schein 1990, p. 111). Weick (1995) has aptly described this continual and collective reality-building process that takes place within an organisation as sense making.

The concept of *core task* is defined as "the result-critical content of a particular work, which defines both the possibilities for action and the demands that must be fulfilled in all situations in order to maintain appropriate interaction with the environment" (Norros & Nuutinen 2002, Norros in preparation). A framework for conceptualising the core task of a particular work has been developed and named Core Task Analysis (see Norros and Nuutinen 2002). The framework was originally developed to analyse situational human-technology-interaction and it has been applied e.g. in NPP operator simulator studies (Hukki and Norros 1998) and in analysing anaesthetists' working practices (Norros and Klemola 1999). Norros and Nuutinen (2002) nevertheless state that the "[core task] concept should not be restricted to individual actions, but … action should be interpreted in a wider perspective of a societal activity that is carried out co-operatively by a number of actors." The problem of defining tasks in complex systems is pointed out by Weick (1987), who cites Gall (1977): "[i]f you go down to ... shipyard and look around for a shipbuilder ... you will find ... welders, carpenters, foremen, engineers, and many other specialist, but no shipbuilders. True, the company executives may call themselves shipbuilders, but if you observe them at their work ... [it] consists of writing contracts, planning budgets, and other administrative activities ... they are not in any concrete sense building ships ... a system is building ships, and the system is the shipbuilder" (Weick 1987, p. 120).

We define *organisational culture* to be the organisation's and its operational groups' learned way of responding to the different demands of its core task (see also Reiman and Oedewald 2002). This definition leads us to the conclusion that if we are able to define the demands of the core task, we also get appropriate criteria for the assessment of the culture of the organisation. This gives a new perspective to the mainly descriptive cultural research tradition (see e.g. Smircich 1983 and Alvesson 2002). What is "good" or "bad" is evaluated against what the organisation is trying to accomplish. In cultural *assessment* the aim is therefore to determine the core task at the level of the whole organisation or its operational groups. Thus, the focus of core task modelling shifts away from modelling the actual working situations to modelling the boundaries and requirements of activity in the whole system. This is a new challenge for the research because approaches that consider work as a group phenomenon (e.g. distributed cognition approach) seldom offer guidance to systematic modelling of the activity (Turner and Turner 2001).

The value of cultural approach to maintenance work is that it enables a generic view of the social dynamics in a complex and diverse domain. Furthermore, one of the central features of any culture is that in order to maintain internal cohesion it forms routines, preconceptions and rules-of-thumb, and hence it inherently resists change. When considering the challenges and pressures for change that the maintenance organisations are currently facing, understanding the impact of culture becomes crucial. Changes in the environment set new demands for the core task of maintenance and thus create a need to develop also the working practices. In terms of development, it is important to examine the cultural foundations of different practices. This can be done through assessing the unity of the personnel's conceptions concerning the organisation, its task, goals and values and, most importantly, by illustrating the continuous process in which these conceptions are formulated and maintained.

In this paper we describe a case study in a nuclear power plant maintenance organisation, in which the core task modelling was used in an assessment of the culture of the organisation. The paper concentrates on illustrating the use of core task modelling on a system-level and attempts to show its relevance to cultural assessment.

2. Methods

2.1. Case Organisation and Data Collection

The case study was carried out at the Loviisa NPP in Finland. Maintenance activities of the two reactor units are conducted by the maintenance department with almost 200 permanent employees. Both units have been in commercial use for over twenty years. At the beginning of the project in 2001, the maintenance activities were organised into the mechanical, electrical, instrumentation and construction maintenance, technical design, planning and coordination and quality control sections. The maintenance department is responsible for both the machinery that is critical to the production, and for the secondary areas of the plant (e.g. the yard, the restrooms and other facilities for the staff). Most of the operative maintenance consists of pre-planned overhauls or periodic testing. Fault repairs are only a fraction of the work. All the operative maintenance work is controlled with a work order procedure, which includes work phases for the technical design and quality or radiation control when needed. The daily work is organised in the morning meetings where the foremen allocate the work to their subordinates.

During the study the maintenance department was reorganised into five sections in order to make the distinction between operative maintenance and supportive functions more clear. The personnel did not know the forthcoming change at the time of the data collection.

The following data collection methods were used:

- Analysis of the central documents concerning maintenance in the target organisation was conducted.

- 23 semistructured interviews were conducted by the authors with the help of two assistant researchers. Three preliminary interviews were performed in February 2001 and 20 interviews during a two-day period in March 2001. The interviewees were from different functions of the maintenance department consisting of six technicians (T) and six foremen (F, from the mechanical, electric and instrumentation sections), two work planners (P), three experts (E) and six managers (M). Each interview lasted about an hour, and the questions covered the following themes:

  - Own job (the content, motivating and demanding features, nature of expertise, utilisation of tools, changes in work)

  - Maintenance task (goals and critical demands)

  - Organising of the maintenance activities (pros and cons of current organisational structure, co-operation between fields)

  - Organisational culture (stories, climate, subcultures).

- The organisational culture and core task survey was conducted to the entire maintenance organisation in May 2001. The survey consists of four measuring instruments: a measure of values, a measure of individual perceptions, a measure of the personnel's conceptions of the core task and a measure of the psychological characteristics related to work. The survey was constructed on the basis of Quinn's et al. competing values model (Quinn and Rohrbaugh 1983, Quinn 1988, Cameron and Quinn 1999), Hackman and Oldham's Job Characteristics Theory (1975) and previous studies on culture in complex environments (see e.g. Koch 1993, Reiman and Norros 2002). Questions were also tailored on the basis of the interviews and the document analysis. The core task instrument of the questionnaire was constructed on the basis of a preliminary core task model (see below).

- Documented group working was conducted during the entire research project. The working group consisted of maintenance experts from the management level and the planning section and it was used mainly in modelling the core task.

In addition, two feedback seminars were organised, where the preliminary findings were presented to the personnel. Also, a final seminar for the entire personnel was organised. The seminar had attendants from all levels and functions of the maintenance department.

2.2. Analysis of the Data

The Contextual Assessment of Organisational Culture (CAOC) –methodology (Reiman and Oedewald 2002) was applied in the case study. It consists of three phases: conceptualisation of the core task of the organisation, description of the main features of the organisational culture and qualitative assessment of the culture. The case study employed an iterative and multimethod research strategy based on method triangulation (Denzin 1970, Yin 1989, see also Silverman 1993). The data was used both to model the core task and to characterise the cultural profile of the case organisation, but the logic of the analysis differed in these two phases. The aim of core task modelling was to abstract common, "objective" demands of work that apply to all the personnel. On the other hand, in the cultural analysis, the purpose was not to aggregate the data until a "common view" is found, but to exemplify the personnel's multiple ways of making sense and acting in the maintenance context, and further, to inspect the shared cultural norms and assumptions.

The interviews were taped and later transcribed. As mentioned, the interviews were used on the one hand for the modelling of the core task and on the other hand for a grounded-theory (see Charmaz 1995) based analysis of the typical features of the organisational culture. The interviews were also used to test hypotheses formed with other methods.

The total sample size of the survey was 135 yielding a response rate of over 70 percent of the personnel. The survey instruments were factor analysed with a principal components -method and reliability coefficients were calculated (Cronbach's alpha ranged from 0,52 to 0,90 with 8 out of 13 scales having alphas over 0,70). The inspection of the functioning of the survey instrument is beyond the scope of this paper and it is described elsewhere (see Reiman and Oedewald submitted). Statistical information is given in the results section when presenting the findings from the survey. Analysis of variance was used to inspect possible subcultures. The connections between the different measures were also inspected. The results from the survey offered hypotheses that were tested with the interview material.

The survey and interview data provided us a common view on the personnel's perceptions concerning what is valued in the organisation and what should be valued. Also the level of job satisfaction and the experienced working climate and stress were analysed. Further analysis was conducted concerning the conditions for job motivation. The cohesiveness of these perceptions and manifestations of culture was tested, and subcultures were found within the maintenance organisation (see Reiman and Oedewald submitted).

These findings, although describing mainly the surface levels of the culture, serve as an important background when developing the organisation. From the theoretical and methodological point of view, however, the more interesting part of the research was to contextualise the analysis. That is, firstly, to create the appropriate criteria for assessing the meaning of these findings. Secondly, to ask the personnel (in interviews and in the core task section of the survey) about the common demands of their work and the conflicts in it. This challenges the personnel's culturally learned way of seeing their job. This is done in order to capture the cultural norms and assumptions that specifically relate to their core task.

A preliminary model of the maintenance core task was conceptualised as a starting point in studying the activity of the maintenance department. It provided an analytical tool with which to focus on the functionally relevant aspects of the culture. In the core task analysis, as in traditional task analysis, we first define the object, goals and subtasks of the activity in question. When modelling the core task from a systemic perspective it is not sufficient to decompose the task into sequential subtasks and single acts and determine the criteria for correct actions. Instead, the aim is to model the shared demands applying to all activity in the organisation.

Characteristics of the object of work were extracted in an analysis of the interview material and group discussions as a first step toward conceptualising the shared demands. Characteristics of the nuclear power plant set constraints and requirements for the maintenance task. The extracted characteristics were further grouped based on previous studies in complex sociotechnical systems (Perrow 1984, Vicente 1999).

Table 1. The main characteristics extracted and examples of constraints and requirements connected to them (see also Perrow 1984, Vicente 1999).

Characteristics	**constraints**	**requirements**
Complexity with tight or loose couplings	- tasks with different degrees of complexity and coupling - unplanned incidents	- tasks have to be planned and co-ordinated - documentation of committed operations - slack resources
Safety-critical nature - risk of core damage	- redundancy - process-related systems and safety-systems - unavailability times	- understanding of the safety significance of different work tasks - tasks have to be accomplished within pre-specified time limits - deviations have to be reported and investigated
Radiation	- closed spaces, time limits - risk of external release	- radiation protection and control - concentration of work to outage situations
Ageing and physical changes	- information about plant state becomes outdated	- continuous plant condition monitoring
Loosely coupled social system	- distributed knowledge and skills - unplanned interactions	- co-operation and co-ordination load - shared goals and methods
Mediated interaction with machinery	- uncertainty of information - time lags for feedback	- active information acquisition - active information management

Table 1 shows that there are multiple requirements in maintenance that have to be taken into account in the daily work. Because the constraints and requirements presented in Table 1 are inherent in the object of the activity, they are present in all activities at all levels of the organisation. In order to understand maintenance as an activity the critical demands for making sense of the complex system were abstracted (see Figure 1).

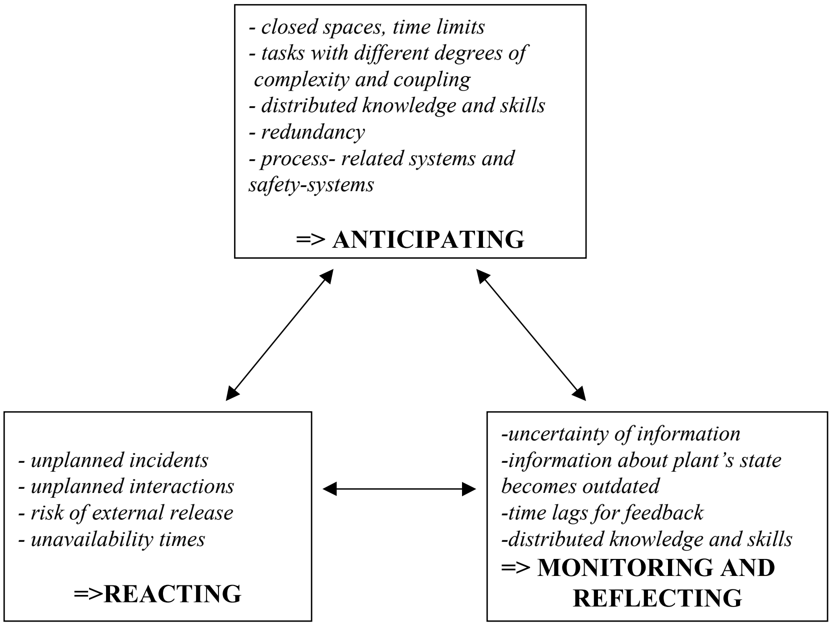

Figure 1. First stage of the core task analysis: By grouping different constraints for activity three critical demands of the maintenance task were identified.

Anticipating refers to an intention to predict the state of the plant and the effects of actions, as well as to plan the needed actions and recourses in advance. Anticipation is central to obtaining reliable and economical operations. It is connected to the way of using the power plant, with one planned outage a year. Machinery that is imperative to the production must be maintained during the annual outage. Because of the complexity of the system, also all the other tasks have to be planned carefully in advance. The safety critical nature of nuclear installations also emphasises the need for anticipation so that radiation can be taken into account (See also Bourrier 1999).

Reacting to unexpected conditions is the second critical demand for the maintenance. In spite of anticipating and planning, unexpected things may happen. Re-establishing the operability of the machinery after sudden failures or exceptional findings in periodic testing is an obvious demand for the maintenance. The safety-critical nature of the maintenance of a nuclear power plant requires efficient reaction to deviations since the technical specifications of the plant set time limits for the accepted unavailability of certain systems.

Monitoring and reflecting refers to a demand arising from the inherent uncertainties of highly complex systems, (see e.g. Perrow 1984, Vicente 1999) and the mediated and uncertain nature of the knowledge concerning the object of activity (see Table 1). Reflectivity means critical reviewing of the effectiveness and results of one's actions. Changes in the economic environment, and, for example ageing phenomena of the plant, put more emphasis on continuous condition monitoring and active reflecting of the maintenance strategy. Reflectivity includes challenging the existing conceptions and working practices, which are embedded in the culture of the workplace. Reflecting is needed to ensure that the actions taken are appropriate and also to create knowledge for anticipation purposes.

3. Results

3.1 Criteria for Assessing Culture: The Core Task Model

On the basis of the interviews it was concluded that the goal of maintenance was generally agreed upon. The objective was seen as that of maintaining the operational reliability and the economic value of the installation so that the power production can continue as long as planned. Usually the core task of the maintenance was described as that of guaranteeing safety and reliability of the power production. The interviewees conceptualised the structure of the maintenance activity by differentiating between three types of maintenance subtasks: preventive maintenance, corrective maintenance and modifications.

The interviewees also pointed out examples of the need to anticipate or to “know beforehand” but in their conceptions anticipating was usually seen as being the responsibility of the planning experts. The field personnel perceived reacting to the deviations in e.g. the condition monitoring data or to sudden machine failures as a central demand. From the perspective of the core task, the three critical demands of maintenance, namely anticipating, reacting, and monitoring and reflecting, have to be taken into account by *all personnel* in *every situation.* This requires balancing between different, partly conflicting demands (cf. Reiman and Norros 2002). This balancing act was manifested in the ways the interviewees described their work and its inherent complexity. By analysing their descriptions we aimed at conceptualising the psychological demands for fulfilling all the three critical demands of maintenance. The psychological demands were termed as instrumental demands, since they facilitate the fulfilment of the critical demands.

The instrumental demand that is associated with balancing between anticipating and reacting was termed *flexibility*. The need for flexibility was brought up with examples of coordinating the timetables for jobs that require different areas of expertise or coordinating the resources and prioritising the tasks in a case of a sudden machine failure. A foreman from mechanical maintenance describes the content of his job:

> "When it comes to different tasks, I have to coordinate things with the electrical section, and if we have to move some machinery, with the truck drivers also. All of these things have to be sewn together in order for this business to go on, and if possible all of this in advance, if you know that we need this or that tomorrow, you should arrange it today, somehow. Then every foreman has his own jobs, and, this is like, how would I describe it, like running a show." (F4)

Balancing between the demands of reacting and reflecting requires a systematic and to a certain degree a pre-specified way of performing actions. That demand was termed *methodicalness.* When asked in the interview, "what do you have to know in order to get by", one technician described:

> "well here's the radiation protection and all that kind of things you've got to take into account so you've to know something about them, and you've to know the procedures and the people you can ask if you don't know. If you consider for example a steam power plant, a lot of these things are very similar, but of course we have the nuclear safety aspect. You have to be more careful, because, if something happens it's in the papers and if the same thing happens in a steam plant it's nothing, it's normal. But it's not normal here." (T3)

Thus methodicalness means following the procedures, verifying what has been done and documenting the results of the actions. Only then can they be later analysed and reflected upon. Another example of methodicalness is fulfilling and updating the maintenance history database, or documenting the conducted repairs.

Balancing between the demands of reflecting and anticipating necessitates information acquisition and management that we have called *learning*. A foreman, when asked about the information systems and the data stored in them, replied:

> "Well if some faults are spotted, they are recorded in the system. And also, if some incipient fault is spotted, which doesn't prevent operation, meaning it works till the next overhaul, you write down that in the next overhaul you will open it and fix it. In a way it is, like, making your own, or your department's, job easier and ... I mean if it breaks down continuously for some reason, you can dig its history from the computer and check why. Or if the reason is elsewhere… I mean that it is not right that you change it once a month for twenty years and the fault is actually elsewhere." (F3)

In order to learn from actions, awareness of uncertainties in the complex system is required, since learning requires challenging existing conceptions and practices. The need for sharing of knowledge and experience is related to learning. An example of learning could be changing the procedures on the basis of feedback or changing the programme of preventive maintenance on the basis of the maintenance history.

Some people considered the difficulties of understanding the demands of the core task. A foreman contemplates a question relating to the differences between novices and experts:

> "Well it's a difficult question, I mean that some can be better than others ... but still the end result might be quite the same, well perhaps not exactly the same, I mean, *if you think of the whole system...* but if the system works, and you look at the indicators, they have both been as good, but the thing is, that *how* you have done the job, it can have some impact on the *future*, the other fellow can take even that into account. I mean that he takes a kind of a larger perspective, not just a single task, an expert takes always the whole process, the whole picture, takes everything into account, and acts accordingly." (F2)

As shown in the sample interviews, the personnel perceived the challenges quite well, but lacked the conceptual model with which to describe the demands and consider their jobs and daily tasks. The critical demands, the instrumental demands and their interactions are thus conceptualised in Figure 2. The figure also shows the working practices associated with each instrumental demand. The working practices are concrete manifestations of the demands. Thus, they can be observed and evaluated.

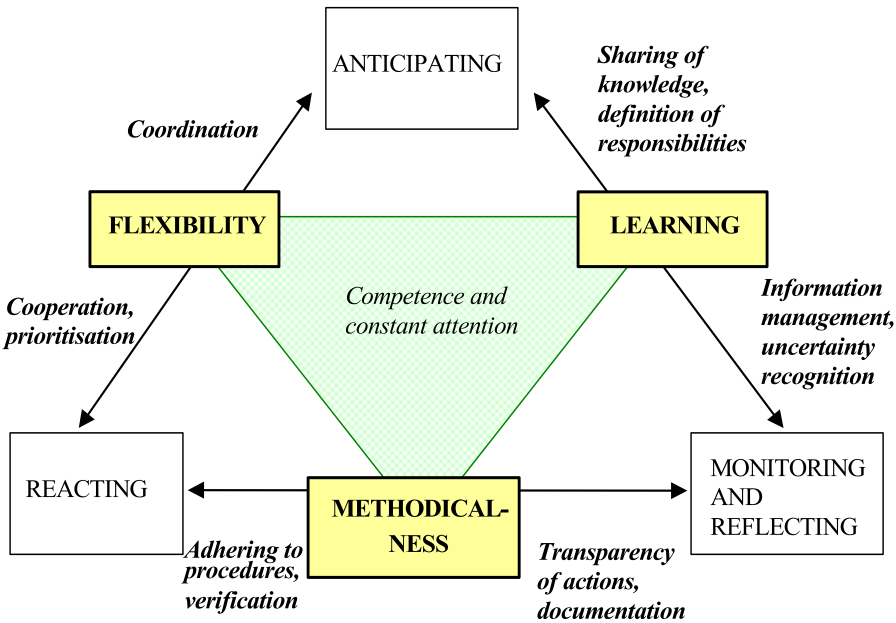

Figure 2. Model of the demands of the maintenance core task: critical demands (in the corners of the triangle), instrumental demands for the critical demands (between each critical demand), and demands for working practices (in italics, outside the triangle).

From a systemic perspective, it can be concluded that effective maintenance is about balancing between the different critical demands. Flexible balancing between anticipating and reacting makes possible the formulation of shared goals and criteria for plant condition. If certain criteria are not met one is required to react on it. By reacting to novel situations and reflecting on the effects of the action, information is created about the object of the activity. This requires that the actions are documented and that the uncertainty connected to the maintenance activity is recognised. In the learning process, e.g. by comparing information to previous experiences and by sharing it with others, information is generalised into knowledge concerning the current state of plant. Thus, the process provides an overview that can be utilised in anticipation.

In the first phase of the assessment of the maintenance culture at the Loviisa NPP, the focus was on the three critical demands. Each critical demand was approached by assessing how the corresponding instrumental demands (e.g. flexibility and methodicalness for reacting) were fulfilled in the culture. Fulfilment of the instrumental demands was in turn evaluated in relation to the corresponding working practices (see

Figure 2). This phase, the strengths and weaknesses of the current working practices, was reported directly to the plant and is not discussed further in this article. Further analysis was needed for understanding the dynamics behind the strengths and weaknesses of the culture.

3.2. Maintenance culture: Personnel's conceptions of instrumental demands

At the time of the study the way of organising activities at the case organisation was highly specialised and distributed according to technical areas. In the nuclear field it is also quite typical to separate the design, operating and controlling functions into independent sections at the power plant. It can therefore be assumed that the personnel view the maintenance task each from a narrow angle (I&C technician, machine maintenance foreman etc.), and that it is difficult to comprehend what the different requirements stand for. In that case, it may also be difficult to see how one's own job affects the whole system. Thus, the interview material was analysed further from the perspective of the interviewees' different interpretations of the instrumental demands (cf. Fig. 2).

From the perspective of the core task, *learning* is the more effective the more it focuses on the object of the activity itself (Norros and Nuutinen 2002, see also Engeström 1999). Workers should maintain an interest and an attention towards the object of work. That is why an awareness of uncertainty can be considered as a prerequisite for learning (see also Klemola and Norros 1997, Norros 1998). The core task section of the survey (see Reiman and Oedewald submitted) gave implications that uncertainty was conceptualised among the respondents as a technical uncertainty inherent in the complex system or as a social uncertainty formed as a learned aspect of the culture. One interviewee (I&C technician) described the content of his job:

> "Most demanding thing is... finding the fault. The kind of fault that you can't inspect. You have to repair it, but it no longer exists, but it has existed, and you are supposed to repair it. Like a light bulb that goes off and then goes on again. Of course, these are also the most interesting tasks. (T2)

Another interviewee described the uncertainty more as a social phenomenon:

> "Well the most demanding thing in my job could be that in here people are used to doing some

> routine for 20 years and you want to change it, that's demanding, I mean that you have to know how to present your idea so that it gets through, I mean that if you present it poorly, it's gonna fail for sure." (E2)

On the basis of previous research on development of expertise (Klemola and Norros 1997, Norros 1998) it can be hypothesised that interpreting uncertainty and unexpected incidents as features of the social organisation is not optimal for the development of expertise. In that case, the learning is focused on the ways of coping with the perceived uncertain culture, not on the means of coping with the uncertain technical system.

It was also found that the interviewees conceptualised *flexibility* in two different ways. Some people understood the need for flexibility as arising from the unanticipated activity of other agents in the system. The people who emphasised the unanticipated activity of others did not perceive so strongly the demands for anticipation in their own work. They emphasised the need to adjust activities for example on the basis of obscure work orders or on the basis of contradicting requirements from the different levels of the organisation. "You have to be flexible since the electrician is never on time and I can only wait". For other people flexibility meant the complex and unanticipated nature of the technical system and a need to coordinate activities with other groups in order to react appropriately. A technician from the electrical department describes his daily activities:

> "Well it can include even four different work tasks. It can be so that there is some fault repair or whatever, which takes a day or more, but then you have to jump a lot: fault jobs and like. Yesterday for example we had a job in the control room and on our coffee break the boss called and said well here's something more urgent for you, go and see what the problem is. We've been working with that since yesterday evening, and tomorrow it will still continue. That kind of stuff." (T3)

On the basis of the interview results, *methodicalness* was found out to mean passive rule following to some and more active documentation and verification of results to others. In the passive conception the demand for documentation was felt as a bureaucratic burden. One technician brought this up when discussing changes in his job:

> "Well yes, there's been an increasing number of rules and all kinds of safety systems and control

> systems and control systems for the control system's control system, and that leads to a massive pile of paper. I sometimes feel that the task itself is in the background." (T4)

Another technician had a more active orientation and he criticised people that he considered as being too passive:

> "... in fault repairs, when the work permit describes there's a fault, go and repair it, it is easy to check from the maintenance history database if there have been similar faults previously and what is wrong there and how it has been repaired in the past, and what has been repaired ... but people don't bother to write so much of the history data, so the system could be utilised more than it currently is." (T3)

Although the examples of the manifestation of the core task demands in the interviewees' own jobs were quite easy to find, the interpretations of the demands differed. Thus, the meanings attached to the demands were not similar. The results from a cluster analysis of the core task section of the survey also suggested the existence of different orientations towards the core task. Contrary to expectations, the orientation was *personal* in a sense that it was independent of age, occupation, task or experience in particular job (chi square tests were non-significant), but the orientation influenced e.g. the perceived meaningfulness of the work ($F(3,130)=4.64$, $p < .01$) (Reiman and Oedewald submitted). It can be hypothesised that the different ways of conceptualising the demands of the work may each be adaptive with the aim of getting by in the organisation, at least in the short term. Still, some of these orientations are unadaptive from the perspective of fulfilling the requirements of the core task (see e.g. Norros and Klemola 1999). The different ways of conceptualising the psychological demands of the maintenance work suggested that differences in the basic assumptions relating to the core task existed. This is analysed in the following, concluding section.

3.3. Core Task -Related Basic Assumptions

In order to conceptualise both the shared and the conflicting norms and basic assumptions we went back to the interview and group-working material. We analysed respondents' explanations for current organisational practises and we identified the following, frequently addressed tensions:

– certainty vs. uncertainty about the impacts of activities

– specialisation vs. maintaining overview

– situational judgement vs. generally applicable rules.

Most of the interviewees brought up the tensions when discussing their own jobs, but in different ways. Some interviewees pointed out that there are different and conflicting ways of handling demanding situations. Other interviewees seemed to prefer one or the other way of thinking about these issues, which they did not question (see Table 2).

Table 2. Extracts from the interviews depicting the tensions in the culture.

Certainty	**Emphasis on certainty** M1: at NPP you can't afford to mess around all by yourself, you have to know exactly what you are doing	**Awareness of uncertainty** T6: even if the work is routine, we always discuss it, the possible dangers … or you have to interact with the control room, the foreman has already called there and then we consider if are there any risks ... you don't just run into there	**Mixed or general reflection** T2: it is not necessary to know anything [in order to get by in here], if you say to some task that I don't know anything about that, the answer is 'ok, let's forget it', nobody takes the responsibility and requires anything.
	F2: this hierarchy in here, there are benefits in it, if I don't know something, I can always go to my superior, it is safe,	M2: you think and then you do, and ask if you don't know … but when information accumulates, you have to start processing it also by yourself, you can't always be asking your superior	T4: we are like robots in here, someone brings me an order, I carry it out, and return the paper to him, but nothing is said to each other
	T1: these are all familiar things we are doing here, there are no difficulties	E1: This job can be done badly or well, and the end result is visible only after several years	
Nature of expertise	**Specialisation** F3: it's very hard to imagine that some kind of a team could function here, in a tough situations, who takes the responsibility then, who does what?	**Overview** M2: the problem with strict job roles is that there is always a no-man's-land, everybody should have a clear area of responsibility, but also an understanding of the interfaces and the big picture	**Mixed or general reflection** T5: there's been some talk about interdisciplinary teams. That could be interesting
	T1: it would be better if everybody attends to some specific area	T3: you should understand a little bit about what the other person is doing [in order to co-operate flexibly]	T5: My job role has been narrowing, in a way it makes your job easier, but at the same time, the variety decreases, and that's bad
		M1: there are too many one-task-men, job roles should be broader	
Rules	**Generic rules** T3: it is good that we have instructions, it guarantees that everybody does the job the same way	**Situational judgement** P1: in work orders you just have to know if the order goes to e.g. rad. protection for a check-up, and if you don't know you've to guess to the safest direction.	**Mixed or general reflection** F1: from the plant's point of view, it's good that we have instructions. If something happens you can always say one didn't follow the instructions.
	M3: we should develop some system in order to suck the information from the older employees and their black booklets to some manageable form	T6: the instructions are such that if you take one and try to do the job you don't necessarily succeed… you have to think also by yourself, what is the main point in this work	T5: we have very clear instructions, and of course since I've done the job for years, they are now even clearer to me
		E1: instructions work poorly in details, you have to interpret them, if you do your job strictly by the book, all the other's work suffers,	P1: Some say that with these instructions, you don't actually have to know anything, you just do, but I don't think so.

The examples in Table 2 reveal that the interviewees had different basic assumptions concerning the predictability of the environment, the nature of expertise and the reliability of human decision-making or the role of written rules. While it can be noted from Table 2 (see also section 3.2) that the interviewees have different personal orientations, many of them also seemed to know what they should have answered, what is the norm in the culture. Thus it can be stated that emphasising certainty was a norm and an ideal state. Also specialisation to an exact area of expertise was considered to be more manageable than larger areas of responsibility. Further, the prevailing culture supported generally applicable rules. The basic assumption seemed to be that the variance in human activity is harmful and should be controlled with strict written rules but, as shown in Table 2, also different conceptions existed.

A generic issue behind all the tensions was a question about the location of responsibility for guaranteeing safety (see also Schulman 1993, p. 37). This was not efficiently resolved in the culture. What was shared in the culture, however, were the conceptions of the conditions of the maintenance work in nuclear power plant. The personnel felt that a NPP is a special environment because of its safety-critical nature. They saw the guaranteeing of safety as the main goal of their work, not the productivity or effectiveness as such. They conceptualised nuclear power as inherently profitable. Everything that is new and unfamiliar is a potential threat to the safety and is thus questioned in the culture.

4. Discussion

This article concentrated on illustrating the use of core task modelling and attempted to show its relevance to cultural assessment. The methodology consisted of an iterative process of core task modelling, organisational culture research and organisational assessment. The case study was conducted in the Loviisa NPP maintenance department.

According to our premises, cultural assessment must be made contextually without exploiting the universal and generic criteria for a good culture. Due to its contextual and participative nature, the methodology acts as an intervention to the culture of the target organisation. The aim of the research is, therefore, not only to assess the given culture, but also to give the personnel new concepts and new tools for reflecting on their organisation, their jobs and their working practices. This necessitates clarification of the meanings given to the various activities and of the dynamics connected with their formation. Cultural assumptions have to be made explicit, so that constructive discussion about the development needs and possible new solutions is possible. Otherwise, the conversation can turn overemotional and be oversensitive to issues too close to the conversationalists' own preconceptions. Thus the conversation is not in a form of a dialogue (Isaacs 1993, Schein 1999b), where the assumptions can be confronted and a common understanding can be built. Capturing the unconscious assumptions among the personnel is considered as very demanding task for the researcher. Core task modelling prompts people to discuss the aspects taken-for-granted in their daily work and it brings out the discrepancies both in own job and in the entire organisation. Thus, it provides a tool to reveal the underlying, core task -related basic assumptions of the given culture.

We defined *organisational culture* to be the learned way of the organisation and of its operational groups to respond to the different demands of its core task. Even though culture is a learned way of responding, or a solution, to the demands of its core task, the solution is not final or unambiguous. On the basis of this study we find it crucial to specify the definition of organisational culture: The concept of organisational culture includes the process of formation and reformation of the above-mentioned solution. This also means that culture includes the dysfunctional solutions and discrepancies, as well as attempts to solve or cover these. That is why the purely functionalistic view of organisation is limited if the aim is to assess culture and to explain its significance to the effectiveness of the organisation. Nevertheless, many of the characteristics of culture which deal with internal integration (Schein 1985), stem from the nature of the particular work and conceptions of the core task of the organisation. Hence, internal characteristics, such as climate or conflicts and power relations should be viewed in relation to the core task demands.

We concluded that effective maintenance is about balancing between anticipating, reacting and monitoring and reflecting. Flexible balancing between anticipating and reacting makes possible the formulation of shared goals and criteria for plant condition. By reacting to novel situations and reflecting on the effects of the action, one creates information about the object of the activity. Information is generalised into knowledge concerning the current state of plant in the learning process, e.g. by comparing information to previous experiences and by sharing it with others. Thus, our model of the maintenance core task demands comes quite close to the demands of knowledge-intensive work, where knowledge acquisition, interpretation and sharing are central for maintaining situation awareness (see e.g. Endsley 1995). Studies of situation awareness usually concentrate on the cognitive processes of the individual or team, whereas our approach emphasises the system and its collective activity. This gives a new perspective for understanding the maintenance work, which has traditionally been considered either from the perspective of special tasks or from the perspective of strategic management.

The case organisation had a shared understanding of the general objectives of maintenance and an underlying assumption that safety is the primary goal of the organisation. However, one of the main features of the culture of the case organisation was that its integrity was quite low. We identified subcultures on the basis of how the personnel perceived their organisation and their working conditions. In addition to that, we found that they interpreted the nature of their work in different ways, and this orientation seemed to be personal. As Bourrier (1999) states, workers develop distinct strategies in order to be able to act in their environment. Also Hollnagel (2002) describes that "… normal performance is not that which is prescribed by rules and regulation but rather that which takes place as a result of the adjustments, i.e., the equilibrium that reflects the regularity of the work environment". Our results show that the strategies for adjusting and coping with the tensions, on the one hand, manifest the way the personnel have *collectively learned* to perceive, think and feel about these issues and, on the other hand, a *personal orientation* towards the object of the work. The different interpretations concerning the demands of the maintenance work may partly stem from the general change situation (e.g. change of generation, privatisation of the company, deregulation) in the organisation. In a field where the need to assure that things are done with a mutual understanding and in a pre-specified way, the low integrity of the culture makes preserving the safety level stressful for the personnel.

The core task model was found to have validity in the sense of credibility and plausibility (see e.g. Hammersley 1990) when presented to the personnel. The model can therefore be claimed to have at least pragmatic value as an instrument in reflecting upon one's work. This procedure corresponds also with Silverman's (1993) concept of *respondent validation*. As discussed e.g. in Silverman (1993), all the results that are not taken as plausible by the case organisation can not be rejected forthwith. The central aspects of the culture are taken for granted and hence sometimes responded to in a denying manner at first (see e.g. Schein 1985). In the cultural analysis, the method triangulation aimed at gathering convergent evidence of the collective assumptions in order to increase the validity and reliability of the results.

The model of the demands of the maintenance core task can be utilised for development of the activities in subsequent studies in different organisations. In this case study, the model was constructed together with the personnel and used in a participatory way. This increased its acceptance and usefulness in the subsequent development work in the target organisation. Because core task analysis is more a framework for analysis than a strict method it is possible that other researchers would have emphasised different aspects of the maintenance core task. Further studies should aim to test both the scientific and practical value of the model. On the basis of this paper, the use of core task modelling in cultural assessment shows promise.

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References

Alvesson, M. (2002). Understanding Organizational Culture. Sage, London.

Bourrier, M. (1999). Constructing organisational reliability: the problem of embeddedness and duality. In Misumi, J., Wilpert, B. and Miller, R (eds.) Nuclear Safety: A Human Factors Perspective. Taylor & Francis, London. Pp. 331–340.

Cameron, K. S. and Quinn, R. E. (1999). Diagnosing and Changing Organisational Culture: Based on the Competing Values Framework. Addison-Wesley, Massachusetts.

Charmaz, K. (1995). Grounded Theory. In Smith, J. A., Harré, R. and Langenhove, L. V. (eds.) Rethinking Methods in Psychology. Sage Publications, London.

Denzin, N. (1970). The Research Act in Sociology. Butterworth, London.

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. Human Factors 37, 32–64.

Engeström, Y. (1999). Activity theory and individual and social transformation. In Engeström, Y., Miettinen, R. and Punamäki. R-L. (eds.) Perspectives in Activity Theory. Cambridge University Press, Cambridge. Pp. 19–38.

Hackman, J. R. and Oldham, G. R. (1975). Development of the job diagnostic survey. Journal of applied psychology 60, 159–170.

Hammersley, M. (1990). Reading Ethnographic Research: A Critical Guide. Longmans, London.

Hollnagel, E. (2002). Understanding Accidents – From Root Causes to Performance Variability. In Proceedings of the IEEE 7th Conference on Human Factors and Power Plants. Scottsdale, Arizona, USA, September 2002.

Hukki, K. & Norros, L. (1998). Subject-Centered and Systemic Conceptualization as a Tool of Simulator Training. Le Travail Humain, 313–331.

Isaacs, W. N. (1993). Taking Flight: Dialogue, Collective Thinking, and Organizational Learning. Organizational Dynamics, Winter 1993, 24–39.

Klemola, U.-M. and Norros, L. (1997). Analysis of the clinical behaviour of the anaesthetics: recognition of uncertainty as a basis for practice. Medical Education 31, 449–456.

Koch, B.A. (1993). Differentiating Reliability Seeking Organizations from Other Organizations: Development and Validation of an Assessment Device. In Roberts, K.H. (ed.). New Challenges to Understanding Organizations. Macmillan Publishing, New York.

Laakso, K., Pyy. P. and Reiman, L. (1998). Human Errors Related to Maintenance and Modifications. STUK-YTO-TR 139.

Moubray, J. (1992). Reliability-centered Maintenance. Industrial press, New York.

Norros, L. (1998). Evaluation and development of process operators' working practices. In Vanttola, T. (ed). The Finnish Research Programme on Reactor Safety 1995–1998, Final Symposium, VTT Symposium 189, Technical Research Centre of Finland, Espoo. Pp. 187–198.

Norros, L. (in preparation). Acting Under Uncertainty. The Core Task Analysis in Ecological Study of Work.

Norros, L. and Klemola, U.-M. (1999). Methodological considerations in analysing anaesthetists' habits of action in clinical situations. Ergonomics, 42 (11), 1521–1530.

Norros, L. and Nuutinen, M. (2002). The concept of the core-task and the analysis of working practices. In Borham, N., Samurcay, R. and Fischer, M. (eds.). Work Process Knowledge. Routledge, London

NRC (1986). Human Reliability Impact on Inservice Inspection. NUREG / CR – 4436. U.S. Nuclear Regulatory Commission.

Perrow, C. (1984). Normal Accidents: Living With High-Risk Technologies. Basic Books, New York.

Pyy, P. (2001). An analysis of maintenance failures at a nuclear power plant. Reliability Engineering and System Safety 72 (3), 293–302.

Quinn, R. E. (1988). Beyond Rational Management. Jossey-Bass, San Francisco.

Quinn, R.E. and Rohrbaugh, J. (1983). A spatial model of effectiveness criteria: towards a competing values approach to organizational effectiveness. Management Science 29, 363–377.

Reiman, T. and Norros, L. (2002). Regulatory Culture: Balancing the Different Demands of Regulatory Practice in the Nuclear Industry. In Kirwan, B., Hale, A. and Hopkins, A. (eds.) Changing Regulation – Controlling Risks in Society. Pergamon, Oxford.

Reiman, T. and Oedewald, P. (2002). The Assessment of Organisational Culture – a Methodological Study. VTT Research Notes 2140. Otamedia, Espoo.

Reiman, T. and Oedewald, P. (Submitted). Measuring maintenance culture and maintenance core task with CULTURE-questionnaire – A case study in the power industry.

Rochlin, G. I. (1999). Safe Operation as a Social Construct. Ergonomics 42 (11), 1549–1560.

Schein, E. H. (1985). Organizational Culture and Leadership. Jossey-Bass, San Francisco.

Schein, E. H. (1990). Organizational Culture. American Psychologist 45 (2), 109–119.

Schein, E. H. (1999a). The Corporate Culture Survival Guide: Sense and Nonsense about Culture Change. Jossey-Bass, San Francisco.

Schein, E. H. (1999b). Process Consultation Revisited. Building the Helping Relationship. Addison-Wesley, Reading, Massachusetts.

Schulman, P.R. (1993). The Analysis of High Reliability Organizations: A Comparative Framework. In Roberts, K. H. (ed.) New Challenges to Understanding Organizations. Macmillan, New York.

Silverman, D. (1993). Interpreting Qualitative Data. Methods for Analysing Talk, Text and Interaction. Sage, London.

Smircich, L. (1983). Concepts of culture and organizational analysis. Administrative Science Quarterly 28, 339–358.

Svenson, O. and Salo, I. (2001). Latency and mode of error detection in a process industry. Reliability Engineering and System Safety 73 (1), 83–90.

Turner, P. and Turner, S. (2001). Describing Team Work with Activity Theory. Cognition, Technology & Work 3, 127–139.

Vicente, K. (1999). Cognitive Work Analysis. Toward Safe, Productive, and Healthy Computer-Based Work. Lawrence Erlbaum, New Jersey.

Wahlström, B., Wilpert, B., Cox, S., Sola, R. and Rollenhagen, C. (2002). Learning organisations for nuclear safety. In proceedings of the 2002 IEEE 7th Conference on Human Factors and Power Plants. Scottsdale, Arizona, USA.

Weick, K. E. (1987). Organizational Culture as a Source of High Reliability. California Management Review 29.

Weick. K. E. (1995). Sensemaking in Organizations. Sage, Thousand Oaks, CA.

Yin, R. (1989). Case Study Research: Design and Methods. Sage, Newbury Park, California.

ARTICLE II

Measuring maintenance culture and maintenance core task with CULTURE-questionnaire – a case study in the power industry

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Measuring maintenance culture and maintenance core task with CULTURE-questionnaire—a case study in the power industry

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Abstract

Organisational culture has become a focus of much attention in industry in general and the nuclear industry in particular. In maintenance work, the research has addressed mainly human error issues or strategic decision making and optimisation. The present study utilises the CULTURE-questionnaire that is designed to measure the different cultural aspects of complex organisations. Functioning of the questionnaire and the results obtained in a case study at a maintenance organisation of a nuclear power plant are reported in this paper. The questionnaire consisted of four instruments: measures of values, psychological job characteristics, individual perceptions and organisational core task. Three of the instruments were factor analysed and 13 summated scales were formed. The core task instrument was used in a cluster analysis to separate the respondents into groups on the basis of their orientation towards the maintenance work. Differences between the work tasks, section, age and length of service were studied. Hierarchical position in the company influenced perceptions of values. Core task orientation influenced the perception and subjective feelings towards one's organisation. Several partially overlapping subcultures were thus identified. The implications of the different work orientations for effective maintenance are discussed.

Keywords: Organisational culture; Maintenance work; Maintenance organisations; Survey methodology

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1. Introduction

The aim of the maintenance of a power plant can be defined as that of guaranteeing safe, reliable and cost-effective production of electricity. This includes planned outages, preventive maintenance, modifications, and different kinds of fault repairs. Proper working of the machinery and technology is critical to both plant safety and productivity. Maintenance is a complex activity in the sense of Vicente's (1999) definition of complex sociotechnical systems, the characteristics of which include e.g. many coupled subsystems, uncertainty in the data available to the workers, mediated interaction via various tools and potentially high hazards (Vicente, 1999, pp. 14–17; see also Perrow, 1984). In addition to the inherent complexities of maintenance, recent changes in society and in the working environment (changes in the age structure and values towards work, utilisation of new technologies, deregulation of the electricity markets, emphasis on outsourcing non-critical functions, etc.) have set new demands on power production (Taylor, 2000; Bier et al., 2001; Salo and Svenson, 2001). The current working practices, ideas and conceptions may no longer be suitable in the new environment. Rigid organisational structures can inhibit change and erode organisational effectiveness.

In safety-critical organisations, for example in the nuclear field human factors studies in maintenance have mostly aimed at classifying, predicting and preventing human errors (Laakso et al., 1998; Pyy, 2001; Svenson and Salo, 2001). These studies have been useful in designing different barriers against errors that have already been made at least once. The psychological demands of the maintenance work, maintenance practices or the nature of the maintenance task itself have seldom been in focus (with the exception of e.g. Vidal-Gomel and Samurcay, 2002).

We propose a cultural approach for studying and developing maintenance work. This approach emphasises the partly unconscious conceptions and assumptions influencing the norms, working practices and organising of work (Oedewald and Reiman, 2003). We utilise a survey method, even though we consider culture as a multidimensional phenomenon and unique to the organisation in question (Schein, 1985). In a complex and distributed work such as maintenance, the survey method gives a general view of the organisation and its cultural integrity, and it also enables the identification of subcultures. Despite the acknowledged significance of organisational culture in complex sociotechnical systems, most studies have mainly focused on purely safety-related matters or the culture has been operationalised simplistically. In this article, a questionnaire designed to measure the maintenance culture and maintenance core task is tested in a case study. Our aim is to examine the validity of a survey method for measuring the organisational culture of a complex sociotechnical system.

1.1. Organisational culture

Organisational values and organisational culture have in the recent years become a focus of much attention in industry in general and the nuclear industry in particular (Cox and Flin, 1998). In safety-critical environments, the term *safety culture* (IAEA, 1991) has been taken into use to describe the attitudes required for a reliable and safety-conscious worker and employer. The attitudes emphasise a questioning, rigorous and prudent approach and communication as the basis for a sound safety culture (IAEA, 1991).

Schein (1985) defines *organisational culture* as "a pattern of basic assumptions—invented, discovered, or developed by a given group as it learns to cope with its problems of external adaptation and internal integration—that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems" (Schein, 1985, p. 9). According to Schein's theory, the deepest layer of organisational culture consists of shared tacit assumptions that have resulted from a joint learning process. These assumptions make an individual's life predictable and meaningful in an organisational context. The next level consists of espoused values, which refer to conscious justifications to activities. They predict what people will say in a variety of situations, but if they are not congruent with their underlying assumptions, they do not necessarily predict what people will actually do in different situations. The surface level of the culture consists of artefacts that include the visible behaviour of the group and the organisational processes, products and technology. These surface level phenomena are hard to decipher since they stem primarily from subconscious assumptions and situational or individual variables (Schein, 1985).

Culture can be seen as a repertoire of positively and negatively loaded meanings (Alvesson, 2002, p. 106). These meanings are not static, rather culture is in an epistemological sense the creation and recreation of a shared reality. In Weick's terms it can be said that organisational reality is an ongoing accomplishment (Weick, 1993). He calls this process sense-making (Weick, 1995). Culture enables shared interpretations of situations and makes co-ordinated action and interaction possible and meaningful (see e.g. Smircich, 1983; Alvesson, 2002). On the other hand, strong cultural meanings can counteract questioning and independent thinking; cultural assumptions can act as constraints and prevent people from considering alternative ways of acting (Alvesson, 2002, p. 118; Parker, 2000).

Martin (1992) has characterised different perspectives to organisational culture. She differentiates three approaches, the integration, differentiation and fragmentation approach. The integration approach emphasises the unity and consistency of cultural assumptions and the lack of ambiguity. The differentiation perspective "describes cultural manifestations as sometimes inconsistent... consensus occurs only within the boundaries of subcultures, which often conflict each other" (Martin, 1992, p. 12). In contrast to these, the fragmentation approach focuses on the ambiguity as the essence of culture and emphasises the "multiplicity of interpretations that do not coalesce into a stable consensus" (Martin, 1992). The approach from which the culture in question is studied influences which aspects of the organisation are considered important in the cultural assessment.

1.2. Assessing culture in complex environments

Traditional ethnographic organisational culture research does not directly take a stand on the "goodness" or "badness" of a culture (Grote and Künzler, 2000,

p. 135). In ethnographic organisational culture research, the aim has been to describe the culture and understand its dynamics, and only rarely to change the culture (cf. Schein, 1985). The same applies to most survey studies. If one desires to assess an organisational culture as well as describe it, the central challenge is the definition of the criteria. In the studies where the organisational culture has been assessed, the focus has generally been on the criteria that maintain internal cohesion, such as a good working climate (e.g. Mearns et al., 1998) or organisational support and commitment of the personnel (Vandenberghe and Peiró, 1999). Accident and incident rates (e.g. Lee, 1998; Mearns et al., 1998, 2003; Williamson et al., 1997) provide another source of criteria. Hofstede et al. (1990) have characterised organisational cultures in six dimensions. They hypothesised that the culture of an organisation is partly predetermined by nationality, industry and task. They state on the basis of their results that four of their six dimensions of organisational culture differ on the basis of the task of the given organisation. They also state that none of the positions in any dimension are intrinsically bad, but depend on the organisation's strategy and its goals. However, no link between the cultural dimensions and organisational performance was found in their data (Hofstede et al., 1990).

In safety-critical environments, numerous criteria for a good (safety) culture have been proposed, for example the questioning attitude of the employees, a clear safety policy, continuous improvement of operations and safety, and a balance between the production and the safety goals (IAEA, 1991, 1996; Grote and Künzler, 2000). In their research in different industries, Flin et al. (2000) surveyed the common features of safety climate measurement. They analysed 18 different indicators and found only five common themes:

- management,
- safety systems,
- risks and the perception of risks,
- competence and training,
- work pressure and workload.

The common denominator in these studies is the focus on safety relevant aspects and the use of e.g. accident statistics when examining the predictive validity of the measures (Flin et al., 2000).

The safety culture concept is often presented separately from the other characteristics of the organisation, such as the organising of work, technology, organisational structure, business strategy and financial decision-making. The safety culture is thus considered to be independent of (or only loosely dependent on) the wider organisational culture. This conceptual separation easily reduces the term safety culture to refer only to factors that are known in advance and are clearly connected with safety, such as safety attitudes and safety values. This results in the loss of the holistic perspective originally sought with the organisational culture concept (Reiman and Oedewald, 2002; see also Guldenmund, 2000). The usefulness of the safety culture concept has been debated (see e.g. Pidgeon, 1998; Sorensen, 2002; Cox and Flin, 1998). Pidgeon (1998) cites Kennedy and Kirwan who conclude that "the existing attempts to study safety culture and its relationship to organisational outcomes have remained unsystematic, fragmented, and in particular underspecified in theoretical terms (Kennedy and Kirwan, 1995).

We agree with Rochlin's (1999) statement that safety means more than the absence of accidents or errors. We also emphasise that even in safety-critical domains it is sensible to consider the overall effectiveness of the organisation, which consists of the productivity, safety and health of the system (cf. Vicente, 1999). Therefore we use the concept of organisational culture instead of safety culture and propose that the criteria for any culture should be defined in relation to the task that it is trying to accomplish (see also Norros and Nuutinen, 2002; Oedewald and Reiman, 2003). The organisation is able to form stable practices as characteristics of its culture by simplifying the reality and by forming preconceptions about the environment. These practices and the actual demands of the organisational core task can sometimes be in conflict. Organisational core task can be defined as the shared motive of the activity of the organisation (Reiman and Oedewald, submitted for publication). A power plant e.g. needs more than just to be safe in order to continue its existence. If we can define the requirements set by a particular core task (in this case, maintenance of a NPP), these requirements can be used in assessing the central dimensions of the organisational culture (Reiman and Oedewald, 2002, submitted for publication; Oedewald and Reiman, 2003).

1.3. Models of organisational functioning

In order to characterise different organisational cultures, Cameron and Quinn (1988, 1999; see also Quinn and Rohrbaugh, 1983) have proposed an approach called the competing values framework. The framework has been developed through empirical research on organisational effectiveness. According to this theory, organisations can be viewed along two dimensions (see Fig. 1): focus on internal processes versus focus on external processes and focus on control versus focus on flexibility. Together, these two dimensions form four quadrants from which four

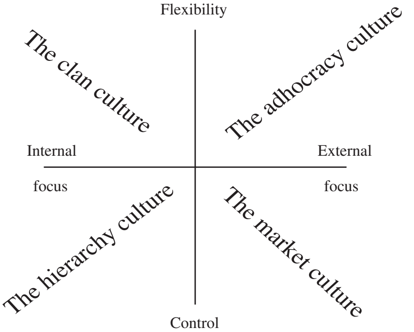

Fig. 1. Cameron and Quinn's (1988, 1999) competing values framework.

dominant culture types emerge. In a culture where hierarchy values are dominant (see Fig. 1), procedures govern what people do and stability, predictability and efficiency are considered to be long-term concerns of the organisation. An organisation with a dominant market culture values productivity and competitiveness by strongly emphasising external positioning and control. The workplace is highly result-oriented. The clan culture values cohesion, participativeness, teamwork and commitment. The adhocracy culture has the fostering of adaptability, flexibility and creativity as a major goal. Readiness for change is advocated (Cameron and Quinn, 1999).

No organisation represents one culture type exclusively but to some degree all four types are involved (Cameron and Quinn, 1999). The type of the resulting culture depends on the meanings and content given to the characteristics of the environment of the organisation (see also Alvesson, 2002, p. 77). It can be stated that the combination of the four culture types in an organisation defines what is *valued* in the work and how the personnel believe the work should be carried out.

Hackman et al. (Hackman and Lawler, 1971; Hackman and Oldham, 1975, 1980) have identified core job characteristics that can be used as criteria for designing and redesigning work. The basic premise of Hackman and Lawler's (1971) theory is that it is possible "under specifiable conditions simultaneously to achieve high employee job satisfaction and high employee effort toward organisational goals" (Hackman and Lawler, 1971, p. 263). This congruence of high satisfaction and high effort is dependent upon two factors: the existence of employee desires for a higher order need satisfaction and "conditions on the job such that working hard and effectively toward organisational goals will bring about satisfaction of these needs" (Hackman and Lawler, 1971, p. 263). Hackman and Lawler emphasise that it is not the objective state of the job characteristics that is essential to employee attitudes and behaviour but how these are *experienced* by the employees and what the employees *perceive* (Hackman and Lawler, 1971). It can be postulated that organisational culture influences (and is influenced by) these perceptions, although Hackman et al. do not explicitly use the term organisational culture.

According to Hackman et al.'s (Hackman and Lawler, 1971; Hackman and Oldham, 1975, 1980) job characteristics model (JCM), high job satisfaction, motivation and high quality of work performance can be acquired if the worker can achieve three psychological states:

- the work must be experienced as meaningful,
- the worker must experience that he is personally responsible for the work outcome,
- the worker must be able to determine what the outcome of his efforts are, what results are achieved and whether they are satisfactory,

The job characteristics model (JCM) argues that five core job characteristics (skill variety, task identity, task significance, autonomy and feedback) influence the three critical psychological states (Hackman and Lawler, 1971).

1.4. Theoretical framework and the aims of the present study

The term organisational culture refers here to the values, norms and underlying assumptions forming over time during the company history and affecting all the company's activities (and are in turn affected by them). In this cultural process, the meanings of safety, productivity and employee well-being are socially constructed (Bourrier, 1999; Rochlin, 1999; see also Weick, 1995). The temporary outcomes of this process at any given time can be described by static models, such as Cameron and Quinn's (1999) competing values model or Hackman et al.'s (Hackman and Lawler, 1971) job characteristic model.

When asking the personnel about the values of their workplace or about the characteristics of their jobs, we get an aggregate of individual conceptions and perceptions. These conceptions are artefacts of the underlying culture reflecting how the personnel perceive, think and feel about (cf. Schein, 1985) their organisation and the organisational core task (Reiman and Oedewald, submitted for publication). By comparing the value profile and conceptions of one's own work, we can make inferences about how the perceived values are experienced and how well they are seen as suited for the task and the individual at hand.

By comparing this static picture to the demands of the core task and the history of the organisation, we get a more dynamic picture of the organisation and its development trend. This can be done through assessing the unity of the conceptions of the personnel concerning the organisation, its task, goals and values. The differences in the value perceptions and psychological job characteristics between members of the personnel create tensions in the organisation, which can be identified with the survey method.

The purpose of this paper is to report the functioning of the CULTURE-questionnaire and the results obtained in a case study at a maintenance unit of a NPP. The following hypotheses are established:

(a) The values part of the CULTURE-questionnaire is internally consistent and produces the dimensions predicted by Cameron and Quinn (1999) and has construct validity (see e.g. Ghiselli et al., 1981) enabling its use in describing the culture of the organisation in question.
(b) The psychological job characteristics part of the CULTURE-questionnaire is internally consistent and has construct validity (Ghiselli et al., 1981) enabling its use in describing the culture of the organisation in question. Furthermore, psychological job characteristics have an influence on job satisfaction as predicted by Hackman and Lawler (1971), and the instrument has a predictive validity enabling this effect to be identified.
(c) The case organisation has subcultures as predicted by Martin's (1992) differentiation perspective on organisational cultures (see also Fried and Ferris, 1986; Young, 1989; Pidgeon, 1998; Parker, 2000). We hypothesise that the perceptions of values differ on the basis of the hierarchical position in the company (see e.g. Cameron and Quinn, 1999) and due to the complex and distributed nature of the maintenance work different maintenance sections have different value profiles.

We also predict that differences between the work tasks on the level of psychological job characteristics will be found. Also, age is hypothesised to affect the perceptions of the psychological job characteristics (cf. Hackman and Oldham, 1980) as does the tenure in the company through a form of socialisation into the given culture.

(d) Conceptions of the core task vary between the workers. Members of the personnel having different conceptions of the core task have different perceptions of the organisational values.

2. Methods

2.1. Research strategy and sample

A survey study of the organisational culture and core task was conducted as part of a larger cultural assessment. The cultural assessment utilised the contextual assessment of organisational culture (CAOC) methodology, which consists of both qualitative and quantitative methods (see Reiman and Oedewald, 2002, submitted for publication; Oedewald and Reiman, 2003).

The case organisation was a maintenance department in a Nordic nuclear power plant. The maintenance activities of the reactor units of the plant are conducted by a maintenance department with almost 200 permanent employees. The maintenance activities at the plant are organised into sections for mechanical, electrical, instrumentation and construction maintenance, technical design, planning and co-ordination and quality control. The plant has been in operation for more than twenty years and has shown an excellent performance record and very few incidents.

Each questionnaire was addressed directly to the personnel and a sealable envelope, pre-addressed to the research institute (VTT) accompanied the questionnaire. The respondents were assured that the responses would be handled confidentially and that the results could not be traced back to individual respondents. Information on the objectives of the research and the methods to be used was given to all personnel at a separate meeting.

A total of 135 valid questionnaires were obtained from the population of 196. Hence, the response rate of the survey was 70%. Five percent of the sample were managers, 10% were line supervisors and 65% ordinary workers. Twenty percent did not mention their occupational status. Gender was not asked since the department in question is very male-dominated.

2.2. Measures

The questionnaire consisted of four different measuring instruments: a measure of workplace values, a measure of the psychological characteristics related to the work, a measure of perceptions of the organisation and a measure of the perceptions of the organisational core task. The questionnaire consisted of a total of 95 Likert-type questions and one open question. The open question was phrased as follows: “What are the main targets for development at your department?" Fifty percent of the respondents answered the open question. Six-point Likert-type scales were used in order to avoid the neutral ("neither agree or disagree") middle point.

Twenty three interviews were conducted as a part of the larger research project and the results of grounded-theory-based (see e.g. Charmaz, 1995) analysis were used in wording the questions. Connotations of the various common terms used by the interviewees were analysed (e.g. teamwork, quality) and ambiguous or emotionally loaded questions (e.g. outsourcing) were avoided in the personal sections (psychological characteristics and individual perceptions) of the questionnaire. On the other hand, some of these terms that could be considered as values were added to the values section of the questionnaire (e.g. "economic efficiency") and some terms that could be considered as demands of the maintenance work, were used in the core task section. This procedure aimed at enhancing the content validity of the questionnaire (see Ghiselli et al., 1981).

A pilot study was conducted by forming a "focus" group with the maintenance experts from the target organisation and by going through the questionnaire question by question. The obscure questions were modified further. The same focus group was active throughout the entire study and participated in directing the research and interpretation of the research material. This procedure aimed at further improving the content validity of the questionnaire by contextualising it to better fit the particular task (maintenance). A more detailed description of the measures and their composition follows below.

2.2.1. Measure of workplace values

The instruction was to mark how much the respondent felt the given statements were valued in the respondent's section. We thus asked the respondent to reflect his/her organisation and decide whether or not some form of conduct or some end-state (Rokeach, 1973) is promoted in the organisation. Thirty two items, each rated on six-point Likert-type scales (from "not at all" to "very much"), were related to values typically manifested in organisations (e.g. "flexibility", "economic efficiency"). The value statements were selected on the basis of Cameron and Quinn's (1999) competing values model and previous organisational culture studies in complex and dynamic organisations (Reiman and Norros, 2002; see also Koch, 1993) and tailored accordingly on the basis of the results of the preliminary interviews and focus group work.

Kaiser–Meyer–Olkin's measure of sampling adequacy (KMO) was 0.883, which is considered as acceptable for factor analysis (see Tabachnick and Fidell, 2001, p. 589). The data was factor analysed with the principal components solution and summated scales were formed on the basis of the factor loadings. Three variables were removed from the final analysis on the basis of low communalities. The initial factor solution was rotated by the Equamax method to guarantee optimal solution with high loadings on every factor. Varimax method was also tested, but it formed substantial loadings on the first factor, with few loadings on the other factors. The principal components solution produced six factors with eigenvalues over one, and explained 67.4% of the total variance of the value questions.

The summated scales that were formed corresponded in some aspects with Cameron and Quinn's (1999) model, especially in the clan and market dimensions. The hierarchy focus was split into two scales, a measure of the bureaucracy and rules and a measure of the safety values and safety regulations. The adhocracy scale was also split into two scales, a measure of the developmental and questioning attitude and a measure of the individual expertise and initiative.

The summated scales that were formed were named as follows:

- *Financial and efficiency values.* This scale is composed of value statements connected to the financial objectives and the efficiency of the maintenance activities. This scale corresponds to Cameron and Quinn's (1999) original market sector. The scale consists of four value statements (e.g. economic efficiency, results).
- *Safety and deliberation values.* This scale includes some dimensions that were hypothesised to load on the hierarchy factor, such as rule following and safety related values. This scale consists of five individual value statements (e.g. occupational safety, rule following, deliberation).
- *Change and development values.* Cameron and Quinn's (1999) adhocracy sector was split into two separate dimensions, a change dimension and an autonomy dimension. This scale measures the extent of innovation- and change-related values at the company. The scale consists of four value statements (e.g. questioning old beliefs and practices, continuous development).
- *Hierarchy values.* This scale corresponds in many respects to Cameron and Quinn's (1999) hierarchy sector. It is composed of value statements related to centralised decision making and detailed work tasks. The scale is composed of three value statements (centralised decision making, detailed work tasks, methodicalness).
- *Autonomy and expertise values.* This scale measures individual-oriented values and values emphasising expertise and personal responsibilities and initiative taking. These values were hypothesised to load onto Cameron and Quinn's (1999) adhocracy sector. The scale is composed of six value statements (e.g. personal initiative, individual responsibility, proficiency).
- *Cohesiveness values.* Cameron and Quinn's original clan sector was renamed on the basis of the factor loadings as cohesiveness. This scale includes values connected to internal cohesion, well-being of the personnel and development of human resources. The scale is composed of seven value statements (e.g. well-being of the personnel, collective accountability, co-operation, and feedback).

2.2.2. Measure of psychological characteristics related to work

Sixteen items, each rated on six-point Likert-type scales, were related to psychological job characteristics, or psychological states, as Hackman and Lawler (1971) call them. The questions were formed on the basis of the theoretical model (see Hackman and Lawler, 1971), job diagnostic survey (Hackman and Oldham, 1975, 1980) and the results of the previous studies (e.g. Reiman and Norros, 2002; Koch, 1993) in safety-critical organisations. Since no objective data about the characteristics of the respondents' jobs could be collected, it was plausible to measure the psychological states directly. Furthermore, Hackman and Lawler (1971) emphasise that it is not the objective state of the job characteristics which is essential to employee attitudes and behaviour but how they are *experienced* by the employees and what the employees *perceive*. Also, substantial corroboration for the linkage between the psychological states and job satisfaction exists, but not so much for the linkage between the objective job characteristics and job satisfaction (see Fried and Ferris, 1987).

Preliminary analysis produced a factor structure that was difficult to interpret. Based on Fried and Ferris's (1986) findings that the dimensionality of job characteristics differs on the basis of the hierarchical level in the organisation we decided to remove the managers from the factor analysis. Also, the focus of the research was more on the worker level than on the management level. *N* for the analysis was therefore 115. Nevertheless, summated scales were calculated for the entire sample for practical purposes, since the management sample was too small to be analysed independently. The KMO measure yielded a score of 0.708, which was considered as acceptable (see Tabachnick and Fidell, 2001, p. 589). The data was factor analysed with the principal components solution and summated scales were formed on the basis of the factor loadings. The rotation method was Varimax. A five-factor solution was obtained on the basis of eigenvalues over one. This solution explained 63.82% of the total variance of the questions.

Four summated scales instead of three as Hackman and Lawler's model (1971) predicted were formed and named as follows:

- *Feedback.* This scale measures the perception that one receives feedback from one's work and its results. This scale corresponds to Hackman and Lawler's (1971) "knowledge of results" psychological state. The scale is composed of four questions, e.g. "My superior gives me clear and constructive feedback" and "I know on what criteria my work is assessed".
- *Meaningfulness.* This scale measures the perception that the job one is doing is important and meaningful. The scale consists of three questions, e.g. "I feel that the work I am doing is important" and "My job is interesting".
- *Sense of personal responsibility.* This scale measures the perception that one is personally responsible for the outcomes of one's work (Hackman and Lawler, 1971). The scale consists of four questions, e.g. "I have a clear picture of my responsibilities and powers" and "my work tasks are clearly defined".
- *Sense of control.* This scale measures the perception that one is in control of one's work and oneself as a worker. The scale is composed of four questions, e.g. "I always have enough time to do my job carefully" and "My job tasks are too demanding" (reverse scoring). Questions initially hypothesised to measure meaningfulness or sense of personal responsibility loaded on this factor.

2.2.3. Measure of individual perceptions and conceptions

Twenty three items, each rated on six-point Likert-type scales, were related to individual conceptions about organisational practices and about one's own behaviour at the work place. The questions were formed on the basis of previous studies

(Reiman and Norros, 2002; see also Koch, 1993) and Cameron and Quinn's (1999) model. The questions were initially designed to measure each of the four competing values sectors (Cameron and Quinn, 1999).

The KMO value of the instrument was 0.673, which modestly exceeds the 0.6 criteria for the factorability of the sample (cf. Tabachnick and Fidell, 2001, p. 589). The data was factor analysed with the principal components-solution. Five factors were selected to be extracted on the basis of a scree test (Cattell, 1966), since there were many factors with eigenvalues slightly over one. The initial factor solution was rotated by the Varimax method. A five-factor solution explained 51% of the total variance of the questions. The two last factors were uninterpretable, and were discarded from further analyses. Summated scales were formed of the first three factors and named as follows:

- *Perceptions about management.* Measured with questions such as "I discuss with my superior the pros and cons of my expertise" and "information distribution in my company is adequate". The scale is composed of five items.
- *Perceptions about working climate.* Measured with questions such as "I am on good terms with my colleagues" and "The working climate in my section is good". The scale is composed of five items.
- *Conception about one's own development orientation.* Measured with questions such as "I strive to find new ways of working to enhance my effectiveness" and "I contemplate on the appropriateness of my working practices". The scale is composed of five items.

2.2.4. Measure of the core task

Twenty three items, each rated on a six-point Likert-type scale, were related to the general and particular demands of the maintenance work at a nuclear power plant. A preliminary core task model was formed on the basis of interviews and work-shops with maintenance experts from the target organisation and on the basis of an extensive literature review (Oedewald and Reiman, 2003). The preliminary core task model consisted of three central demands. *Anticipating* means interaction with other people and utilisation of collective knowledge in order to cope with the complex system and plan the needed resources. It also includes routine inspections and preventive maintenance. *Reacting* means acting in unpredicted situations and sudden incidents. *Reflectivity* means critical reviewing of the results and effectiveness of one's actions. Reflectivity includes challenging the existing conceptions and working practices embedded in the culture of the workplace. These dimensions were not hypothesised to be independent, but to be taken into account holistically in the action. Furthermore, we identified tensions between the different demands. The questions of the core task instrument were constructed on the basis of these tensions. For example, we identified a tension between specialisation and general knowledge of the plant. This tension was measured with questions such as "knowledge sharing is imperative to effective maintenance" and "getting along with people is paramount to working in maintenance". Another tension that was identified was the tension between relying on plans and acting in unanticipated situations. This was measured with questions such as "unexpected things happen unavoidably" and "the effects of actions are known in advance" (Oedewald and Reiman, 2003).

We hypothesised that there are qualitative differences in the respondents' conceptions of the organisational core task, and because of that we were interested in classification of the respondents into categories, or different orientation types. Cluster analysis was conducted in order to group the respondents on the basis of their orientation towards the core task. Three items were removed from the final analysis on the basis of non-normal distributions and low variance. Hierarchical cluster analysis was conducted in order to determine the optimal number of clusters. The clustering (agglomeration) coefficient showed a large increase in going from four to three clusters. This was the largest relative difference between the agglomeration coefficients in the whole agglomeration schedule table. On that basis, a four cluster solution was selected (see Hair et al., 1998). *K*-means cluster procedure was used to assign the respondents into four clusters on the basis of their responses to the core task section.

2.2.5. The open question

The open question was analysed qualitatively. Nine development themes emerged as a result of the analysis that was based on grounded-theory (see e.g. Charmaz, 1995):

- organising of work and division of labour (24% of all individual development targets),
- work community and working climate (14% of all individual development targets),
- object and tools (12% of all individual development targets),
- power and decision making (12% of all individual development targets),
- goals and values (10% of all individual development targets),
- communication (8% of all individual development targets),
- co-operation (7% of all individual development targets),
- motivation (7% of all individual development targets),
- developing and maintaining competence (6% of all individual development targets).

The concrete development ideas under the themes were reported directly to the case organisation.

2.2.6. Demographic information and covariates

Age was measured on a five-level scale, with the first level (people under 25) receiving no entries. The other categories were 25–35 ($n = 20$), 36–45 ($n = 42$), 46–55 ($n = 48$) and over 55 years of age ($n = 16$).

Position in the company was asked directly and coded as technician, foreman, work planning and designer, special tasks or manager (five positions).

Section was asked directly. The maintenance department had eight sections at the time of measurement. The respondents were asked to indicate the corresponding section.

Tenure was asked directly and coded into an interval-type scale to allow its use as an independent variable. The categories were selected so that each category would be approximately of same size. The categories were as follows:

- less than 10 years of service ($n = 19$),
- 11–15 years of service ($n = 32$),
- 16–20 years of service ($n = 27$),
- 20–25 years of service ($n = 27$),
- more than 25 years of service ($n = 20$).

The first category spanned 10 years since the sample included only 11 respondents (8% of the sample) with 5 or less years of service.

Time spent on the same job (e.g. machine mechanic) was asked directly. The mean tenure in the sample was 14.3 years and the standard deviation was 7.7.

Changes in the job were asked by a Likert-type six-point scale, where six indicated major changes recently ($M = 3.70$, $SD = 1.50$).

Perceived increase in the workload was asked by a Likert-type six-point scale, where six indicated major increase recently ($M = 4.61$, $SD = 1.07$).

Perceived need for more training was asked by a Likert-type six-point scale, where six indicated that the respondent felt a strong need for training ($M = 3.81$, $SD = 1.20$).

General satisfaction with one's work was measured with one question "I am generally satisfied with my work", with a six point Likert-type scale ($M = 4.36$, $SD = 1.07$).

3. Results

3.1. Functioning of the instrument and linear relations between the scales

The data, being ordinal in nature, did not meet all the assumptions for parametric tests. Nevertheless, due to the relatively large sample size for a case study and variables that approximate the normal distribution, parametric statistical tests were used. Also, aggregated scores are closer to interval measurement than original ordinal scale variables. Care was taken to use only methods that are known to be robust to the effects of non-normal distributions and measuring scales (cf. Hair et al., 1998; Tabachnick and Fidell, 2001). The data was analysed with the SPSS statistical package. Bonferroni-corrected significance level of 0.005 was used in interpreting the results.

Internal consistency of the measures was inspected by calculating a reliability coefficient (Cronbach's alpha coefficient, see e.g. Ghiselli et al., 1981, p. 256) for every summated scale (Table 1).

Table 1
Reliabilities (coefficient alphas), mean scores and standard deviations of the summated scales

Variables	Items	α	Mean	SD
Value instrument				
Financial and efficiency	4	0.75	3.87	0.98
Safety and deliberation	5	0.80	4.13	0.87
Change and development	4	0.81	2.77	0.93
Hierarchy	3	0.63	3.68	0.96
Autonomy and proficiency	6	0.88	3.48	0.96
Cohesiveness	7	0.90	2.98	0.92
Psychological characteristics				
Feedback	4	0.75	3.47	0.96
Meaningfulness	3	0.73	4.35	0.94
Personal responsibility	4	0.62	4.42	0.71
Sense of control	4	0.52	4.28	0.74
Individual perceptions				
Management	5	0.72	2.77	0.82
Climate	5	0.59	4.10	0.70
Development orientation	5	0.61	4.15	0.63

α = Cronbach's alpha coefficient; SD = standard deviation.

Reliabilities (coefficient alphas) of the value instrument ranged from 0.63 to 0.90 (see Table 1), of the psychological characteristics instrument from 0.52 to 0.75 and of the individual perceptions from 0.59 to 0.72. Eight of the thirteen measures obtained alphas over 0.7, which is generally considered an acceptable level for reliable interpretations (see Hair et al., 1998; Nunally, 1978) also across the case study. Moreover, given the nature of the constructs of psychological job characteristics (consisting of different perceptions of the job itself) lower reliabilities should be expected (Ghiselli et al., 1981, p. 285).

Table 1 shows the mean values of the summated scales. The mean values of the summated scales for the value-instrument differed at a highly significant level on the basis of ANOVA ($F(5,804) = 41.9$, $p < 0.001$). As can be expected in the nuclear field, the perceived change values were lowest and the perceived safety values were highest. The differences between the mean scores of psychological characteristics were also highly significant ($F(3,536) = 37.3$, $p < 0.001$), as were the differences between the mean scores of individual perceptions ($F(2,402) = 158.5$, $p < 0.001$).

3.2. Linear relations between the scales

The intercorrelations (Pearson's r) among the summated scales are presented in Table 2. As can be seen from the table, there are many statistically significant and positive relations between the different scales of the value-instrument. This suggests a slightly positive response tendency, or acquiescence effect (Krosnick and Fabrigar, 1998) since many of the values could be considered as having positive overtones (in the nuclear field, at least).

Table 2
Intercorrelations (Pearson's r) among the summated scales

	1	2	3	4	5	6	7	8	9	10	11	12
1. Financial												
2. Safety	0.47***											
3. Change	0.30***	0.39***										
4. Hierarchy	0.44***	0.51***	0.19*									
5. Autonomy	0.37***	0.63***	0.76***	0.34***								
6. Cohesiveness	0.41***	0.54***	0.73***	0.33***	0.78***							
7. Feedback	0.36***	0.52***	0.49***	0.36***	0.56***	0.52***						
8. Meaningfulness	0.16	0.27**	0.32***	0.11	0.39***	0.40***	0.52***					
9. Personal responsibility	0.27**	0.33***	0.10	0.25**	0.16	0.13	0.41***	0.19*				
10. Sense of control	−0.18*	0.09	−0.04	−0.11	−0.03	−0.14	0.08	0.08	0.25**			
11. Management	0.27**	0.40***	0.57***	0.26**	0.55***	0.65***	0.68***	0.42***	0.14	−0.11		
12. Climate	0.08	0.47***	0.39***	0.07	0.52***	0.46***	0.44***	0.42***	0.23**	0.20*	0.32***	
13. Development orientation	0.13	0.00	0.12	0.29***	0.02	0.08	0.01	0.18*	−0.08	0.00	0.12	−0.17*

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

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Of the psychological job characteristics (see Table 2), perceived meaningfulness of the work is associated positively and significantly with all the other value variables except financial and hierarchy values. Sense of personal responsibility correlates positively with the financial, safety and hierarchy values. Only one value dimension correlates positively with all Hackman's job characteristics, namely the perceived safety values. Sense of control and the perceived financial values correlate negatively with each other.

It is also noteworthy in Table 2 that the perception of one's own development orientation has only one statistically significant correlation to the perception of values (hierarchy values) and none to the psychological job characteristics. This implies that the perception of one's own development orientation at work is an independent dimension that is not affected by the perception of one's own work or the perception of organisational values, at least not linearly. It also has quite a low reliability coefficient (see Table 1), which means that the functioning of the scale remains unclear at this point. Table 3 depicts the correlations of the summated scales to ordinal and interval scale covariates.

As can be seen from Table 3, the perceived increase in the workload relates positively ($p < 0.05$) to development orientation, but not to the perceived values (cf. Table 2). At the same time, increase in the workload correlates negatively with sense of control ($p < 0.05$). Age and tenure have few significant correlations and time spent in the same job has none. Job satisfaction correlates positively with almost all the variables, except the perceived financial values and development orientation. Job satisfaction also correlates positively and statistically significantly with tenure

Table 3
Correlations (Pearson's r) of summated scales with the ordinal and interval scale covariates

	Age	Tenure	Time in same job	Changes in job	Increase in work-load	Need for training	Job satisfac-tion
Value instrument							
Financial and efficiency	−0.04	0.09	−0.04	−0.06	0.10	−0.02	0.11
Safety and deliberation	−0.03	−0.06	−0.15	−0.14	−0.01	−0.22**	0.29***
Change and development	0.17*	0.18*	0.06	0.14	−0.02	−0.16	0.30***
Hierarchy	−0.04	−0.06	−0.17	−0.08	0.15	0.02	0.20*
Autonomy and proficiency	0.07	0.06	−0.04	−0.01	−0.02	−0.16	0.36***
Cohesiveness	0.04	0.07	−0.06	0.06	0.04	−0.12	0.29***
Psychological characteristics							
Feedback	0.18*	0.15	−0.10	−0.05	−0.05	−0.24**	0.47***
Meaningfulness	0.12	0.18*	−0.10	0.13	0.10	−0.03	0.56***
Personal responsibility	0.02	0.07	−0.03	−0.18*	−0.05	−0.26**	0.28***
Sense of control	−0.08	−0.03	0.00	−0.01	−0.20*	−0.13	0.18*
Individual perceptions							
Management	0.14	0.08	−0.04	0.06	−0.05	−0.18*	0.37***
Climate	−0.07	−0.01	−0.11	−0.06	−0.06	−0.20*	0.40***
Development orientation	0.03	0.00	−0.04	0.12	0.21*	0.07	0.03

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

($r = 0.28$, $p = 0.002$) and age ($r = 0.22$, $p = 0.013$). Age and tenure correlate also strongly with each other ($r = 0.63$, $p < 0.001$).

3.3. Effects of biographical variables

Influence of age and tenure on the perception of values, psychological job characteristics and individual conceptions was studied with ANOVA. The analysis showed little effect of age on any of the summated variables (see Table 4). Only development orientation differed on the basis of age. The mean scores are highest for the youngest and the middle-age (46–55) groups, and the Bonferroni Post Hoc test indicated a significant difference between the middle-age (46–55) group and the age group of 36–45 ($p = 0.042$).

Perceived change and development values showed statistically significant differences between different tenures. On the basis of post hoc analyses (Bonferroni), the difference between the tenure of 21–25 years and the tenure groups of 10–14 and 15–20 years of service differed on a statistically significant level ($p = 0.036$ and $p = 0.018$, respectively). The mean scores show that the two tenure groups who have been employed for more than 20 years in the company perceive that their section emphasises change and development values more than anybody else. Also hierarchy and autonomy values differed on the basis of tenure, as did perceptions of management.

It can be concluded that age has little effect on the perception of organisational values, at least not in the particular nuclear power plant, where most of the personnel

Table 4
Summary of analysis of variance of the value instrument, psychological characteristics instrument and individual perceptions instrument as dependent variables and age and tenure as independent variables

Variable	Age $F(3, 122)$	Tenure $F(5, 83)$	Age with tenure removed $F(1, 3)$	Tenure with age removed $F(1, 4)$
Value instrument				
Financial and efficiency	2.35	1.47	3.31*	1.87
Safety and deliberation	0.53	0.82	0.59	0.62
Change and development	1.78	3.88**	2.22	3.38**
Hierarchy	0.40	2.06	0.35	1.64
Autonomy and proficiency	0.44	2.66*	0.61	2.17
Cohesiveness	1.36	2.73*	1.49	2.30*
Psychological characteristics				
Feedback	1.77	2.30	1.51	2.08
Meaningfulness	0.76	1.18	1.25	0.95
Personal responsibility	0.61	1.56	0.65	1.21
Sense of control	2.00	0.61	1.57	0.57
Individual perceptions				
Management	1.46	3.56**	1.12	3.00*
Climate	0.32	0.42	0.37	0.59
Development orientation	3.11*	0.40	2.34	0.34

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

have been working for quite a long time. To study the effect of age with the influence of tenure removed, an ANCOVA was conducted with the tenure as a covariate. Only financial values ($p < 0.05$) showed significant differences between the various age groups (see Table 4).

The influence of tenure on the dependent variables was studied by ANCOVA with the age as a covariate (see Table 4). Of the dependent variables, change values ($p < 0.01$) and cohesiveness values ($p < 0.05$) and perceptions of management ($p < 0.05$) were statistically significant. This implies that tenure has more influence on the perception of organisational values than age does. Still, partial correlations with the effect of age removed show no statistically significant relationship between tenures and perceived values or psychological characteristics, which rules out linear relationships between the variables.

Results from ANOVA with the covariates as dependent, and age as the independent variable, showed significant differences only in job satisfaction ($F(3, 122) = 3.26$, $p = 0.024$). When controlling for tenure, the significance level rises ($F(1, 3) = 3.21$, $p = 0.015$), but it is still not within the limits set by the Bonferroni-correction (0.005). The mean scores showed that the youngest employees were the most dissatisfied and the oldest group of workers were the most satisfied with their job (Bonferroni Post Hoc test $p = 0.023$). The same effect ($p < 0.05$) was manifest for tenure, since job satisfaction of the personnel with more than 25 years of service differed (Bonferroni Post Hoc test $p = 0.034$) from those that had been less than 10 years with the company. The personnel with less service years were more dissatisfied (mean score 3.7) than the employees with longer service (mean score 4.8).

3.4. Effects of position and section

The effect of position and section in the organisation on the perceived values, psychological job characteristics and individual conceptions was analysed. ANOVAs were calculated with the six value scales, four psychological job characteristics and three individual perception scales as dependent variables, and the position in the company (technician, foreman, etc.) and section (electrical, mechanical, etc.) as the independent variables. The two smallest of the eight sections were removed from the zanalysis, since there were only five and seven responses from them, respectively. Also special tasks ($n = 6$) were removed from the position variable. The total N for the analysis was 83. The results of the analysis are summarised in Table 5.

As shown in Table 5, section has not as much influence on the perceived values as does the position in the company, although the question was worded "think of the values endorsed in your section". There were no statistically very significant differences between the sections.

The difference in the cohesiveness values on the basis of position is highly significant ($p < 0.001$). The Bonferroni test indicates that technicians differed from managers on a statistically significant level ($p = 0.006$). The various positions differed on the variables of change values, autonomy values, cohesiveness values, feedback from one's own work, sense of control and perceptions of the management. Technicians had lower mean scores on all the above variables than for example

Table 5
Summary of analysis of variance of the value instrument, psychological characteristics instrument and individual perceptions instrument as dependent variables and section and position in the company as independent variables

Variable	Position $F(3, 83)$	Section $F(5, 83)$	Position with Section removed $F(1, 3)$	Section with position removed $F(1, 6)$
Value instrument				
Financial and efficiency	1.19	1.75	0.95	1.02
Safety and deliberation	3.04*	2.20*	2.32	2.74*
Change and development	3.35*	2.36*	3.07*	2.99**
Hierarchy	1.90	2.40*	2.80*	3.53**
Autonomy and proficiency	4.41**	2.83*	3.71**	3.65**
Cohesiveness	6.87***	2.43*	5.35***	4.62***
Psychological characteristics				
Feedback	4.55**	0.70	4.11**	1.78
Meaningfulness	0.70	1.35	1.01	1.26
Personal responsibility	1.84	1.42	1.99	0.98
Sense of control	3.74*	0.66	2.91*	1.22
Individual perceptions				
Management	7.25***	1.86	5.61***	4.88***
Climate	0.57	2.57*	1.82	2.70*
Development orientation	2.56	2.11	2.00	1.26

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

foremen or managers had. The sense of control scale was an exception since there the technicians and personnel in special tasks scored the highest (no significant differences were found on the basis of the Bonferroni Post Hoc tests, however).

The estimated marginal mean scores between the sections showed that different sections emphasise different values when controlling for position. This indicates that all sections had slightly different cultural profiles.

It can be concluded that as predicted by hypothesis C, various subcultures emerged. Position in the company was one of the strongest predictors of subculture membership. Section had only a small influence and age had practically no influence on the value scales.

3.5. Core task clusters and the effects of core task orientation

An analysis of variance was performed to determine the relationship between the conception of the core task and the summated scales. The independent variable was the new core task variable separating the sample into four groups on the basis of the respondents' orientation towards the core task of the maintenance (see Section 2.2). The results are summarised in Table 6.

It can be observed from Table 6 that the orientation towards the core task has a statistically significant relationship to three of the value variables and to the per-

Table 6
Summary of analysis of variance and summary of mean scores for the four core task groups on the 13 dependent variables

	CT cluster $F(3, 130)$	Group 1 ($n = 22$)	Group 2 ($n = 30$)	Group 3 ($n = 19$)	Group 4 ($n = 63$)
Value instrument					
Financial and efficiency	0.96	3.99	4.03	3.57	3.85
Safety and deliberation	3.10*	4.15	4.48a	3.75a	4.06
Change and development	2.23	2.60	3.00	2.36	2.83
Hierarchy	2.61	3.98a	3.68	3.18a	3.70
Autonomy and proficiency	4.35**	3.26	3.92a	2.99a	3.49
Cohesiveness	5.02**	2.81	3.41a	2.44a	2.99
Psychological characteristics					
Feedback	10.91***	3.47a	4.03bc	2.58abd	3.45cd
Meaningfulness	4.64**	4.45a	4.59b	3.65abc	4.41c
Personal responsibility	1.62	4.49	4.56	4.12	4.42
Sense of control	0.54	4.15	4.36	4.41	4.26
Individual perceptions					
Management	6.62***	2.75	3.19a	2.19ab	2.74b
Climate	4.63**	4.06	4.44a	3.73a	4.05
Development orientation	1.90	4.35	4.01	3.97	4.20

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
Statistically significant differences between the groups identified by Bonferroni Post Hoc test ($p < 0.05$) are indicated by corresponding alphabetical letters.

ceived feedback, meaningfulness of the job, perceptions about the management and perceptions about the working climate. Of the covariates, job satisfaction ($F(3, 130) = 3.85$, $p = 0.011$) and increase in the workload ($F(3, 130) = 3.50$, $p = 0.017$) had a statistically significant relationship to the core task variable, but they were not within the limits set by the Bonferroni-correction (0.005). Group 2 (mean score 4.67) differed (Bonferroni Post Hoc test value $p = 0.032$) from Group 3 (mean score 3.68) on the job satisfaction variable.

Chi square tests were used to inspect the distribution of the respondents on the basis of age, tenure, position and section in the four cluster groups. None of the test statistics were statistically significant, so it can be concluded that the tested distributions are random. Thus, the conception of the core task varies between the workers independently of age, tenure, position and section. The mean scores of the four groups on all the dependent variables are illustrated in Table 6.

As Table 6 shows, Group 2 perceives their work as more meaningful than the other groups (as noted, they had also the highest job satisfaction). Group 3 felt their work was the least meaningful of all the groups and they also perceived the organisation's safety values as the lowest of all the groups. Group 3 has generally a more negative view of their work and the organisation. Group 4 is the largest group in the sample, and this group perceives its work as highly meaningful, yet they also feel a lack of feedback and have rather a negative view about the management (see Table 6).

The perceptions of the core task in the different groups were investigated by comparing the cluster centres of the individual core task questions. The core task questions that load high on cluster 3 emphasise the uncertain nature of the maintenance task (high mean score on "unexpected things happen unavoidably") with a strong focus on rule-following as a means to overcome the uncertainty ("By following the rules, one is relieved of personal responsibility"). Group 1 also emphasises the uncertainty inherent in the maintenance task, but they also emphasise active and interactive orientation where information sharing and personal contacts are endorsed ("Getting along with people is paramount to working in maintenance"). Groups 2 and 4 differ from Groups 1 and 3 by their emphasis on certainty as an ideal state in maintenance ("The effects of actions are known in advance") and from each other by the means to accomplish the maintenance task. Group 2 (which is also the most satisfied with their work and management, cf. Table 6) focuses on rules and procedures ("You should never deviate from the plans"), whereas Group 4 emphasises interaction with people and knowledge sharing.

The open question of the CULTURE-questionnaire was examined further from the perspective of different core task orientations. The Chi square test indicated that the orientation did not influence whether or not the respondent had responded to the open question. The distribution of the responses to the nine content themes identified earlier (see Section 2.2.) was studied. Thirty eight percent of the development targets of the uncertain and active orientation (Group 1) addressed the theme "goals and values" (18%, 17%, and 13% in Groups 2–4, respectively) and wished for more emphasis on long-term planning, preventive maintenance and condition monitoring instead of predetermined maintenance schedules. They also wanted improved communication between all levels of the organisation (23% of their development targets addressed the theme "communication"). Personnel with certain and passive orientation (Group 2) had few complaints about the social climate (only one person out of 30 addressed the theme), and they were not eager to have more power (also only one person addressed power issues). The biggest problem in their opinion was the transfer of existing knowledge to the younger generation organisation (27% of their development targets addressed the theme). Group 3, personnel with uncertain and passive orientation, emphasised the problems in the climate (33%) and the distribution of authority (42%). Group 4, personnel with certain and active orientation, emphasised single concrete improvements in tools, machines, computer systems etc. (37% of their development targets addressed the theme "object and tools"). They also emphasised improvements in the climate, co-operation and distribution of authority. Thus the groups clearly differed from each other in perceptions of the values of the organisation, in conceptions of one's own work and the maintenance organisation and in the development initiatives that they wished for. What they did share was perception of high safety (excluding Group 3) and financial values in the company, perception of low change values, high sense of personal responsibility and a high sense of control.

4. Discussion

The purpose of this article was to present a survey methodology for studying organisational culture in complex sociotechnical systems. The survey was tested in a case study in the maintenance organisation of a nuclear power plant with an excellent performance record. Perceived values, psychological job characteristics, individual conceptions of work and the organisation and perceptions of the maintenance task were measured. Internal consistency and discriminatory power of the instrument were studied. Both shared and ambiguous issues in the maintenance culture were identified with the survey.

4.1. *Perceived workplace values and the value structure*

The factor solution for perceived workplace values differed from the hypothesised Cameron and Quinn (1999) model (see Fig. 1 and Table 1). An interesting difference was the separation of safety related values (e.g. rule following and occupational safety) from hierarchy related values (e.g. centralised decision making and detailed work tasks). This suggests that they are conceptualised by the personnel as two partially independent dimensions. Job satisfaction and the perceived meaningfulness of work also correlated more positively with the safety values than with the hierarchy values.

The perceived change values were lowest in the mean scores and the perceived safety values were highest. Perhaps surprisingly, values related to financial efficiency were marked the second highest. This could be related to increased talk during the couple of years prior to the study about optimisation of expenses and possible outsourcing of some maintenance functions in the target organisation. Job satisfaction and meaningfulness of work did not correlate positively with the perceived financial values. Sense of control was instead negatively related to the perception of financial values. Safety seems to be thus more strongly experienced as an "end-state" (Rokeach, 1973) of maintenance than financial efficiency or cost-effectiveness. Nevertheless, the existence of financial goals in NPP maintenance was acknowledged.

Job satisfaction had a strong positive correlation to the values of safety, autonomy, change and cohesiveness. It can be assumed that in the nuclear field perceiving the company as emphasising safety affects job satisfaction more than the other way around. The influence of job satisfaction on the safety values is in accordance with the previous research on safety culture (see e.g. Harvey et al., 2002). The perceived hierarchy values did not affect job satisfaction (Table 3), but the perception of strong hierarchy values was related to a high personal development orientation (Table 2). This implies that the personnel who emphasise the development of their own expertise experience the organisation as more hierarchical and centralised than the others.

4.2. *Psychological job characteristics*

The factor solution for the psychological job characteristics instrument differed from that proposed by Hackman and Lawler (1971, see also Fried and Ferris, 1986, 1987). Also, managers had to be removed from the analysis due to an obscure initial factor structure. Nevertheless, alphas calculated for the entire sample were mostly within acceptable limits. Two of the three dimensions obtained alphas over 0.7. As predicted by hypothesis B, the perceived psychological job characteristics had a positive influence on job satisfaction. This is in accordance with Hackman's et al. (Hackman and Lawler, 1971; Hackman and Oldham, 1975, 1980) theory.

On a general level, the work was perceived as highly meaningful, but the perceived feedback from one's work was quite low. Sense of control was also very high. Certainty was emphasised by the majority of personnel as a demand of the maintenance work (Groups 2 and 4 in Table 6, $n = 93$ out of 135). The high sense of control seems to be a norm in the organisation. The question arises as to what the optimal level is for the sense of being in control of the outcome of one's work and oneself as a worker in order to maintain a sufficient working capacity without being overconfident about one's skills.

The sense of personal responsibility scale received the highest mean score. The sense of personal responsibility scale correlated positively with the perceived hierarchy values but not with the perceived autonomy values. The question arises as to what the scale measures in this particular environment, where activities are highly governed by rules and procedures. Rochlin (1999) states that in a nuclear power plant "safety is sought through collective (inter)action, through shared knowledge and responsibility" (Rochlin, 1999, p. 1554; see also Schulman, 1996; Klein et al., 1995). This prompts the personnel to respond to unexpected events through collective action instead of individual initiative as is the case in some other potentially risky domains (see e.g. Rochlin, 1999). Hackman and Oldham (1980, p. 75) also point out that "[t]he irony is that in many such significant jobs [such as an aircraft brake assembler], precisely *because* the task is so important, management designs and supervises the work to ensure error-free performance, and destroys employee motivation... in the process". In that case, the sense of personal responsibility should be low.

It can be concluded that the sense of personal responsibility scale did not measure the construct as defined by Hackman et al. (Hackman and Lawler, 1971; Hackman and Oldham, 1975, 1980), rather it measured either the sense of personal responsibility as it is constructed in the particular plant or collective responsibility as defined by Rochlin (1999). Judging from the questions comprising the scale ("I have a clear picture of my responsibilities and powers", "my work tasks are clearly defined") it can be hypothesised that the scale measures the clarity of the work role (cf. Koch, 1993, p. 83) and the sense of personal responsibility arising from knowing one's own role in the system. Further research should aim to clarify the construct of the sense of personal responsibility in complex safety-critical environments and its relation to the sense of control dimension identified in this case study. It can be hypothesised that in safety-critical environments Hackman's dimensions address only the productivity and wellbeing of the personnel, but not safety (cf. Vicente, 1999). The sense of control might be linked with the additional psychological demand for job satisfaction and job motivation produced from working in a potentially risky environment.

4.3. Subcultures in the organisation

As predicted by hypothesis C, various subcultures were identified. Age and tenure were first considered as possible variables in the formation of subcultures. Based on their survey, Lee and Harrison (2000, see also Lee, 1998) speculate that younger staff (and those with shorter service time, which they did not specifically measure) begin on a relatively positive note in respect to some attitudes, but then converge with the plant norms for their job type and age group (Lee and Harrison, 2000, p. 77). Age and tenure did create differences on the perceived values that were related to change and development. People with longer service time with the company tended to view their organisation as more change-oriented than the newer employees. When discussing these results with the employees, an interpretation was made: Recent changes (computerisation of work, economic pressures) are experienced as more stressful by some of the older workers than by younger employees. The fact that age does not seem to have significant effect could be explained by the fact that people of older age but shorter tenure have come to the power plant from outside the nuclear field, where changes in the work have been more dramatic and have started earlier. The perceived development orientation was highest for age groups 25–35 and 46–55, which partially supports Lee and Harrison's (2000) claim. Younger people consider themselves as having a higher development orientation, but they do not see the company as supporting this (as shown by the perceived low change values). Instead, they experience the maintenance organisation as strongly emphasising the values related to hierarchy.

Position in the company influenced the measured variables to a large degree. Technicians had generally lower mean scores than managers. This means that they had more negatively loaded meanings toward their organisation than the managers. The separation of subcultures on the basis of position in the company is in accordance with the research by e.g. Harvey et al. (2002), but in contrast with the research by e.g. Klein et al. (1995). Managers have also previously been identified as having a tendency to perceive their organisation as more supportive than their subordinates do (Cameron and Quinn, 1999; for different results see Klein et al., 1995). This was the result also in this case study. Technicians can be said to have a collective climate (Gonzáles-Romá et al., 1999; see also Joyce and Slocum, 1984) when it comes to perceiving values related to change and cohesiveness. It can be stated that the personnel at the maintenance department had several overlapping group identifications as depicted by e.g. Parker (2000) and Alvesson (2002).

4.4. Perceptions of the core task of maintenance

The personnel's orientation towards the maintenance core task differed along two dimensions, depending on whether or not they emphasised certainty as a basis for maintenance practices and whether or not they emphasised active interpretation of rules and procedures, and interaction with the other workers. Different orientations towards the core task mean that the demands of work are viewed in a different light. The meanings ascribed to maintenance and its demands have a different content.

The conception of the core task had a strong relationship to the psychological job characteristics and perceived values. A question arises, whether certainty versus uncertainty is a simple response bias (or impression management) factor, since it also separates the more positive people from the people with negative views. Or is the traditional definition of response bias too narrow (concealing different orientation towards work or the world at large)? Verkasalo and Lindeman (1994) state that instead of being a threat to validity, this "socially desirable responding" might indicate something about the respondents' personalities.

What was interesting about the core task orientation is that it was not formed by the traditional means by which subcultures form, aka by age, occupation, shared task or social interaction processes (Hofstede et al., 1990; Parker, 2000; Alvesson, 2002; Young, 1989). Similar differences in task orientation among the workers in another complex and dynamic task (anaesthetist's work) have been obtained with qualitative research methods by Klemola and Norros (1997) and Norros and Klemola (1999). Klemola and Norros also discovered that core task orientation was not (linearly) affected by age or even by experience in a particular work. The results correspond with the fragmentation perspective of culture (Martin, 1992). Alvesson points out that "the challenge [in cultural research] is to consider the frequently *simultaneous* existence of (a) relative clarity and common orientations associated with a degree of shared meanings across the organization, (b) diversity, conflict and multitude of overlapping group identifications, and (c) ambiguity and fragmentation on different levels." (Alvesson, 2002, p. 164). The orientation towards the organisational core task could serve as a differentiating variable in cultural analysis (Reiman and Oedewald, submitted for publication).

It seems that in the nuclear field certainty is valued and emphasised (cf. Ignatov, 1999; Rochlin, 1999; Oedewald and Reiman, 2003). This could explain the finding that the groups emphasising certainty had on a general level more positive attitude towards their work and towards their organisation, and a higher overall job satisfaction. On the other hand, awareness of uncertainty is considered a prerequisite for the development of expertise (see e.g. Klemola and Norros, 1997; Norros and Nuutinen, 2002). It can be hypothesised that high job satisfaction does not guarantee optimal performance and development of expertise in the long run if the satisfaction is derived from the social aspects of work.

It is apparent that in order to develop the working practices and organisational culture it is essential to take into account that even the demands of the same task can be construed differently. This influences the workers' conceptions about the need to change and the means to achieve the change, as could also be noted in the variance in the responses to the open question.

4.5. Conclusions

On the basis of this survey research, we were able to sum up the following description of the cultural features of the case organisation. The values related to change were lowest and safety values highest at the case organisation. Only safety values correlated positively with all the Hackman's (Hackman and Lawler, 1971) job characteristics, indicating the importance of the subjective perception of safety at the nuclear power plant. Safety was perceived as the primary goal of maintenance and financial aspects more as internal requirements or constraints. High emphasis on economic values was experienced as stressful. Technicians formed a strong subculture and were more critical towards their organisation. Nevertheless, the meaningfulness of work was equally high on all the organisational levels and in all tasks. Some differences in the values were also found between the different sections. The differences between the sections can be assumed to reflect the different nature of the work (e.g. mechanical maintenance versus instrumentation maintenance).

Four different orientations towards the core task of maintenance were identified, which were independent of age, tenure and task. These orientations affected the perceptions of organisational values and of one's own work. Personnel who felt their job as the least meaningful were those who emphasised awareness of uncertainty and passive rule following as requirements of the maintenance task. Certainty was emphasised by the majority of the personnel as a demand of the maintenance work (Groups 2 and 4 in Table 6, $n = 93$). Even though the certain and active orientation was the largest group (Group 4), the results gave implications that the certain and passive orientation was more dominant in the culture of the case organisation (see also Oedewald and Reiman, 2003, p. 290). This was implicated e.g. by the fact that the certain and passive group was the most satisfied with their job. High self-confidence seemed to be a norm in the organisation. This also implies that the objectively largest group (in numbers) is not necessarily the dominant group in the terms of having an influence on the organisational culture.

A common claim is that it is impossible to measure culture by a survey (Schein, 1999) and at best a survey is able to measure the organisational climate (see e.g. Schein, 1985; Payne, 2000; Denison, 1996; Guldenmund, 2000). Climate has been defined as an artefact of the organisational culture (Schein, 1985) and as a more superficial phenomenon than the culture (Flin et al., 2000). If the survey results are taken as subjective conceptions, they are manifestations of the underlying culture. They nevertheless offer hypotheses about the cultural assumptions (e.g. certainty as a norm and a basic assumption). Interviews and focus groups gave depth to the results obtained by the questionnaire. Also presentation of the results to the personnel acted as a crucial phase of the project. The relations between the single variables of the survey offered multiple hypotheses about the features of the culture of the case organisation. These hypotheses were presented to the personnel, but were not discussed in this article, since the focus here was more on the functioning of the whole instrument. The way the personnel respond to, the way they think and feel about the survey results is as meaningful and informative from the researcher's point of view, as are the quantitative results from the survey. This discussion with the personnel validates or invalidates the hypotheses about the basic assumptions generated by the survey. Thus, by survey method alone, hypotheses about the cultural assumptions would remain very uncertain. Nevertheless, we claim that without the survey results acting as facilitator of the discussion many of the cultural assumptions would have remained hidden. Also, some of the survey results were surprising for the majority of the members of the organisation (e.g. the high overall job satisfaction, lack of statistical differences between the sections on psychological job characteristics), and would probably not have surfaced in collective seminars or even in individual interviews.

The validity of the instrument was inspected by different means. One means of validation is the usefulness of the obtained results in the development work. Although traditionally considered a criterion for qualitative research, the plausibility and credibility of the results to the personnel (Hammersley, 1990) can be considered an indication of the validity of the results, since the aim is also to change the culture. On the other hand, results deemed as unplausible by the personnel cannot be rejected outright, since the central aspects of the culture are taken for granted and sometimes responded to in a denying manner at first (see e.g. Schein, 1985).

The research did not aim at finding performance indicators or other objective characteristics to validate the connection of the results to the operational reliability of the plant. Neither did the research strategy, being a case study, allow for statistical comparisons and other tests required to validate such links even if the data for this case study had existed. Further research should aim at clarifying the influence of organisational culture to objective measures of plant reliability.

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References

Alvesson, M., 2002. Understanding Organizational Culture. Sage, London.

Bier, V., Joosten, J., Glyer, D., Tracey, J., Welsh, M., 2001. Deregulation and nuclear power safety: what can we learn from other industries? The Electricity Journal, 49–60.

Bourrier, M., 1999. Constructing organisational reliability: the problem of embeddedness and duality. In: Misumi, J., Wilpert, B., Miller, R. (Eds.), Nuclear Safety: A Human Factors Perspective. Taylor & Francis, London, pp. 331–340.

Cameron, K.S., Quinn, R.E., 1988. Organizational paradox and transformation. In: Quinn, R.E., Cameron, K.S. (Eds.), Paradox and Transformation. Toward a Theory of Change in Organization and Management. Ballinger, Massachusetts.

Cameron, K.S., Quinn, R.E., 1999. Diagnosing and Changing Organisational Culture: Based on the Competing Values Framework. Addison-Wesley, Massachusetts.

Cattell, R.B., 1966. The scree test for the number of factors. Multivariate Behavioral Research 1, 245–276.

Charmaz, K., 1995. Grounded theory. In: Smith, J.A., Harré, R., Langenhove, L.V. (Eds.), Rethinking Methods in Psychology. Sage, London.

Cox, S., Flin, R., 1998. Safety culture: philosopher's stone or man of straw? Work & Stress 12 (3), 189–201.

Denison, D.R., 1996. What is the difference between organizational culture and organizational climate. A native's point of view on a decade of paradigm wars. Academy of Management Review 21 (3), 619–654.
Flin, R., Mearns, K., O'Connor, P., Bryden, R., 2000. Measuring safety climate: identifying the common features. Safety Science 34, 177–192.
Fried, Y., Ferris, G.R., 1986. The dimensionality of job characteristics: some neglected issues. Journal of Applied Psychology 71 (3), 419–426.
Fried, Y., Ferris, G.R., 1987. The validity of the job characteristics model: a review and meta-analysis. Personnel Psychology 40, 287–322.
Ghiselli, E.E., Campbell, J.P., Zedeck, S., 1981. Measurement Theory for the Behavioral Sciences. W.H. Freeman and Company, San Francisco.
Gonzáles-Romá, V., Peiró, J.M., Lloret, S., Zornoza, A., 1999. The validity of collective climates. Journal of Occupational and Organizational Psychology 72, 25–40.
Grote, G., Künzler, C., 2000. Diagnosis of safety culture in safety management audits. Safety Science 34, 131–150.
Guldenmund, F.W., 2000. The nature of safety culture: a review of theory and research. Safety Science 34, 215–257.
Hackman, J.R., Lawler, E.E., 1971. Employee reactions to job characteristics. Journal of Applied Psychology Monograph 55 (3), 259–286.
Hackman, J.R., Oldham, G.R., 1975. Development of the job diagnostic survey. Journal of Applied Psychology 60, 159–170.
Hackman, J.R., Oldham, G.R., 1980. Work Redesign. Addison-Wesley, Reading, MA.
Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C., 1998. Multivariate Data Analysis, fifth ed. Simon & Schuster, New Jersey.
Hammersley, M., 1990. Reading Ethnographic Research: A Critical Guide. Longmans, London.
Harvey, J., Erdos, G., Bolam, H., Cox, M.A.A., Kennedy, J.N., Gregory, D.T., 2002. An analysis of safety culture attitudes in a highly regulated environment. Work & Stress 16 (1), 18–36.
Hofstede, G., Neuijen, B., Ohayv, D.D., Sanders, G., 1990. Measuring organizational cultures: a qualitative and quantitative study across twenty cases. Administrative Science Quarterly 35, 286–316.
IAEA, 1991. Safety Culture. Safety Series No. 75-INSAG-4. Vienna: International Atomic Energy Agency.
IAEA, 1996. ASCOT Guidelines. Revised 1996 Edition. Guidelines for Organizational Self-Assessment of Safety Culture and for Reviews by the Assessment of Safety Culture in Organizations Team, TECDOC-860. Vienna: International Atomic Energy Agency.
Ignatov, M., 1999. Implicit social norms in reactor control rooms. In: Misumi, J., Wilpert, B., Miller, R. (Eds.), Nuclear Safety: A Human Factors Perspective. Taylor & Francis, London.
Joyce, W.F., Slocum, J.W., 1984. Collective climate: agreement as a basis for defining aggregate climates in organizations. Academy of Management Journal 27, 721–742.
Kennedy, R., Kirwan, B., 1995. The failure mechanisms of safety culture. In: Carnino, A., Weimann, G. (Eds.), Proceedings of the International Topical Meeting on Safety Culture in Nuclear Installations. American Nuclear Society of Austria, Vienna, pp. 281–290.
Klein, R.L., Bigley, G.A., Roberts, K.H., 1995. Organizational culture in high reliability organizations: an extension. Human Relations 48 (7), 771–793.
Klemola, U.-M., Norros, L., 1997. Analysis of the clinical behaviour of the anaesthetics: recognition of uncertainty as a basis for practice. Medical Education 31, 449–456.
Koch, B.A., 1993. Differentiating reliability seeking organizations from other organizations: development and validation of an assessment device. In: Roberts, K.H. (Ed.), New Challenges to Understanding Organizations. Macmillan Publishing, New York.
Krosnick, J.A., Fabrigar, L.R., 1998. Designing Good Questionnaires: Insights from Psychology. Oxford University Press.
Laakso, K., Pyy, P., Reiman, L., 1998. Human Errors Related to Maintenance and Modifications, STUK-YTO-TR 139.
Lee, T., 1998. Assessment of safety culture at a nuclear reprocessing plant. Work & Stress 12 (3), 217–237.

Lee, T., Harrison, K., 2000. Assessing safety culture in nuclear power stations. Safety Science 34, 61–97.
Martin, J., 1992. Cultures in Organizations: Three Perspectives. Oxford University Press, New York.
Mearns, K., Flin, R., Gordon, R., Fleming, M., 1998. Measuring safety climate on offshore installations. Work & Stress 12 (3), 238–254.
Mearns, K., Whitaker, S.M., Flin, R., 2003. Safety climate, safety management practice and safety performance in offshore environments. Safety Science 41 (8), 641–680.
Norros, L., Klemola, U.-M., 1999. Methodological considerations in analyzing anaesthetists' habit of action. Ergonomics 42 (11), 1521–1530.
Norros, L., Nuutinen, M., 2002. The core-task concept as a tool to analyse working practices. In: Borham, N., Samurcay, R., Fischer, M. (Eds.), Work Process Knowledge. Routledge.
Nunally, J., 1978. Psychometric Theory. McGraw-Hill, New York.
Oedewald, P., Reiman, T., 2003. Core task modelling in cultural assessment—a case study in nuclear power plant maintenance. Cognition, Technology & Work 5 (4), 283–293.
Parker, M., 2000. Organizational Culture and Identity. Sage, London.
Payne, R.L., 2000. Climate and culture. How close can they get. In: Ashkanasy, N.M., Wilderom, C.P.M., Peterson, M.F. (Eds.), Handbook of Organizational Culture and Climate. Sage, Thousand Oaks.
Perrow, C., 1984. Normal Accidents: Living With High-Risk Technologies. Basic Books, New York.
Pidgeon, N., 1998. Safety culture: key theoretical issues. Work & Stress 12 (3), 202–216.
Pyy, P., 2001. An analysis of maintenance failures at a nuclear power plant. Reliability Engineering and System Safety 72 (3), 293–302.
Quinn, R.E., Rohrbaugh, J., 1983. A spatial model of effectiveness criteria: towards a competing values approach to organizational effectiveness. Management Science 29, 363–377.
Reiman, T., Norros, L., 2002. Regulatory culture: balancing the different demands of regulatory practice in the nuclear industry. In: Kirwan, B., Hale, A.R., Hopkins, A. (Eds.), Changing Regulation—Controlling Risks in Society. Pergamon, Oxford.
Reiman, T., Oedewald, P., 2002. The Assessment of Organisational Culture. A Methodological Study. VTT Research Notes 2140. Espoo: The Technical Research Centre of Finland. Available from <http://www.vtt.fi/inf/pdf/tiedotteet/2002/T2140.pdf>.
Reiman, T., Oedewald, P., submitted for publication. The assessment of an organizational culture and core task in complex sociotechnical systems.
Rochlin, G.I., 1999. Safe operation as a social construct. Ergonomics 42 (11), 1549–1560.
Rokeach, M., 1973. The Nature of Human Values. Free Press, New York.
Salo, I., Svenson, O., 2001. Human Factors in Maintenance: Development and Research in Swedish Nuclear Power Plants. SKI Report 01:40.
Schein, E.H., 1985. Organizational Culture and Leadership. A Dynamic View. Jossey-Bass, San Francisco.
Schein, E.H., 1999. The Corporate Culture Survival Guide: Sense and Nonsense about Culture Change. Jossey-Bass, San Francisco.
Schulman, P.R., 1996. Heroes, organizations and high reliability. Journal of Contingencies and Crisis Management 4 (2), 72–82.
Smircich, L., 1983. Concepts of culture and organizational analysis. Administrative Science Quarterly 28, 339–358.
Sorensen, J.N., 2002. Safety culture: a survey of the state-of-the-art. Reliability Engineering and System Safety 76, 189–204.
Svenson, O., Salo, I., 2001. Latency and mode of error detection in a process industry. Reliability Engineering and System Safety 73 (1), 83–90.
Tabachnick, B.G., Fidell, L.S., 2001. Using Multivariate Statistics, fourth ed. Allyn & Bacon, Boston.
Taylor, J.C., 2000. The evolution and effectiveness of maintenance resource management (MRM). Industrial Ergonomics 26, 201–215.
Vandenberghe, C., Peiró, J.M., 1999. Organizational and individual values: their main and combined effects on work attitudes and perceptions. European Journal of Work and Organizational Psychology 8 (4), 569–582.
Verkasalo, M., Lindeman, M., 1994. Personal ideals and socially desirable responding. European Journal of Personality 8, 385–393.

Vicente, K., 1999. Cognitive Work Analysis. Toward Safe, Productive, and Healthy Computer-Based Work. Lawrence Erlbaum, London.

Vidal-Gomel, C., Samurcay, R., 2002. Qualitative analyses of accidents and incidents to identify competencies. The electrical systems maintenance case. Safety Science 40, 479–500.

Weick, K., 1993. Organizational redesign as improvisation. In: Huber, G.P., Glick, W.H. (Eds.), Organizational Change and Redesign: Ideas and Insights for Improving Performance. Oxford University Press, Oxford.

Weick, K.E., 1995. Sensemaking in Organizations. Sage, Thousand Oaks, CA.

Williamson, A.-M., Feyer, A., Cairns, D., Biancotti, D., 1997. The development of a measure to safety climate: the role of safety perceptions and attitudes. Safety Science 25, 15–27.

Young, E., 1989. On the naming of the rose: interests and multiple meanings as elements of organizational culture. Organization Studies 10 (2), 187–206.

ARTICLE III

Characteristics of organizational culture at the maintenance units of two Nordic nuclear power plants

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Characteristics of organizational culture at the maintenance units of two Nordic nuclear power plants

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Abstract

This study aims to characterize and assess the organizational cultures of two Nordic nuclear power plant (NPP) maintenance units. The research consisted of NPP maintenance units of Forsmark (Sweden) and Olkiluoto (Finland). The study strives to anticipate the consequences of the current practices, conceptions and assumptions in the given organizations to their ability and willingness to fulfill the organizational core task. The methods utilized in the study were organizational culture and core task questionnaire (CULTURE02) and semi-structured interviews. Similarities and differences in the perceived organizational values, conceptions of one's own work, conceptions of the demands of the maintenance task and organizational practices at the maintenance units were explored. The maintenance units at Olkiluoto and Forsmark had quite different organizational cultures, but they also shared a set of dimensions such as strong personal emphasis placed on safety. The authors propose that different cultural features and organizational practices may be equally effective from the perspective of the core task. The results show that due to the complexity of the maintenance work, the case organizations tend to emphasize some aspects of the maintenance task more than others. The reliability consequences of these cultural solutions to the maintenance task are discussed. The authors propose that the organizational core task, in this case the maintenance task, should be clear for all the workers. The results give implications that this has been a challenge recently as the maintenance work has been changing. The concepts of organizational core task and organizational culture could be useful as management tools to anticipate the consequences of organizational changes.

Keywords: Organizational culture; Maintenance work; Safety culture; Organizational assessment; Work psychology; Task analysis

1. Introduction

The term *safety culture* was introduced into common usage after the Chernobyl nuclear accident in 1986 [21]. The main reasons for accidents were proposed to be not only technical faults or individual human errors. It was suggested that management, organization and attitudes also influence safety for better or worse. In a 1991 report INSAG [21] defined safety culture as follows: "Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance." [21: p. 1]. The demand for 'a proper safety culture' quickly became a (more or less explicit) requirement by the regulatory authorities, first in the nuclear field and gradually also in other safety-critical domains (e.g. offshore drilling industry, railway industry). For an overview of the field see e.g. [9,15,34,50].

The concept of safety culture was coined partly because of a need to assess the operating risk associated with the overall functioning of safety critical organizations [21]. Sorensen [50] nevertheless criticizes the approach taken by INSAG towards the safety culture concept: "The fundamental problem with INSAG's approach to safety culture is that it specifies in great detail what should be included, but provides little guidance on overall criteria for acceptability. Furthermore no link is made (or even seems possible) between safety culture as INSAG defines it and human performance or human reliability. A positive relationship is simply assumed." [50: p. 191].

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Sorensen's (and other's, see e.g. [34,39]) critique concerning INSAG's approach to safety culture brings up two important issues. First, the term safety culture was expected by the 'risk' community to help explain the causes and probabilities of human errors that affect the operating risk. But the concept was adopted from an entirely different scientific tradition than that commonly used in safety science. The lack of criteria for acceptability or evidence of causal links stems partly from the tradition in ethnographic culture study. The ethnographic culture tradition is basically descriptive in nature and its researchers do not aim to assess the 'goodness' or 'badness' of cultures [1,48]. Sorensen concludes "although INSAG has borrowed the term "culture" from either anthropologists or the organizational development community (who in turn borrowed it from anthropologists), the INSAG publications make no reference to the bodies of literature in those fields… Nevertheless, suggestions that "culture" might help explain organizational behavior, and that management and organizational factors could influence safety performance, both predated INSAG's introduction of the term 'safety culture'" [50: p. 191].

Also, management and organizational 'factors', have received considerable attention in organizational research, where the dominant focus is on corporate performance. Starting in the late 1970s, traditional mechanistic management models were repeatedly found to be inadequate and to tend to neglect issues associated with knowledge about human nature. A new concept was needed to describe and explain the individuals' actions in an organization so that the effectiveness of the organization could be improved [2]. Organizational culture was suggested to be such a concept. Despite the almost immediate popularity of the organizational culture concept, no clear and widely accepted definition of the concept has emerged [27,46,48]. Also the evidence of a link between organizational culture and effectiveness is tentative at most [56]. The reasons for this state of affairs are numerous, and stem, e.g. from different conceptualizations of organizational culture and effectiveness, and from problems in assessing culture and performance independently [42,56].

Cultural approaches are particularly interested in meanings and the generation of these meanings in organizations [1: p. 106]. The meanings that the personnel relate to the demands of their work are of special interest from the perspective of the present authors. These meanings are assumed to be constructed in interaction with other members of the organization as they are trying to maintain the internal cohesion and external adaptation of the organization [31,46]. Cultural approach thus emphasizes collective issues (and those issues that should be shared) over e.g. individual decision making. Individuals act and make decisions in a social context. The effect of this context can be so strong that the individual is not even aware of making a decision—choosing between alternative ways of acting [1: p. 118,42].

We define organizational culture as a learned way of responding, or a solution, to the demands of the organizational core task [31,42,46]. A solution, however, is not final or unambiguous since organizational culture includes the process of formation and reformation of the above-mentioned solution. This also means that the organizational culture as we define it includes dysfunctional solutions, dissent and conflicts of interests, as well as the attempts to solve or cover these [31: p. 292]. This process, which has close connections to Weick's [55] concept of sense-making, may be perceived as the essence of an organizational culture. Weick has described this continual and collective reality-building process constantly taking place in the organization. In this process, the meanings of various events are deliberated and a common view is formed based on perpetually incomplete information [55]. It seems reasonable to state that the influence of this phenomenon is crucial to acknowledge in safety-critical environments. This is especially the case in activities where large groups act with some degree of autonomy, performing different tasks, but having a common goal for their work and a need to co-operate in a number of situations. All these characteristics apply to, e.g. maintenance, technical support organizations, the construction industry and health care.

Maintenance of a nuclear power plant is a complex activity characterized by many coupled subsystems, uncertainty in the data available to the workers, mediated interaction via various tools and potentially high hazards [52: p. 14–17], see also [33]. In addition, recent changes in society (changes in the age structure and values towards work, utilization of new technologies, deregulation of the electricity markets, emphasis on outsourcing noncritical functions, etc.) have set new demands on the nuclear power plants [25,54]. The competence in maintenance consists of different technical fields but also requires strategic understanding as well as practical handicraft skills. For example in annual outages, the maintenance organizations have to schedule and plan hundreds of work packages requiring multiple technical disciplines [5]. In addition to that, all the tasks have to be coordinated with the operations and done according to organizational procedures. Despite the organizational challenges, the human factors research has focused mainly on occupational accidents [53], human errors [35,37] or reliability of individual task performance, e.g. probability of detecting flaws by non-destructive testing. Due to the diversity of the maintenance tasks and the numerous competence requirements, focusing on a single task (e.g. electric installation), special situation (e.g. outage) or a single psychological problem (e.g. memory overload) can only partially explain maintenance as a job.

Culture approaches share a relation with many systemic approaches that focus on the adaptive potential of a culture/system [42]. Safety of an organization is suggested to be related to the ability of the organization to cope with changes (its adaptive potential)—in order to explore this issue it is essential to get hold of, e.g. the general values and orientations in an organization that transcends the specific focus on safety [28,31].

The cultural approach to maintenance work raises a number of important questions: To what extent do the personnel perceive maintenance as a safety-critical activity? Do the personnel feel that the maintenance of a NPP is demanding? How to maintain the safety and reliability of maintenance activities when conducting organizational changes? What aspects in the organization contribute to the experience that the worker is able to cope with his tasks and experiences his work as meaningful? What kind of cultural features are required for reliable maintenance in NPP? Our hypothesis is that due to the social complexities of the maintenance work, the cultural features and the challenges related to safety and reliability variy between the different maintenance organizations. On the other hand, the content of the work and the objectives of the maintenance organizations should be quite similar. Thus, the second hypothesis is that there are common dimensions in how the maintenance personnel experience their work independent of their organization. These hypotheses are considered in two case studies, where the aim is to identify the cultural similarities and differences related to the above-mentioned questions.

2. Methods

2.1. Research strategy

The study aimed at characterizing and assessing the organizational cultures of Nordic nuclear power companies' maintenance units The research focused on two NPP maintenance units, Forsmark (FKA) in Sweden and Olkiluoto (TVO) in Finland. Both companies can be considered as high reliability organizations [24,44] by showing a good performance record and few incidents. We aimed to illustrate how the identified cultural features might affect safety and efficiency in the case organizations.

The cultural assessment was made by the means of maintenance core task modeling—a strategy that has already been used in our previous studies [29,31,40]. This approach has been titled 'The Contextual Assessment of Organizational Culture (CAOC)' [31,40,42]. The methodology utilizes two concepts, organizational culture and organizational core task (OCT). OCT refers to the shared motive of the activity of the organization and to the requirements for and constraints of the organizational practices [42] (Fig. 1).

The theoretical OCT model was used in evaluating the characteristics of the organizational culture (Fig. 1). We aimed at identifying the strengths and weaknesses of the case organization's culture in relation to its core task. The focus of the assessment was not on explaining causal relations to objective measures (e.g. occupational accidents or number of common cause failures). Instead, we strove to anticipate the consequences of the current practices, conceptions and assumptions in the given organizations to their ability and willingness to fulfill the OCT [42]. However, the purpose of this article is not to evaluate which organization is better, but to raise issues that require attention in the organizations. When evaluative statements are made, the criteria are formed on the basis of the core task model: Even though the practices differ, they may both be as effective from the perspective of the maintenance core task [42].

The methods utilized in the study were organizational culture and core task questionnaire (CULTURE02) and semi-structured interviews [40,41]. We propose, along with many others [27,45: p. 206], that one of the best ways to study organizational culture in complex sociotechnical systems is to use both qualitative and quantitative methods, since we strive to understand the unique organizational culture in question and also to compare the profiles of similar organizations and identify subcultures within the organizations.

2.2. Criteria for the assessment: the core task of maintenance

Maintenance activity is viewed through a conceptual model of the demands of the maintenance core task. This model has been conceptualized in our previous studies [31,40]. The model has been further iterated by the participating researchers (the authors) and in discussions

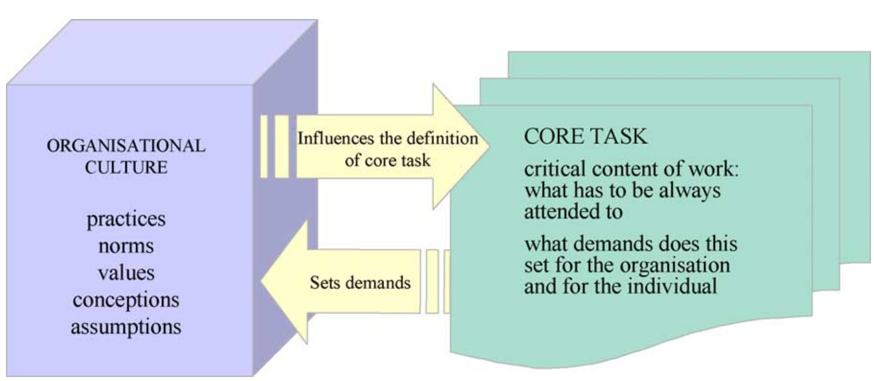

Fig. 1. The central concepts of CAOC methodology, from Reiman and Oedewald [40].

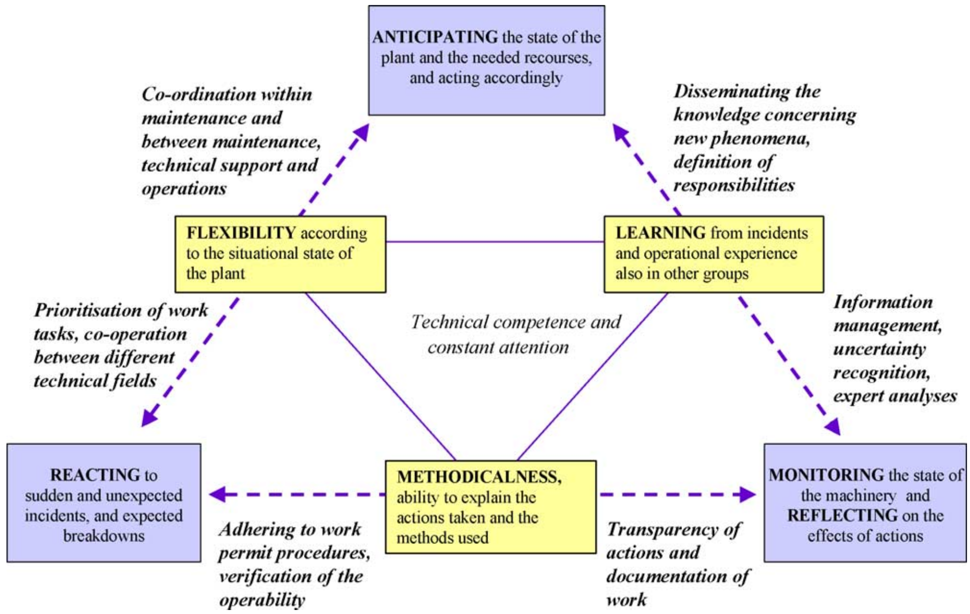

Fig. 2. The model of the demands of the maintenance core task, adapted from Oedewald and Reiman [31].

with maintenance experts from TVO. The model aims at presenting a general framework of the demands of the maintenance work. The model serves as a starting point for the discussion of organizational practices and strengths and weaknesses of the culture [31].

The model depicts maintenance as balancing between three critical demands: *anticipating*, *reacting*, and *monitoring and reflecting* (Fig. 2). In addition to the critical demands, three instrumental demands that facilitate the fulfillment of the critical demands, have been extracted; *flexibility*, *methodicalness* and *learning*. Working practices related to the fulfillment of the critical demands are also depicted in the figure.

The model depicts knowledge creation and problem solving activity as being inherent in the maintenance task and brings thus the demands of the maintenance work closer to those of knowledge work. Simultaneous multiple and parallel tasks, some of which are independent and some which are dependent on one another present a challenge to the maintenance work. Individual maintenance activities (e.g. corrective maintenance) can be modeled linearly as a work process starting from planning and ending in documentation of the work [3]. The OCT model, however, depicts the demands of the activity in the entire organization. The different activities and technical disciplines have to be coordinated in the daily work in a manner that also ensures the creation of new knowledge concerning the (changing state of the) plant.

2.3. The case organizations

2.3.1. Olkiluoto maintenance

TVO's organizational structure was reformed in January 2003, after the main data collection. The new organization comprises five departments: *Operation* responsible for the operation and maintenance of units OL1 and OL2, *Project* responsible for the construction of the fifth NPP in Finland (OL3), *Engineering, Finance* and *Corporate resources* [51]. Approximately 120 employees work with issues related to maintenance in the operation department. The case study concentrated on the two offices of the operation department in charge of the maintenance at Olkiluoto: The office of mechanical maintenance and the office of electrical and I&C maintenance. These offices changed little in the 2003 reorganization.

The offices consist of a number of groups with a group manager, foremen and technicians. The group manager also attends to the duties of the foremen. At TVO, a system of equipment responsibility areas has been used to organize the work since the middle of the 1990s. At the same time, a comprehensive new information system was taken into use to organize the work, store plant-related information and plan the maintenance activities on a short- and long-term basis. The system of equipment responsibility means that the foreman or the group manager 'owns' the particular equipment group and plans, e.g. the program of preventive maintenance and budget for the machinery. The owner of the equipment plans all the maintenance activities conducted for the corresponding equipment, irrespective of the type of maintenance (electrical, mechanical, instrumentation) required. The owner utilizes experts of the other fields to accomplish this.

2.3.2. Forsmark maintenance

The maintenance function at FKA lay in the aftermath of a major reorganization at the time of the data collection. Before the reorganization, maintenance activities were distributed so that each of the three nuclear power stations had their own dedicated maintenance support-organization. Control was previously exhibited in terms of a line organization within each station-specific maintenance organization. In the new maintenance organization, the previous functions were centralized into a single maintenance unit and a matrix organization was introduced. A total of 180 employees work in the new unit.

Four 'business areas' (Operative maintenance, Maintenance projects, Installation, Analysis and development) controlled and implemented operative maintenance projects that were ordered from the stations at the site (with a lot more 'business' flavor than previously). Responsibility for the execution of the various maintenance projects was, in the new organization, separated from the responsibility for the maintenance resources (the matrix). As usual in a matrix organization, the operative personnel had several 'bosses'. A technician could conduct work at request from several business areas under the manager from that area. The line manager 'sells' the technician to the particular business area that needs the resources. In Spring 2003 there was again a change in the maintenance organization. The matrix type was discarded in favor of a more traditional line organization; the centralization aspect was retained, however.

2.4. Description of the methods and data collection

2.4.1. CULTURE-questionnaire

The questionnaire consists of four different measuring instruments: measure of the perceived values, measure of the psychological characteristics related to work, measure of the personnel's conceptions of the organizational core task and measure of the ideal values of the organization. The questionnaire consists of about 100 multiple choice questions and two open questions. The open questions are phrased as follows: "What are the strengths of the maintenance activities at X" and "What are the weaknesses of the maintenance activities at X" (X being the plant in question). The questionnaire was piloted at a Nordic NPP [40,41]. The current version was tailored and translated into Swedish in three meetings together with the researchers (the authors).

The respondents were assured that the responses would be handled confidentially and that the results could not be traced back to the individual respondents. In Finland, each questionnaire was addressed directly to the personnel with a sealable envelope, preaddressed to the research institute. In Sweden, the questionnaires were distributed at six section meetings and completed individually by each participant. Ten questionnaires were returned by mail by subjects who had not participated in the section meetings. Eighty-four responses were obtained from TVO (with a response rate of 60%), and 132 responses from Forsmark (with a response rate of 72%). The missing values were replaced by mean scores, after making sure that the missing values were random and no respondent had more than 20% missing in a given section. This criterion was not fulfilled by one respondent in Section B, and by two in Section D, and hence their values were not replaced.

2.4.1.1. Measures of workplace values (perceived and ideal), sections A and D. According to Cameron and Quinn's [6] Competing Values Framework, organizations can be typified into four dominant culture types (see also [36]). In a *hierarchy-focused* culture, procedures govern what people do and stability, predictability and efficiency are considered as long-term concerns of the organization. A *market culture* values productivity and competitiveness by emphasizing external positioning and control. The workplace is result-oriented. A *clan culture* values cohesion, participativeness, teamwork and commitment. An *adhocracy* culture has the fostering of adaptability, flexibility and creativity as a major goal. Readiness for change is advocated [6,36].

Thirty-four items, each rated on a six-point scale (from 'completely disagree' to 'completely agree'), were related to the values typically manifested in organizations (e.g. 'flexibility', 'economic efficiency'). The values were initially selected on the basis of Cameron and Quinn's [6] Framework and previous studies [38,40,41]. The instruction was to mark how much the respondent felt that the given values were endorsed in the respondent's section. The respondents were also asked to select their ideal values in the final (D) section of the questionnaire, with the same 34 items and the same six-point scale.

2.4.1.2. Measure of conceptions of one's own work (B-section). Thirty-two questions, each rated on a six-point scale, addressed the conceptions concerning one's own work and the organization. According to Hackman et al. [16–18], see also [11], high job motivation and high quality of the work performance can be acquired if the worker can achieve the following three psychological states:

- the work must be experienced as meaningful;
- the worker must experience that he is personally responsible for the work outcome;
- the worker must be able to determine how his efforts are coming out, what results are achieved and whether they are satisfactory.

The questions were initially formed on the basis of the above-mentioned theoretical model and previous organizational culture studies [38]. The pilot study [41] identified a fourth psychological 'state', sense of control [22,26]. Questions measuring this concept were also included in the B-section.

Three personal work-related scales were identified in the pilot study: perception of the working climate, attitudes toward the management and personal development orientation [41]. Questions related to these scales were included in the B-section of the questionnaire.

2.4.1.3. Measure of the maintenance core task (C-section). Twenty-three items, each rated on a six-point scale, related to the general demands of the maintenance work at a nuclear power plant. The questions were initially formed on the basis of interviews and workshops with maintenance experts from the pilot organization, and they were tailored on the basis of the pilot study [31,41]. The maintenance core task model that was constructed in the previous study identifies three critical demands of the maintenance task: anticipating, reacting and reflecting/monitoring (Fig. 2). The measure aimed at grasping the features of the maintenance task that are common to the entire organization. The measure included questions such as 'knowledge sharing is imperative to effective maintenance', 'close co-operation between different technical fields is required in order to be able to carry out the maintenance tasks', and 'unexpected things happen unavoidably in maintenance activities'.

2.4.2. Interviews

The participating researchers (authors and Irene Eriksson from Mälardalen University) formed the interview questions in concert CAOC-methodology [42] and previous studies [31,40] served as a background for the questions. The interview themes were as follows:

- Own job (the content, motivating and demanding features, nature of expertise, changes in work);
- Maintenance task (goals and critical demands);
- Organizing of maintenance activities (pros and cons of current organizational structure, co-operation between different technical fields);
- Organizational culture (stories, climate, subcultures).

Twenty interviews were conducted at TVO, ten in fall 2002 and 10 in spring 2003. At Forsmark, 12 interviews were conducted during fall 2002–spring 2003. The interviews were transcribed and used for an analysis of the typical features of the organizational culture, based on grounded-theory [7]. The interviews were also used as an aid in the interpretation of the survey results.

3. Results

3.1. Descriptive statistics and factor solutions for the survey

Table 1 depicts the demographic variables and their descriptive statistics. In addition to the demographic information, several covariates were included in the survey. Generic satisfaction with one's work was measured with one question 'I am generally satisfied with my work'. Job motivation was measured with the question 'My work is motivating'. Job stress was measured with the question: 'My work is stressful', and the sense of coping with one's tasks with question 'I can cope with my tasks'. All four questions were included in the B-section of the survey.

As shown in the table, only tenure, job stress and the perceived proficiency value differed significantly between the plants. Job stress and the perceived proficiency value received higher mean scores at Forsmark, whereas average tenure was higher at Olkiluoto.

The primary data was factor analyzed by the principal components method [19]. Results of the pilot study [41] were used in defining the hypothesized factor structure for the survey data. Four variables were removed from A and D-sections due to technical problems in the translation (see Section 2.4.1). A four-factor solution of the A-section was obtained on the basis of eigen values over one, which explained 58.9% of the total variance of the questions. The initial solution was rotated by the Equamax method, similarly to the pilot study. A five-factor solution of the B-section was obtained on the basis of scree plot and it explained 57% of the total variance of the questions. The initial solution was rotated by the Varimax method. A five-factor solution of the D-section was obtained on the basis of scree plot, which explained 54.3% of the total variance of the questions. The initial solution was rotated by the Equamax method. Factor scores from all solutions were formed by the regression method. The factor scores were used as dependent variables in subsequent analyses. Also summated scales were formed from the highest loadings in order to compare the unstandardised mean scores.

Table 1
The demographic information and the modes or mean scores and standard deviations in the entire sample and *F*-scores and significance levels from the analysis of variance with the plant as an independent variable

Variable	Scale	Categories	Mode/mean	Standard deviation	*F* score	Sig.
Age	Ordinal	5	Mode = 46–55 (4)	1.03	0.29	0.590
Position	Nominal	5	Mode = technician (1)	–	–	–
Section	Nominal	Varied	–	–	–	–
Tenure	Ratio	n.a.	$M = 17.6$	10.09	13.33	0.000
Time in same task	Ratio	n.a.	$M = 13.8$	8.39	2.15	0.144
Job satisfaction	Ordinal	6	$M = 4.39$	0.97	2.32	0.129
Job motivation	Ordinal	6	$M = 4.33$	0.97	0.12	0.728
Job stress	Ordinal	6	$M = 3.65$	1.16	5.98	0.015
Coping with tasks	Ordinal	6	$M = 4.74$	0.84	3.20	0.075
Proficiency value	Ordinal	6	$M = 4.69$	1.04	8.51	0.004

The summated scales and factor scores were formed as follows.

3.1.1. A-section

1. Wellbeing and development values (e.g. wellbeing of personnel, openness for new ideas, efficient work tasks, cooperation).
2. Goals and feedback values (e.g. feedback, well-defined tasks, goal setting, learning).
3. Safety and rules values (e.g. occupational safety, rule following, carefulness, collective responsibility).
4. Financial values (e.g. cost-effectiveness, financial objectives).

3.1.2. B-section

1. Knowledge of expectations concerning one's own work (e.g. I have a clear picture of my responsibilities, I know on what basis my work is assessed).
2. Meaningfulness (e.g. I feel that the work I am doing is important, My job tasks are varied).
3. Development orientation (e.g. I actively develop my skills, I generally enjoy challenges in my work).
4. Sense of control and personal responsibility (e.g. I always have enough time to do my job carefully, I make sure that my tasks lead to the desired outcomes, I am able to influence the quality of my work).
5. Communication and climate (e.g. My superior gives me constructive feedback, The working climate in my group is good).

3.1.3. D-section

1. Goals and feedback values (e.g. feedback, well-defined tasks, goal setting).
2. Safety and wellbeing values (e.g. wellbeing of the personnel, occupational safety, learning).
3. Effectiveness values (e.g. cost-effectiveness, efficient work tasks).
4. Procedures and rules values (e.g. rule following, collective responsibility, systematic way of work).
5. Development and change values (e.g. openness for new ideas, questioning old beliefs).

In the A-section, four scales were formed in comparison to the six dimensions identified in the pilot study. The development and wellbeing values were considered as being one dimension, as were the safety and rule related values. At the pilot study, they formed their own factors. The goals and feedback dimension combined the values related to both management activities (goal setting) and to personal activity (learning) in a manner that did not come up in the pilot study [41]. At the ideal value section (D), the development and change values formed their own factor, approaching the structure in the pilot study.

In the B-section, the knowledge of expectations resembles the feedback scale at the pilot unit, but it emphasizes more the structural aspects of the work itself in the sense of communicating the expectations to the workers. The new dimension that was identified at the pilot study, sense of control, blended with the sense of personal responsibility scale in this sample.

The difference between the solutions in the A and D-sections is noteworthy. Especially interesting is the connection of safety values to rules in the perceived values section and to wellbeing in the ideal values section. This implies that safety is currently seen as being related to rule following, procedures and collective responsibility (possibly manifested in procedures and instructions), but the maintenance personnel would prefer safety to be related more to the general wellbeing and cohesiveness of the organization. The summated scales and their mean scores are shown in Table 2.

Table 2 shows that safety and rules values had the highest mean scores in the perceived values section, whereas financial values ranked the lowest. Meaningfulness of work, sense of control and personal responsibility and development orientation all received quite high mean scores. At the ideal values section, goals and feedback had the highest mean scores. The value statements of the CULTURE-questionnaire did not, however, include the plausible goals

Table 2
The summated scales, number of items, reliability coefficients, mean scores and standard deviation (SD)

	No. of items	Alpha	Mean	SD
Values				
Wellbeing and development	11	0.92	4.12	0.85
Goals and feedback	8	0.89	4.15	0.85
Safety and rules	7	0.83	4.50	0.75
Financial	3	0.67	3.88	0.91
Psychological characteristics				
Knowledge of expectations	5	0.87	3.96	0.94
Meaningfulness	4	0.79	4.43	0.77
Sense of control	6	0.75	4.49	0.63
Development orientation	4	0.68	4.51	0.64
Communication and climate	4	0.72	4.15	0.81
Ideal values				
Goals and feedback	8	0.82	4.87	0.56
Safety and wellbeing	6	0.77	4.28	0.91
Effectiveness	4	0.74	3.97	0.78
Procedures and rules	5	0.76	4.42	0.76
Development and change	5	0.73	4.73	0.62

In all the scales except two, the reliability coefficients (Cronbach's alpha coefficient, see e.g. [13: p. 256]) were over 0.70 which is usually considered as acceptable for reliable interpretations [19,30]. The total N for the analysis was 216 in the values section, 215 in the psychological characteristics section and 214 in the ideal values section.

of a power plant, such as nuclear safety, reliability of power generation, profit or shareholder value. Thus, the high mean score of the goals and feedback variable does not indicate which specific goals are deemed as important. Neither does Table 2 show the possible differences between the plants in the mean scores. It is necessary to further analyze the conceptions of the personnel about the goals and demands of the maintenance task with the use of interview data. Prior to this, the statistical differences between the plants are explored in order to illustrate the similarities and differences in the cultural features.

3.2. Plant specific analyses of the survey

The factor scores were used to inspect the differences between the plants (see Table 3).

It can be noted from Table 3 and the mean scores in Table 2 that the values related to safety and rules were perceived to be high at both plants. Also, meaningfulness of work was high and showed no statistically significant differences between the plants. Knowledge of expectations is much lower at FKA, which could explain the result that goals and feedback are more strongly emphasized as ideal values there than at TVO. Safety and wellbeing is, on the other hand, more strongly emphasized as an ideal value at TVO, and wellbeing as being currently valued significantly less at TVO than at FKA.

ANOVA was conducted with the factor scores as dependent variables and the task in the organization as an independent variable separately for both plants. At TVO, the perceived goals and feedback values differed ($F(7,76)=2.14$, $p=0.049$) with the technicians scoring lower than the foremen or managers. Also the ideal values of procedures and rules differed ($F(7,76)=2.42$, $p=0.027$), with managers emphasizing it less than technicians (Bonferroni post hoc test $p=0.013$). Furthermore, communication and climate differed on the basis of the task in the organization ($F(7,75)=2.75$, $p=0.013$), with the foremen scoring lower than others. At FKA, only the knowledge of expectations differed between the task groups ($F(8,123)=2.84$, $p=0.006$), with the managers scoring higher than others. Of the covariates, at both plants only the experienced work stress differed between the tasks ($p<0.05$). At FKA, the managers scored higher, and at TVO, the foremen scored higher.

Table 3
Summary table of ANOVA with the factor scores as dependent variables and the plant as independent variable

	df	F score	Sig.	Higher score
Values				
Wellbeing and development	1.214	39.724	0.000	FKA
Goals and feedback	1.214	14.337	0.000	FKA
Safety and rules	1.214	1.235	0.268	–
Financial	1.214	25.026	0.000	TVO
Psychological characteristics				
Knowledge of expectations	1.213	22.453	0.000	TVO
Meaningfulness	1.213	0.019	0.892	–
Sense of control	1.213	10.267	0.002	TVO
Development orientation	1.213	0.364	0.547	–
Communication and climate	1.213	0.006	0.939	–
Ideal values				
Goals and feedback	1.212	18.368	0.000	FKA
Safety and wellbeing	1.212	5.206	0.024	TVO
Effectiveness	1.212	0.127	0.722	–
Procedures and rules	1.212	39.697	0.000	FKA
Development and change	1.212	2.939	0.088	–

Table 4 depicts the plant-specific correlations of the factor scores to ordinal and ratio scale covariates.

Table 4 indicates that sense of control relates positively to job satisfaction at FKA but not at TVO. Development orientation correlates positively with job motivation but not with job satisfaction. The proficiency value correlates positively with structure at TVO and with meaningfulness at FKA. Also, the ideal value of proficiency is connected to both the safety and wellbeing and procedure and rules values at FKA, but at TVO it only has a slight (non-significant) negative correlation to the development and change values.

The core task section of the survey was inspected next. The sharing of knowledge as well as anticipation and planning were commonly seen as important requirements of the maintenance core task at both plants. The questions that suggested bypassing the bureaucracy in the name of efficiency scored very low at both plants. On the other hand, both plants also scored low on questions that suggested that rules relieve of personal responsibility or that it is enough to merely follow the instructions in unanticipated situations.

Significant differences between FKA and TVO were found in questions that concerned, e.g. the ability to know the consequences of the maintenance activities in advance, and the way of dealing with uncertainty. At TVO, the personnel were more confident about the consequences of the various daily maintenance tasks (e.g. question ‘it is possible to predict the effects of various maintenance activities’, $F(1,214)=6.5, p=0.011$). They also emphasised that ‘if you are uncertain you should do nothing’ ($F(1,214)=28.6$, $p<0.001$). Furthermore, they did not see a contradiction between economy and safety, as the personnel at Forsmark did ($F(1,214)=21.0$, $p<0.001$). The responses to questions concerning the role of rules and instructions also differed between the plants. At TVO, the personnel did not see a need to interpret the rules, whereas at Forsmark, where the personnel perceived more uncertainty they also stated more strongly that the ‘rules have to be sometimes interpreted’ ($F(1,214)=12.6$, $p<0.001$).

Table 4
Correlations (Pearson's *r*) between the factor scores and covariates at Olkiluoto (TVO) and Forsmark (FKA)

	Age		Tenure		Same task		Job satisfaction		Job motivation		Work stress		Coping with tasks		Proficiency value	
	TVO	FKA	TVO	FKA	TVO	FKA	TVO	FKA	TVO	FKA	TVO	FKA	TVO	FKA	TVO	FKA
Values																
Wellbeing and development	0.138	0.038	0.124	0.074	−0.033	−0.025	0.309**	0.129	0.285**	0.307***	−0.040	−0.043	0.044	0.015	0.334**	0.450***
Goals and feedback	−0.020	−0.051	0.082	0.002	−0.155	0.017	0.492***	0.171*	0.512***	0.203*	0.112	0.050	−0.008	0.177	0.482***	0.278***
Safety and rules	−0.172	0.055	−0.192	0.119	−0.182	0.018	0.121	0.109	0.106	0.046	−0.038	0.053	0.058	0.044	0.451***	0.291***
Financial	0.121	0.110	0.240*	0.095	0.063	0.057	0.059	0.084	−0.002	0.237**	0.003	0.042	0.033	0.067	0.121	0.133
Own work																
Knowledge of expectations	0.025	0.346***	0.115	0.297***	0.118	0.147	0.292**	0.268**	0.325**	0.248**	0.112	0.178*	0.157	0.328***	0.340**	0.087
Meaningfulness	0.249	−0.138	0.335**	−0.036	−0.028	−0.101	0.476***	0.477***	0.624***	0.622***	0.192	0.215*	0.186	0.055	0.116	0.371***
Sense of control	−0.175	−0.074	−0.166	−0.060	0.086	0.031	−0.057	0.367***	−0.087	0.245**	−0.244*	−0.372***	0.266*	0.325***	−0.066	0.00
Development orientation	0.000	−0.170	−0.231*	−0.202*	−0.164	−0.164	0.173	0.133	0.225*	0.259**	0.189	0.093	0.392***	0.298***	0.083	0.201*
Communication and climate	−0.203	−0.051	−0.111	−0.002	−0.324	0.028	0.226*	0.384***	0.058	0.289***	−0.177	−0.102	−0.224*	0.056	0.265*	0.287***
Ideal values																
Goals and feedback	0.236*	−0.080	0.063	−0.041	−0.114	−0.14	0.182	0.171	0.246*	0.244**	0.145	0.056	0.217*	0.189*	0.017	0.284***
Safety and wellbeing	−0.013	−0.221*	0.054	−0.166	0.139	−0.03	−0.149	0.161	−0.151	0.260**	0.021	−0.073	−0.036	0.109	−0.070	0.237**
Effectiveness	−0.007	0.126	0.025	0.105	−0.116	0.06	0.270*	0.292***	0.398***	0.304***	−0.029	0.090	0.240*	0.228*	0.346***	0.036
Procedures and rules	−0.080	0.190*	0.039	0.104	0.031	0.224*	−0.066	0.205*	−0.091	0.114	−0.214*	0.062	−0.150	0.122	−0.056	0.126
Development and change	−0.224*	−0.174*	−0.096	−0.086	−0.043	−0.087	−0.038	0.044	−0.128	0.215*	−0.118	−0.073	0.019	0.073	−0.204	0.168

*$p<0.05$, **$p<0.01$, ***$p<0.001$. Note that number of respondents vary in TVO sample from 74 (same task), 77 (tenure), 80 (age) to 83 in the rest of the variables, and at FKA sample from 122 in tenure and same task to 129 in age and 132 in others.

The results thus suggest that knowledge sharing, planning and anticipation and personal proficiency are considered as important requirements of the maintenance task in a NPP. However, at TVO the personnel experienced less uncertainty in the maintenance work itself. They approached the work more through routines and formal procedures than Forsmark did. There, the uncertainties of the sociotechnical systems were more apparent and the personnel also emphasized the maintenance work more as a learning and problem-solving task.

The strengths and weaknesses of the maintenance culture were asked in the survey. At TVO the personnel saw their strengths mainly in the know-how and experience of the workers (57 respondents out of 59 raised either know-how or experience as the main strength) and in the attitude and motivation (responsibility) of the personnel. Also, viability of the organization (ability to react to problems, methodicalness, flexibility) was emphasized, as were good tools and procedures and the good condition of the plant. The current age structure of the personnel and inadequate attention paid to the problems of knowledge retention were perceived as central weaknesses. Furthermore, leadership and personnel values of the organization were experienced as needing improvement.

At FKA, the need for clarification of the new organizational structure was the most acute problem according to the respondents (30 persons out of 76 raised this issue explicitly). Also cooperation between the work groups and the quality of leadership were raised as needing improvement. It is possible that these stem in part from the reorganization, together with the unclear division of labor that 10 persons raised as needing improvement. Only one person raised the age structure and knowledge retention as problems needing attention. Communication and cooperation within the work groups was experienced as working well at FKA. A few employees explicitly raised the safety thinking as a strength and a few emphasized the managerial and leadership aspects.

3.3. Conceptions of maintenance work—results from interviews

Interviews were used to illustrate how the personnel perceived and conceptualized their own work and the maintenance task. The interviewees were first asked about what motivates them at their work. The results show that the answers varied in content between the plants. At FKA, the personnel were motivated by new learning opportunities, technical problem solving, fault situations, and also by good colleagues and the social aspects of the job. At TVO the personnel experienced more meaningfulness from non-events, smooth functioning of the plant, and of being ‘the best in the world’, but also special situations, wage and the social climate motivated at TVO as they did at FKA.

The most demanding aspects in the interviewees’ jobs were asked. In the analysis of the interviews, based on grounded theory, qualitatively different categories emerged. The categories resembled the findings of the survey. At TVO, the following categories emerged:

– nothing special (‘I have to admit that I don’t know’, ‘I’ve been here for so long that nothing is anymore’, ‘routine-like, normal work-work’) (4);
– personnel relations (4);
– special situations, e.g. outage, modifications (4);
– the achievement of certainty and the endurance of strain (‘so you don’t start to rush’, ‘safety requirements… that the work’s done correctly’, ‘fault repairs…gets you thinking’) (3);
– other things related to the maintenance of expertise, e.g. language skills, deteriorating eyesight (3);
– knowledge of the machinery (‘upgrades and modifications’, ‘to know these machines’) (2).

At FKA, the following categories emerged:

– prioritizing the tasks, work load (6);
– seeing the goals, trust in the management (‘purpose of the reorganization’) (4);
– social demands (3);
– technical competence (2).

At TVO, feedback was considered as a mostly negative indication, that something had been done poorly. Positive feedback was rare according to the personnel. On the one hand, the personnel emphasized that they themselves usually knew whether or not the particular job had been done well. On the other hand, some people felt that the culture is somewhat problematic in the sense that high quality performance is taken for granted. This leads to the practice in which high quality is an assumption and positive feedback is not given, but mistakes and poor quality immediately gets attention from the managers.

At FKA, current maintenance organization evoked mixed feelings. Several interviewees complained about the matrix form and found it confusing. On the other hand, there were also signs that the new organization had led to a broader scope of work tasks and to positive challenges in one’s work. On the downside there were indications that the new maintenance organization had led to negative changes in the perceived ownership for the technology—previously the maintenance organization had been separate for each of the three stations. Several of the interviews included indications of a general cost pressure that affected the maintenance organization: ‘it is talk about costs all the time’ and ‘costs have got a too high focus’. On the other hand, several of the interviewees said that they were personally strong in their ambition to keep the plant in a state of high quality.

3.4. Summary of the main results

The main characteristics of the maintenance cultures are summarized in Table 5. From the table it can be noted that

Table 5
Summary table of the main results from the case studies

Plant	Workplace values	One's own work	Perceptions of organization	Perceptions of maintenance task	Perceptions of development targets
TVO	Safety values highest, cohesiveness values lowest, also financial values quite high, safety and wellbeing values emphasized most as ideal values	Meaningfulness of work high, mostly routine work with few demanding aspects, workload experienced as high by the foremen	Sense of pride in the plant, the company and in one's own expertise. On the other hand, criticism of leadership and communication practices within the maintenance	Clear, few uncertainties, procedures and information systems central, planning and anticipating emphasized, emphasis on the systematicalness demand of maintenance	Change of generation and the transfer of existing knowledge to newcomers, management and leadership, employee wellbeing
FKA	Safety values highest, financial values lowest, goals and procedures related values emphasized most as ideal values	Meaningfulness of work high, technical problems experienced as both demanding and motivating	Organizational structure experienced as unclear, cost pressures experienced as stressing, climate in work groups good	Uncertainties perceived in the maintenance task itself, planning and anticipating emphasized, learning emphasized as being critical in maintenance	Clarification of the organization, cooperation, leadership

the maintenance units at TVO and FKA had quite different organizational cultures, but they also shared several issues and conceptions.

Safety was highly valued at both plants, and in that sense they both had strong safety cultures. Otherwise the cultural features were quite different, and thus it seems that the means of maintaining high safety differ. The reasons for the similarities and differences in the cultural features are considered further in the discussion section. Also, the implications of the cultural features to safety and reliability of the maintenance units in the long run are debated.

4. Discussion

4.1. Case organizations and the maintenance core task

It was common to both plants that at a general level the goals of the maintenance task were considered to be very clear; maintenance is a prerequisite for reliable production of electricity. Knowledge sharing, long-term planning and anticipation of the plant condition were considered as important requirements for the maintenance task. However, critical attitudes towards the management and the values prevalent in the organization existed at both plants. The task groups within the units also differed in their perceptions of the organization. The shop floor workers were more critical in their attitudes, which is quite common in organizations, see, e.g. [6,20,41: p. 877].

In order to be reliable and effective, the case organizations have developed different strategies for coping with everyday challenges. The fact that organizations with the same task develop distinct ways of acting has also been discussed by Bourrier [4,5]. We try to evaluate the relation of these different strategies to the safety and reliability of the plant with the help of the core task model [31]. Our conception of organizational reliability is not restricted to compliance with procedures or absence of human errors. The aim is to anticipate the direction of the evolution of the organization [42].

A central finding in terms of organizational reliability is that at TVO, the maintenance personnel experienced less inherent uncertainty in the maintenance task itself. They approached the work more through procedures and routines than the personnel at Forsmark did. At TVO, the maintenance work itself was experienced as quite routine-like and the personnel had difficulties in identifying any challenging aspects in their own tasks. It was pointed out that the plant is well-functioning and everybody has sufficient competence to get along with his daily tasks. The focus of the maintenance organization had for some time been in anticipating the plant condition and conducting preventive maintenance accordingly. This has both advantages and disadvantages. At TVO, where organizational procedures and information systems have been intensively developed to facilitate the anticipation, the personnel also saw the overall goals of the organization and their own contribution to them more clearly than at FKA. Anticipating the plant condition was dependent more on the methodicalness of the current activity than on critical reflection or questioning of the existing approaches. This works efficiently as long as the existing approaches are adequate and are seen as tools and not as mere aims. Understanding and verification of the accuracy of the data in the computerized maintenance programs is not easy either when the fulfillment of the program is considered as an aim as such. Thus, for example, an accidental deactivation of the periodical testing program for some equipment might go unnoticed. At the moment this is compensated by the high personal competence and experience of the workers who know the safety significance of the equipment. It can be concluded that the culture at TVO currently focuses more strongly on the fulfillment of the critical demand of anticipating than the other demands of the maintenance core task (see Fig. 2).

At FKA, the uncertainties of the sociotechnical system were more apparent and the personnel also emphasized the maintenance work as learning and problem solving task. Reflectivity and learning (Fig. 2) were currently pointed out as being critical to achieving the goals of maintenance since many workers had new responsibility areas. Currently, this may lead the personnel to question the practices and procedures previously taken for granted. Even some latent failures could be spotted with 'new eyes'. The prioritizing of tasks and managing of the increased workload were seen as demanding since the workers lacked the overall picture of the goals of the plant and of the organizational responsibilities. In order to manage the situation, the social aspects of the organization were emphasized by the personnel (e.g. good team spirit). In the long run, however, this kind of a situation is stressful and unmotivating to the personnel. Furthermore, gathering and interpreting systematic information of the entire plant condition is extremely demanding in the current situation. This may lead to increased events because the knowledge concerning the plant's state either does not exist or is not shared sufficiently. The culture of the FKA was in transition. In practice, the organization was currently focusing on the reacting demand. The significance of the demand for reflecting was emphasized. Nevertheless, the change in the organizational structure also changed the means of reflecting more from formal to informal networks.

The reasons for the differences in the emphases of the core task demands stem partly from the different situations within the case organizations. Forsmark was in the aftermath of a major reorganization, and it is thus expected that learning requirements would be emphasized. A future challenge for both plants is to take into account all the critical demands of the maintenance core task. Otherwise the maintenance cultures can develop assumptions that disregard some of the demands, concentrate on only some of the criteria and measure the effectiveness of maintenance in relation to these criteria.

4.2. Working in complex organizations—typical features and challenges

The research gave implications about the common features of work in complex organizations. We propose on the basis of this case study and Ref. [41] that the work in these systems could be characterized along the following psychological dimensions (cf. Table 2):

- Structure (manifesting as knowledge of expectations).
- Communication climate.
- Experienced control over one's own work.
- Meaningfulness of work.

We define *structure* as the degree to which people feel that goals, tasks and responsibilities are well defined. New information technology and the new forms of organizing work (e.g. outsourcing) are not only changing the structure, but also the nature and requirements of the maintenance work (see also [8]). This seems to happen in quite a similar way to what Zuboff [58] noted happening in the late 1970s in the process control task in industrial work.

The current focus on strategic optimization and new information technology can threaten the traditional conception of proficiency (based on handicraft skills and experience) among the personnel. The new expectations created by the new technology are not congruent with the old cultural conceptions of a skilled worker. The personnel do not want to see the machinery as merely numbers on a computer screen or data base, but as concrete objects to work and play with (cf. [58]). This means that when new structural solutions are introduced, the other dimensions of the work, communication climate, sense of control and meaningfulness also have to be taken into account. It was noted in the pilot study that the personnel with longer tenure saw the maintenance organization as more change-oriented than the newcomers did. Implications were also found that the employees with longer tenure did not like the changes that they perceived [41: p. 883].

Introduction of complex and large matrix organizations, such as in the case of Forsmark, makes it more difficult to structure the communication. In fact, the more 'matrix' used, the more important communication seems to become for supporting the functioning of the matrix. To some extent this increased need seems to counteract the efficiency benefits looked for in the matrix arrangement (cf. [57: p. 143]). Communication practices also appear to be more and more abstract and in some sense also to have less of a face-to-face nature in today's workplace. Orr [32] noted that the technical knowledge of the machine repairers was strongly dependent on face-to-face encounters between the repairers and on the task-related stories that they shared in the meetings (cf. [55: p. 127]). Due to confusion in the organizational structure, the technicians emphasized the meaning of face-to-face communication at FKA. In the study, the communication climate was found to correlate positively with job satisfaction, but negatively with the sense of control at TVO (see Table 4), suggesting that the quality of communication is more important than its quantity. Hence the term *communication climate*.

Experienced control means the degree of personal sense of coping with the tasks and the demands that they set (cf. [22,26: p. 65]). The sense of control was quite high among the maintenance personnel (cf. [41: p. 882]), especially at TVO. This is partly explained by the more stable situation at TVO and the higher average tenure. Long tenure or experience as such does not, however, guarantee competence (cf. [23]). New technology sets new requirements (cf. [8: p. 979]), which means that some of the old habits have to be unlearned. The longer the habits have been in use, the more difficult the change. Long tenure can also lead to routinization [37: p. 105]. Experience is then no longer a benefit, but can actually be a source of errors when the work and its outcome are not actively reflected upon (experienced control is too high). At the same time a change of generation is happening. This means that some of the cultural values and artefacts (e.g. emphasizing certainty and talking about proficiency as something taken for granted) have to change. The newcomers should achieve a realistic sense of control based on one's own skills and abilities and on the demands of the work.

Meaningfulness is a complex psychological state resulting from several dimensions, such as the content and variation of the tasks and the feeling that the work is important and leads to personal development (cf. [11,18]). Meaningfulness was in the present study found to exhibit a high, significantly positive correlation with job motivation and job satisfaction. Maintenance work appeared to produce a feeling of meaningfulness when there are technical problems to solve with safety significance and time pressure (see also [43]). This is a paradox in the sense that one of the goals of maintenance is to avoid problems and keep the technology running reliably. If one assumes that the technology in the future can be made more reliable and fewer problems will occur, then this could be a challenge for the personnel to retain meaningfulness of the work. The maintenance task should be focused on maintaining the entire plant, not some individual pump or valve. In other words, we propose that meaningfulness in one's work should be connected to the organizational core task (cf. [41: p. 884]). One possibility for enhancing the meaningfulness of the maintenance work is to try to give the maintenance workers more opportunities to participate in the various modernization projects [8].

The connection of meaningfulness to the task itself and the gradual shift of the source of meaningfulness (e.g. to social relations) in change situations are important phenomena to take into account when considering the overall reliability of the system. An interesting dimension that does not come up directly from the present data is *sense of personal responsibility* [16,18,41]. The sense of personal responsibility can be hypothesized to refer more to the internal state of motivation and a feeling of being personally accountable for the results of one's actions. In nuclear power plants, the achievement of a sense of personal responsibility is complicated by strict rules, procedures, and a tendency to emphasize shared responsibility and collective action instead of individual action [18: p. 75,41,44: p. 1554]. An ambiguous sense of personal responsibility could lead to overemphasis of the formal structural features of the organization as a source of sense of control and meaningfulness. Responsibility would then mean that you do what is formally required, not what would be felt personally as a sensible course of action in the given situation. Personal responsibility is thus not directed towards the fulfillment of the organizational core task, but towards the fulfillment of the subtasks and subgoals that the given actor is directly accountable for.

4.3. Implications

The results provide some insights into the discussion on organizational culture and reliability. We would like to see the results contribute both to the academic discussion on measuring safety culture as well as to the safety analyst's challenges in evaluating organizational performance. The main motivation of the study was, however, to create knowledge that the case organizations themselves could utilize.

When considering organizational culture, one should take into account that contradictions and different points of view may exist within the organization in question [1,27]. Another premise is that these differences are not a priori 'bad'. The homogeneity of the culture (widely shared conceptions and assumptions) as such is thus not always a criterion for good culture (which is often an implicit assumption in the safety culture research). The starting point of all evaluation is the demands of the work, i.e. the core task of the organization. Thus the demands of the OCT dictate whether or not certain cultural features (e.g. differences in opinion) are good, bad or insignificant for the effectiveness of the organization [42]. For example, different opinions can facilitate discussion and be adaptive in fulfilling the demands of safety and reliability. The demands of the task create the boundaries within which the activity has to 'sail' (in contrast to 'drift', as depicted by Snook [49]). Practical drift means gradual local optimization of the working practices, which does not necessarily take the entire organization into account [49]. The OCT model could be used as a starting point in the analysis of deficiencies in specific work processes [3,29].

If the case organizations were analyzed from the traditional viewpoint of safety culture, the attention would probably focus on the safety values or on the safety record of the plants. From that perspective, the plants would probably be categorized as 'well performing' plants. We state that despite the good performance, both organizations have challenges in fulfilling the organizational core task and thus maintaining plant reliability in the future. For example, implementation of new technologies or new management philosophies and a gradual change in the maintenance task have led to a work overload in some personnel groups. This kind of a situation includes the risk that the employee experiences too low a sense of control or learns an unhealthy strategy of focusing solely on issues that are measured or that the management attends to. Measuring safety attitudes does not necessarily show these phenomena since, for example, implementing new technologies or practices is usually presented as an investment for the future, an upgrade [57: p. 141]. In fact, they can be seen as (and they usually are) an indicator of a strong safety focus for the part of the management.

Our study also gave implications that organizational changes do not seem to affect the safety climate or safety culture as defined by the employees valuing safety. Instead, the changes affect more the psychological work characteristics, such as meaningfulness of work and sense of control. Changes that seem to endanger safety are experienced as highly stressful, especially since safety remains highly valued. Developing only the safety values and safety attitudes of the organization is thus not beneficial, since the safety attitudes are at least as high as before the change (most likely even higher). Still, incidents can be caused by, e.g. unclear organizational structures, lack of communication, or low sense of control among the workers.

The model of the work features depicted above (see Section 4.2) offers a preliminary structure of psychological issues directly or indirectly related to safety and reliability of complex sociotechnical systems. For example, events (incidents and accidents) could be understood more deeply with the concepts depicted in the model combined with an understanding of the demands of the particular work [29, 57]. Meaningfulness of work or sense of control, which affect the decision making in everyday work, are seldom considered in event investigations [14: p. 99–100]. However, work pressure and workload are included in most safety culture instruments, see [10]. Our purpose is not to suggest that events should be characterized only by mental states; rather it is suggested that by asking about the mental states of the personnel one can achieve an understanding of how the working conditions and the organizational factors influence the actions of the personnel [12: p. 151].

The results can be used in redirecting how the managers perceive their organization. Especially the way of conducting the case studies from 'bottom-up' created for the managers new insights into their own organization. Managers are as much a part of the culture as the workers are. Their ability to become aware of and question the cultural assumptions is thus limited. The study helped to enrich the language that the managers and the personnel used for talking about their organization and their task [31]. This was noted especially at TVO, where two seminars were held on the basis of the results for the entire maintenance personnel. The study offered neutral concepts ('organiz-organizational core task', 'cohesiveness', 'sense of control') with which to tackle issues that had previously been too sensitive to question, allowing the personnel to engage in dialogue with each other. In a dialogue, the cultural values and assumptions can be confronted and a common understanding can be built [31,47]. We propose that the starting point of the dialogue and the value creation should be the core task of the organization. Values are experienced as meaningful when they are clearly connected to the work itself.

Many of the issues that are discussed in this article are relevant from the perspective of change management. Anticipation, certainty and stability are central features in high reliability organizations [31,41,44]. Change seems to endanger all of these, and thus change situations are demanding and experienced as stressful. Resistance to change on the part of the personnel can actually reflect the strong commitment to safety that they feel is in danger in the new situation. This requires better communication of both the goals and the methods of change to the personnel. Furthermore, the managers would benefit from listening more to the ideas of the field workers since they usually know the plant best. As stated by Woods and Cook, changes in complex systems are "opportunities to learn how the system actually functions" [57: p. 142]. The CAOC methodology aims to provide the means for anticipating the functioning of these systems so that poorly functioning systems need not fail before their dynamics are understood [42].

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References

[1] Alvesson M. Understanding organizational culture. London: Sage; 2002.
[2] Alvesson M, Berg PO. Corporate culture and organizational symbolism. Berlin: Walter de Gruyter; 1992.
[3] Apostolakis GE. Organizational factors and nuclear power plant safety. In: Misumi J, Wilpert B, Miller R, editors. Nuclear safety: a human factors perspective. London: Taylor & Francis; 1999.
[4] Bourrier M. Organizing maintenance work at two American nuclear power plants. J Contingencies Crisis Manage 1996;4(2):104–12.
[5] Bourrier M. Constructing organisational reliability: the problem of embeddedness and duality. In: Misumi J, Wilpert B, Miller R, editors. Nuclear safety: a human factors perspective. London: Taylor & Francis; 1999.
[6] Cameron KS, Quinn RE. Diagnosing and changing organisational culture: based on the competing values framework. Massachusetts: Addison Wesley; 1999.
[7] Charmaz K. Grounded theory. In: Smith JA, Harré R, Langenhove LV, editors. Rethinking methods in psychology. London: Sage; 1995.
[8] Cooke FL. The important role of the maintenance workforce in technological change: a much neglected aspect. Hum Relations 2002; 55(8):963–88.
[9] Cox S, Flin R. Safety culture: philosopher's stone or man of straw? Work Stress 1998;12(3):189–201.
[10] Flin R, Mearns K, O'Connor P, Bryden R. Measuring safety climate: identifying the common features. Safety Sci 2000;34:177–92.
[11] Fried Y, Ferris GR. The validity of the job characteristics model: a review and meta-analysis. Personnel Psychol 1987;40:287–322.
[12] Fujita Y, Hollnagel E. Failures without errors: quantification of context in HRA. Reliab Eng Syst Safety 2004;83(2):145–51.
[13] Ghiselli EE, Campbell JP, Zedeck S. Measurement theory for the behavioral sciences. San Francisco: W.H. Freeman; 1981.
[14] Gordon RPE. The contribution of human factors to accidents in the offshore oil industry. Reliab Eng Syst Safety 1998;61:95–108.
[15] Guldenmund FW. The nature of safety culture: a review of theory and research. Safety Sci 2000;34:215–57.
[16] Hackman JR, Lawler EE. Employee reactions to job characteristics. J Appl Psychol Monograph 1971;55(3):259–86.

[17] Hackman JR, Oldham GR. Development of the job diagnostic survey. J Appl Psychol 1975;60:159–70.
[18] Hackman JR, Oldham GR. Work redesign. Reading, MA: Addison Wesley; 1980.
[19] Hair JF, Anderson RE, Tatham RL, Black WC. Multivariate data analysis, 5th ed. New Jersey: Simon & Schuster; 1998.
[20] Harvey J, Erdos G, Bolam H, Cox MAA, Kennedy JN, Gregory DT. An analysis of safety culture attitudes in a highly regulated environment. Work Stress 2002;16(1):18–36.
[21] IAEA. Safety Series No. 75-INSAG-4. Safety Culture. Vienna: International Atomic Energy Agency; 1991.
[22] Karasek RA, Theorell T. Healthy work: stress productivity, and the reconstruction of working life. New York: Basic Books; 1990.
[23] Klemola U-M, Norros L. Analysis of the clinical behaviour of the anaesthetics: recognition of uncertainty as a basis for practice. Med Educ 1997;31:449–56.
[24] Klein RL, Bigley GA, Roberts KH. Organizational culture in high reliability organizations: an extension. Hum Relations 1995;48: 771–93.
[25] Kettunen J, Jones B, Reiman T. Assessing challenges to nuclear power plant management in five European countries: methods, results and lessons learned. In: Proceedings of PSAM7—ESREL'04 Conference in Berlin; 14–18 June 2004.
[26] Lazarus RS, Folkman S. Stress, appraisal, and coping. New York: Springer; 1984.
[27] Martin J. Organizational culture. Mapping the terrain. Thousand Oaks: Sage; 2002.
[28] Neal A, Griffin MA, Hart PM. The impact of organizational climate on safety climate and individual behavior. Safety Sci 2000;34:99–109.
[29] Norros L, Nuutinen M. The concept of the core-task and the analysis of working practices. In: Borham N, Samurcay R, Fischer M, editors. Work process knowledge. London: Routledge; 2002.
[30] Nunally J. Psychometric theory. New York: McGraw Hill; 1978.
[31] Oedewald P, Reiman T. Core task modelling in cultural assessment: a case study in nuclear power plant maintenance. Cogn, Technol Work 2003;5(4):283–93.
[32] Orr JE. Talking about machines: an ethnography of a modern job. Ithaca, NY: ILR Press; 1996.
[33] Perrow C. Normal accidents: living with high-risk technologies. New York: Basic Books; 1984.
[34] Pidgeon N. Safety culture: key theoretical issues. Work Stress 1998; 12(3):202–16.
[35] Pyy P. An analysis of maintenance failures at a nuclear power plant. Reliab Eng Syst Safety 2001;72(3):293–302.
[36] Quinn RE, Rohrbaugh J. A spatial model of effectiveness criteria: towards a competing values approach to organizational effectiveness. Manage Sci 1983;29:363–77.
[37] Reason J, Hobbs A. Managing maintenance error. A practical guide. Hampshire: Ashgate; 2003.
[38] Reiman T, Norros L. Regulatory culture: balancing the different demands of regulatory practice in the nuclear industry. In: Kirwan B, Hale AR, Hopkins A, editors. Changing regulation—controlling risks in society. Oxford: Pergamon Press; 2002.
[39] Reiman T, Oedewald P. The assessment of organisational culture—a methodological study. VTT Research Notes 2140. Otamedia: Espoo; 2002.
[40] Reiman T, Oedewald P. Contextual assessment of organisational culture—methodological development in two case studies. In: Kyrki-Rajamäki R, Puska E-K, editors. FINNUS. The Finnish Research Programme on Nuclear Power Plant Safety, 1999—Final Report. VTT Research Notes 2164. Helsinki: Yliopistopaino; 2002.
[41] Reiman T, Oedewald P. Measuring maintenance culture and maintenance core task with CULTURE-questionnaire—a case study in the power industry. Safety Sci 2004;42(9):859–89.
[42] Reiman T, Oedewald P. Assessment of complex sociotechnical systems—methodological issues concerning the use of organizational culture concept. Submitted for publication.
[43] Reiman T, Oedewald P, Rollenhagen C. Comparison of organisational cultures at two NPP maintenance units. When is maintenance work motivating and meaningful? In: Proceedings of PSAM7—ESREL'04 Conference in Berlin; 14–18 June 2004.
[44] Rochlin GI. Safe operation as a social construct. Ergonomics 1999;42: 1549–60.
[45] Rousseau DM. Assessing organisational culture: the case for multiple methods. In: Schneider B, editor. Organisational climate and culture. San Francisco: Jossey Bass; 1990.
[46] Schein EH. Organizational culture and leadership. A dynamic view. San Francisco: Jossey-Bass; 1985.
[47] Schein EH. Process consultation revisited. Building the helping relationship. Reading, MA: Addison-Wesley; 1999.
[48] Smircich L. Concepts of culture and organizational analysis. Administrative Sci Q 1983;28:339–58.
[49] Snook SA. Friendly fire. The accidental shootdown of U.S. Black Hawks over Northern Iraq. New Jersey: Princeton University Press; 2000.
[50] Sorensen JN. Safety culture: a survey of the state-of-the-art. Reliab Eng Syst Safety 2002;76:189–204.
[51] TVO. Annual Report 2002. Teollisuuden Voima Oy. Available from http://www.tvo.fi/316.htm
[52] Vicente K. Cognitive work analysis. Toward safe, productive, and healthy computer-based work. London: LEA; 1999.
[53] Vidal-Gomel C, Samurcay R. Qualitative analyses of accidents and incidents to identify competencies. The electrical systems maintenance case. Safety Sci 2002;40:479–500.
[54] Wahlström B, Wilpert B, Cox S, Sola R, Rollenhagen C. Learning organisations for nuclear safety. In: Proceedings of the IEEE seventh conference on human factors and power plants, Scottsdale, Arizona, USA; 2002.
[55] Weick KE. Sensemaking in organizations. Thousand Oaks, CA: Sage; 1995.
[56] Wilderom CPM, Glunk U, Maslowski R. Organizational culture as a predictor of organizational performance. In: Ashkanasy NM, Wilderom CPM, Peterson MF, editors. Handbook of organizational culture and climate. Thousand Oaks: Sage; 2000.
[57] Woods DD, Cook RI. Nine steps to move forward from error. Cogn, Technol Work 2002;4:137–44.
[58] Zuboff S. In the age of the smart machine: the future of work and power. New York: Basic Books; 1988.

ARTICLE IV

Assessing the maintenance unit of a nuclear power plant – identifying the cultural conceptions concerning the maintenance work and the maintenance organization

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Assessing the maintenance unit of a nuclear power plant – identifying the cultural conceptions concerning the maintenance work and the maintenance organization

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Abstract

Various organizational accidents have indicated that the shared interpretations and experiences of the personnel concerning the work, the organization, and the associated risks are of crucial importance for the safety and effectiveness of the operations. These conceptions are an element of the organizational culture. The cultural conceptions should thus be studied and their contribution to the organizational safety and effectiveness should be assessed proactively. Nevertheless, organizational assessments often focus on either the general safety attitudes and/or values of the personnel, or formal organizational structures and the official practices. In this article a case study is reported that was carried out in a Nordic nuclear power plant maintenance unit. We will illustrate how the employees in the organization construct their work, their organization and the demands of the maintenance task. We focus on explicating and assessing the cultural conceptions prevalent in the maintenance organization. Our aim is to illustrate how the cultural conceptions and organizational practices, tools and the organizing of the work and the organizational climate influence each other, and how they relate to the demands of the maintenance work. The principal methods utilized in the case study were organizational culture questionnaire (CULTURE), semi-structured interviews, group working, and personnel development seminars.

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1. Introduction

Major organizational accidents such as Challenger, Piper Alpha or Chernobyl have indicated that the (shared) interpretations and experiences of the personnel concerning the work, the organization, and the associated risks are of crucial importance for the safety and effectiveness of the operations in complex industrial organizations (Vaughan, 1996; Rasmussen, 1997; Turner and Pidgeon, 1997). These *conceptions* (Sandberg, 2000, p. 12) are an element of the organizational culture and they are thus more or less taken for granted in the daily work. The cultural conceptions should thus be studied and their contribution to the organizational safety and effectiveness should be assessed proactively. Several accident investigations have also uncovered maintenance function as one of the main contributors to unanticipated events in various domains (Wright, 1994; Paté-Cornell, 1993; Hale et al., 1998; Reason and Hobbs, 2003; Perin, 2005).

This article reports a case study on organizational assessment in a nuclear power plant (NPP) maintenance unit. Previously, maintenance work has not been studied much from the cultural perspective and former approaches have seldom taken into account the demands of the maintenance work in the entire organization. The article proposes that the assessment should concentrate on explicating the personnel's cultural conceptions concerning the demands of the work and on clarifying their relation to the actual demands of the task that the organization is carrying out. We strive to illustrate how the cultural conceptions and organizational practices, tools and the organizing of the work influence each other and ultimately the safety and effectiveness of the NPP maintenance.

Three general issues related to work in complex industrial organizations are explored with the case study; (1) the nature of maintenance work in a nuclear power plant as conceptualized by the workers themselves, (2) the definition of criteria in the organizational assessment, and (3) the nature of organizational culture in these organizations. The first question illustrates the unique challenges that the maintenance work sets for the organization and the personnel. The last two questions have relevance for the management of safety and effectiveness in organizations also outside the context of maintenance.

1.1. The context

Organizations that operate in high hazard domains face extraordinary demands from the society. They are expected to function reliably and to anticipate the operating risks caused by either the technology itself or the organizational structures and practices. In addition, these organizations are complex in both technology and structure. The core technology requires heavy technical competence. The organizational structures, the redundant safety systems and the official rules of conduct create additional sources of complexity in addition to the complexities of the core technology. The goals of safety and efficiency must be balanced in everyday tasks on the shop floor. Changes in technology or the operating environment also cause new demands to which the personnel have to adapt.

These complex sociotechnical systems strive to manage their operation effectively by e.g. applying the principles of learning organizations, various auditing and benchmarking programs, and the concept of "safety culture". The attitudes and commitment of both the workers and the supervisors are emphasized. Continuous development of organizational practices and procedures is considered the cornerstone of safety and effectiveness. Assessment of the current organizational practices and attitudes of the personnel are a crucial and challenging element in the development programs. Even though the organizational assessment is only a starting point of the development process, assessment contains more or less explicit criteria and premises that direct the attention of the development initiatives.

An important premise of organizational assessment is its primary focus. Organizational assessments in safety critical organizations have often targeted either the safety values and/or attitudes of the personnel, or the organizational structures and the official practices (Reiman and Oedewald, submitted for publication). The former approach has limitations, since as Gherardi and Nicolini (2002, p. 216) have argued, safety is an aspect of practice, not a separable form of knowledge (see also Rochlin, 1999). The latter approach does not always tell much about the reality on the shop floor level, which might differ drastically from the official documents (see also Bourrier, 1999). In order to provide an overview of the organization, the assessment should be able to grasp the employees' conceptions and their working practices.

Another important premise is the method of assessment that is used. For example, the problem with many safety audits is that the personnel usually know the "right" answers. They are better at identifying formal practices and structures, and the espoused values of the organization (cf. Schein, 1985) than the cultural conceptions. In this article we argue that the questions should focus on how the personnel conceptualize their work and its demands.

1.2. Previous studies of the maintenance of a NPP

The competence in industrial maintenance consists of different technical fields (electrical, mechanical, instrumentation and control, real estate) and it requires strategic understanding as well as practical handicraft skills. Mercier (1988, pp. 86–87) characterizes the maintenance work of a NPP as follows: "It is rare for so many non-repetitive tasks to be concentrated in an industrial environment that is so very hostile to human activity. The forces in this environment are considerable. Temperatures, pressures, the multitude of fluids, mechanical power, omnipresent electricity, even the sheer weight of the equipment … all culminate to make maintenance actions potentially dangerous and to weigh against success. The 'nuclear' hazard and the associated radiation protection restraints are simply one more risk, but a risk that is often quite minimal compared to the others."

Maintenance as an activity or the maintenance work itself in the nuclear industry has not been studied much from the human factors perspective. Because maintenance routines and plant modifications are the activities that intervene most with the plant equipment, they are also the dominant sources of technical faults. Most of the behavioral scientific studies of the maintenance work have relied on this fact. Those studies have aimed at classifying, predicting and preventing human errors or minimizing their consequences (Reason, 1990, 1997; Laakso et al., 1998; Isobe et al., 1999; Pyy, 2001; Svenson and Salo, 2001; Toriizuka, 2001; Reason and Hobbs, 2003). In addition to human error studies, some specific tasks (such as NDT, non-destructive testing of the equipment, see e.g. NRC, 1986; Enkvist et al., 1999; Enkvist, 2003) and special situations (mainly annual refueling outage, see e.g. Gauthereau, 2003; Bourrier, 1999; Kecklund, 1998; Jacobsson and Svenson, 1991) have been studied from the human factors perspective. Some studies have also focused on work stress (Jacobsson and Svenson, 1991; Doniol-Shaw, 1997; Kecklund, 1998).

Due to the diversity, the temporal and spatial separation of the tasks, and the numerous competence requirements, focusing on a single task (e.g. electric installation), special situation (e.g. outage) or a single psychological problem (e.g. error of omission) can only partially explain the requirements of maintenance work and the organizational challenges of effective maintenance. What are needed are accounts of how the personnel themselves construct the maintenance work and its demands and how these demands manifest in the practices and structures of the organization.

Ethnographic or cultural studies of NPP maintenance organizations are rare (see Bourrier, 1996, 1999; Gauthereau, 2003). Bourrier (1996, 1999) has compared practices in four maintenance units of NPPs in France and the USA, and noted differences between the units in e.g. the co-ordination of work, the structuring of the tasks and the role of procedures during the annual outages at the plants. She did not, however, assess the effectiveness of the different practices in respect to the demands of the maintenance work. From the point of view of an organizational assessment, ethnographies produce interesting results about the culture of the workplace, but that is not sufficient. The aim of the ethnographic research is not to extract criteria for assessment, or evaluate the cultural features that they depict (cf. Geertz, 1973).

1.3. Aims of this study

In this article we will present an assessment of an organizational culture conducted in a Nordic NPP maintenance unit. We focus on explicating and assessing the cultural conceptions prevalent in the maintenance organization. Our aim is to illustrate how the cultural conceptions and organizational practices, tools and the organizing of the work influence each other. We will further illustrate the role that the technical solutions and the organizational practices play in embedding the cultural conceptions.

After presenting the case results we will discuss some key issues relating to organizational assessment. Firstly, we will discuss maintenance work as a knowledge-intensive and complex industrial activity that has previously been overlooked in the human factors research. Secondly, we will discuss the importance of considering the demands of the work in the assessment of the organizational culture of complex sociotechnical systems. Thirdly, we will argue that tensions, discrepancies and emergent conceptions in the organization are important but methodologically challenging elements of the organizational culture in complex sociotechnical systems.

2. Research strategy and data analysis

The study was carried out in a maintenance unit of a Nordic NPP. The aim of the study was to assess the organizational culture of the maintenance unit against the demands of the maintenance task. The study was conducted by the researchers (the authors) from the Technical Research Centre of Finland (VTT). Funding for the research came from VTT and a national nuclear safety research program with a small contribution from the power plant.

The research questions were formulated as follows: (1) What are the characteristics of the organizational culture at the maintenance unit, (2) what demands does the maintenance work set for the organizational culture, and (3) how does the current organizational culture support the perceiving and fulfilling of the demands of the maintenance task. The research strategy was that of an explanatory case study (Yin, 1994, pp. 4–15) with multiple sources of evidence (see Table 1). This article addresses the questions 1 and 3. Question 2 has been reported in Oedewald and Reiman (2003) and will only be referred to in this paper.

The Contextual Assessment of Organizational Culture (CAOC) methodology (Reiman and Oedewald, 2006b; Reiman and Oedewald, submitted for publication; Reiman et al., 2005) was utilized in the data collection and analysis. Fig. 1 illustrates the basic idea of the methodology. Organizational culture includes three main elements, namely the organizing of the work including the practices, structure, tools, and the formal competence of the personnel, internal integration aspects (climate, norms and values), and conceptions (cf. Sandberg, 2000) concerning the work. The demands of the work are depicted on the left in Fig. 1. These are formed from the objective of the work, from the characteristics of the object (e.g. NPP), and from external influences. The personnel's conceptions of the demands of the work are historically constructed and rooted in the culture of the organization. The history of the organization is physically present in the tools, practices and organizational structures (cf. Hutchins, 1995; Weick, 1995).

Organizational culture, as we conceptualize it, is a "root metaphor" (Smircich, 1983) for the organization. Alvesson and Berg (1992, p. 78) state that this approach "means that the cultural dimension can be found in – and not "alongside" – formal organizational structures, administrative systems, technologies, strategies" (see also Alvesson, 2002, p. 25). The cultural way of studying organizations is to study "the meanings and beliefs which members of organizations assign to organizational behavior and how these assigned meanings influence the ways in which they behave themselves" (Schultz, 1995, p. 5).

2.1. Phases of the cultural assessment

The cultural assessment consisted of three phases:

1. Characterizing the culture of the organization according to the three elements of organizational culture (cf. Fig. 1).
2. Modeling the demands of the maintenance task (for details see Oedewald and Reiman, 2003) in order to get appropriate criteria for the assessment of the organizational culture.
3. Explaining the effect of the culture on organizational effectiveness by qualitative assessment based on the demands of the work and the extracted cultural features.

The purpose of the cultural analysis (Phase 1) is not to aggregate the data until a "common view" or an average opinion is found. The aim is to exemplify the personnel's multiple ways of making sense of and interacting in the organizational context (cf. Sackmann, 1991; Rochlin, 1999; Weick, 1995) and to inspect what type of conceptions are shared among the personnel, and to what extent. The mode of analysis is interpretative (cf. Schultz and Hatch, 1996, p. 538) in its search for the creation of meaning in the organization.

The focus of the maintenance task modeling (Phase 2) is on the constraints and the requirements of the work in the entire organization. Workers construct the nature and

Table 1
Methods and data analysis

Method	Description	Analysis
Interviews of key informants	Semi-structured interviews were conducted for the three members of the project group. The interviews were taped and later transcribed. Each interview lasted approximately one and half an hour. The interview questions were in most respects similar to the those of the personnel interviews (see Appendix A), but focused more on the demands of the maintenance task	Constraints and requirements of the maintenance work were extracted. The goals of maintenance were extracted. The features of the plant (e.g. technical complexity, radiation) that place demands on maintenance work were extracted
Document analysis	The main documents of the maintenance unit (org. charts, responsibility areas, work permit procedure) were analysed qualitatively	Constraints and requirements of the maintenance work that were depicted in the documents were extracted. The official roles and responsibilities of the various sections of maintenance were extracted, as well as the official rules of conduct
Group working with the project group	A project group was established for the duration of the study. Five maintenance experts participated in the project group. The demands of the maintenance work were modelled and preliminary results were presented at the meetings	When modelling the demands of the maintenance task, the researchers asked questions (“what is the goal of maintenance?”, “what is critical in achieving the goal?”, “how maintenance of a NPP differs from maintenance of some other facility?”) and wrote all the answers down on a computer screen that was projected to all the participants (see Oedewald and Reiman, 2003). After the sessions, researchers grouped the material and made e.g. illustrations, which were again discussed at the next meeting
	Altogether six sessions were held. The maintenance task was modelled in the first three meetings. After that, the focus of the group working shifted to commenting and discussing on preliminary results rather than generating new raw data	The presentation of the raw data concerning both the demands of the maintenance task and the characteristics of the culture offered further hypotheses and explanations for the preliminary findings. The group acted for the entire research as an arena where the plausibility (Silverman, 1993) of the results and the saturation of the analysis (Strauss and Corbin, 1998) was tested
Personnel interviews	Nineteen semi-structured interviews were conducted. They had four main themes: one’s own work, the maintenance task, organizing of maintenance work and organizational culture (see Appendix A for the specific questions)	Interviews were utilized in the analysis in two different ways: (1) classification, certain questions concerning the three elements of organizational culture (questions 2, 3, 12, and 13, see Appendix A) were

Table 1 (*continued*)

Method	Description	Analysis
	Interviews were conducted by the authors with the help of two assistant researchers. Either the first or the second author was present in all the interviews. The interviews were taped and later transcribed. Each interview lasted about an hour The interviewees were six technicians, six foremen, two work planners, two experts, three line managers and the head of maintenance. They were all male	analysed by categorizing the responses into content groups, e.g. what kind of things are considered as demanding. (2) creation of a theory; common themes were searched that would surface in speech in various ways and contexts. The analysis was done from the grounded theory perspective (cf. Charmaz, 1995; Smith, 1995) The interviews were also used to test and elaborate specific hypotheses generated by the other methods (e.g. the survey findings or comments at the seminars), see Hammersley (1996)
Survey	Organizational culture questionnaire (CULTURE01) included four measures: 1. workplace values, 2. psychological characteristics of work, 3. individual perceptions, 4 maintenance task (see Reiman and Oedewald, 2004). The questionnaire consisted of a total of 95 questions with six-point Likert-type scale and one open question. The open question was phrased as follows: "What are the main targets for development at your department?" Each questionnaire was addressed directly to the personnel, and was accompanied with a sealable envelope, pre-addressed to the research institute. The respondents were assured that the responses would be handled confidentially and that the results could not be traced back to the individual respondents The measures were constructed with the help of the interviews, the document analysis, theories of the dimensions of organizational culture (Cameron and Quinn, 1999; Reiman and Norros, 2002), and theories of common work characteristics (Hackman and Lawler, 1971; Hackman and Oldham, 1980). Pilot version of the measures 1 and 2 were used in a study of Nuclear Regulatory Agency (Reiman and Norros, 2002). Gender was not asked since the unit was very male dominated	The sample size was 135, with response rate of 70%. The three measures of the questionnaire (1, 2 and 3) were factor analysed with principal components solution. Summated scales were formed on the basis of the factor loadings. The initial factor solutions were rotated by orthogonal rotation methods; see Tabachnick and Fidell (2001). The reliability coefficients (Cronbach's alpha) are reported in Table 2. ANOVAs were calculated with the summated scales as independent variables and age, tenure, task and section as dependent variables. Fifty percent of the respondents answered the open question, with a total of 155 statements (ranging from one word to half a page of written text) about the targets for development. The statements were analysed qualitatively by grouping them into categories by grounded theory based analysis (see Charmaz, 1995). For example, statements"clarification of the work tasks and minimizing insubstantial work", and "organization should be formed according to the work processes instead of technical fields" were grouped under the theme of "organizing of work and division of labor"

(*continued on next page*)

Table 1 (*continued*)

Method	Description	Analysis
Observation of work activities during the annual outage	The authors visited two annual refuelling outages. During the first outage a night was spent observing the decovering of the reactor in addition to one day of touring around the plant. During the second outage the mechanical workshop was visited The researchers also attended the necessary training courses in order to get a pass to the controlled area of the plant	The researchers made notes of the working conditions (e.g. noise, closed spaces, radiation) at the plant. Also other manifestations of the organizational culture, such as the general tidiness, language, and tools were observed
Final seminar	A final seminar with about 100 participants from all the levels and tasks of the maintenance unit was carried out a year after the administration of the survey. The results of the study were presented to the participants at the seminar. The seminar lasted for about three hours	After the seminar, the participants were asked to answer three questions: (1) were the results accurate (2) were the results interesting (3) were the results useful. 67 persons filled the survey, 64 answered yes to (1), 62 to (2) and 53 to (3)
Working groups	Four working groups from different sections were established in order to develop the culture in accordance with the new organizational structure, which was set in place after the main data collection Each group met three times (three hour meetings) during a period of six months, with the researchers facilitating discussion	All the group sessions were videotaped. For the purposes of this case study, the first sessions in which the results of the cultural assessment were discussed with the groups were analysed qualitatively

demands of their task in qualitatively different ways (see e.g. Sandberg, 2000; Norros and Klemola, 1999) and thus the answers vary in content also within the same task domain. The analysis of the interviews (Table 1) tells us how the personnel take personally into account the constraints and requirements set by the maintenance task in their work (cf. Norros, 2004, p. 65). Different aspects of the overall task (in this case, maintenance) are perceived by different workers. The aim of the modeling is to extract the demands of the work that apply to all the personnel. The analytical process in the modeling is thus more convergent (cf. Schultz and Hatch, 1996, pp. 538–539) than in the cultural analysis, which is divergent in its search for multiple interpretations.

The cultural assessment (Phase 3) was made by comparing the characteristics of the organizational culture against the extracted demands of the work. The aim of the assessment was not on seeking causal relations to some objective measures. Instead, the aim was to anticipate the consequences of the current conceptions and practices in the organization for the fulfilment of the demands of the maintenance task, and to clarify the role of technical solutions (including tools) in embedding the conceptions concerning the work.

2.2. Methods

The methods utilized in the case study were an organizational culture questionnaire (CULTURE01, for details see Reiman and Oedewald, 2004), semi-structured interviews, group working (with maintenance experts), observation of the work activities during the annual outage, seminar for the entire maintenance department and working groups for the technicians and foremen. Also informal conversations with the personnel during the one and half years of the study and the formal organizational documents were utilized in the analysis. The methods, their use and analysis are depicted in Table 1. All data gathering and analyses have been conducted by the authors unless otherwise noted. In addition to the methods depicted in Table 1, two feedback seminars were organized, where the preliminary results were presented to the personnel. The interview questions are listed in Appendix A. In addition to the list, numerous follow-up questions on emerging topics were made in each interview.

The study employed a multimethod research strategy based on method triangulation (Silverman, 1993; Yin, 1994, pp. 90–94; Hammersley, 1996, pp. 167–172). Analysis of the data provided by the methods described in Table 1 was thus conducted iteratively.

3. Results

The results are presented as follows: The culture of the case organization is briefly characterized according to the elements of organizational culture (see Fig. 1). Then, the criteria for the assessment and the main conceptions of the organizational culture are presented. After that, the main cultural conceptions concerning the work are elaborated. Finally, the consequences of the cultural conceptions to the safety and effectiveness of maintenance are considered.

3.1. Description of the organizational culture

3.1.1. Organizing of work, history and the tools

The maintenance department at the case plant had approximately 200 full-time employees. Other departments of the plant organization were operations, technical support, administration and training. The maintenance activities at the department were organized into seven sections for mechanical, electrical, instrumentation and construction maintenance, technical design, planning and co-ordination and quality control. The plant had been in operation for more than 20 years and had shown an excellent performance record (annual load factor approximately 90%) and very few incidents or occupational accidents (no fatal accidents in the history of the plant at the time of the study). The plant had previously been operated by a state-owned energy company. A few years prior to the study the company was privatized and merged with another company operating in a different industrial field.

The department was responsible for both the equipment that is critical to the safety and production, and for the secondary areas of the plant (e.g. the yard, the restrooms). Most of the operative maintenance consisted of pre-planned overhauls or periodic testing. Fault repairs were only a fraction of the work. All the operative maintenance work was controlled with a work order procedure. The daily work was organized at the morning meetings (separate for all sections) where the foremen allocated the work to their subordinates.

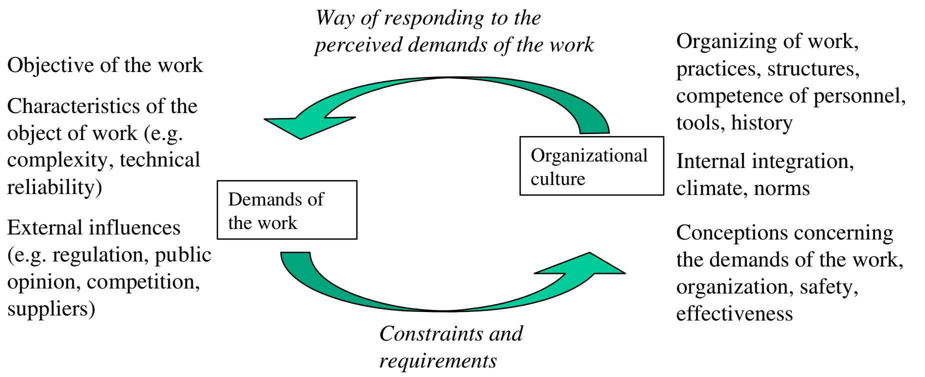

Fig. 1. The basic idea of the methodology. Adapted from Reiman and Oedewald (2006a, submitted for publication).

The *work permit* includes the description of work, the necessary precautions to be taken (e.g. radiation protection), and a list of the needed tools and instructions. The work permit is made by the work planners with the plant information system (PLIS) on the basis of a work order. The shift supervisor from the operations department has to approve all the permits. The work permit is prepared after somebody has made a failure notification or the PLIS system has informed of a periodic maintenance. The foreman issues the approved permit to the technician who carries out the job. The technician then returns the permit to the foreman who notes down the work as done and the findings in the PLIS. During the work, the permit is tagged to the machinery under work. The foreman returns the permit to operations, where the approval to restart the system is given after the required tests have been conducted. Each foreman has a certain responsibility area and he co-ordinates the work done in that area. A foreman commented on what he considered as the most demanding aspects of his job:

> "It's quite demanding that the equipment is placed on the order of importance, they have maximum unavailability times… when some machinery breaks, you have three days to fix it and you have to start planning it on the run, in order to get the work started immediately. And when the bureaucracy is what it is here, all the papers have to move and so on. So that we get the permit, and are allowed to do anything. You always need the work permit, you cannot rush in headlong there. And it requires that you know quite well your organization, so you know who to pressure; 'do your work'." (1)

Overall, the daily maintenance activities were based on the long shared history of working together and on the implicit knowledge of who knows what and how to get by with the sometimes cumbersome and slow official system. The formal competence of the personnel was also high.

3.1.2. Internal integration

At the interviews the personnel characterized their culture as *hierarchical* and *conservative* in decision making. Co-workers were typically described as *responsible*, *safety-conscious* and *deliberate* in attitude. The personnel turnover had been low and the average age and the average tenure (>14 years) of the personnel were both high. There existed some dissatisfaction among the personnel with the current organizational practices, such as the amount of bureaucracy and poor co-operation between the sections. This was evident from both the survey responses to the open question and from the interviews (The largest category of the development targets [24% of all statements] in the open question of the survey [see Table 1] was labeled "organizing of work and division of labor".) The problems of co-operation had in part to do with strained personal relationships between some individuals.

According to the survey the mechanical maintenance experienced their work as most important of all the technical fields (highest mean score on question "I feel that my work is important", ANOVA showed a significant difference ($F(6, 113) = 2.27$, $p < .042$)). In the interviews and in the informal discussions implications were also found that the other fields felt that the mechanical maintenance is organizationally the most appreciated technical field in the organization, largely due to the apparent visibility of their work involving "large machines and plenty of grease". On an organizational level, very few indications were found that the maintenance workers considered their work as undervalued at the plant (cf. Perin, 2005).

The climate was considered as somewhat deteriorated over the years. The sense of pride in the company and in the plant was not what it used to be. This was partly due to the recent merging and privatization of the firm. Previously the plant had been the "jewel" in the state-owned company's collection of conventional power plants. Now the plant was one among the many power plants and other industrial organizations in a multinational corporation. The growing economic focus and the loss of decision autonomy to a (psychologically) distant head office were stressful to the personnel. A foreman commented on the change:

> "I think it's quite a big change, money's a lot more a subject for talk now, how much everything costs… Yes it is a big change… it wasn't like this in the old [company]. We came here to stay until our retirement days. 'State-owned company and an easy job'. … We still haven't got rid of the old [company in our minds]. We have mourned over it… Now we are wondering what is expected of us. Nothing seems certain anymore." (2)

On the level of daily work and practices, though, few changes were perceived. A slightly increased feeling of haste prevailed, but it was also acknowledged that if something was considered important, the required time could always be found.

The summated scales from the CULTURE01-survey are reported in Table 2 (the response scale was from 1 to 6). ANOVAs with position, section, age and tenure in the organization as independent variables are also shown (adapted from Reiman and Oedewald, 2004). For comparison purposes a combined mean score from three other measures made with CULTURE02/03 surveys in Nordic NPP maintenance units ($N = 316$) is also shown, see e.g. Reiman et al. (2005). Note that not all the summated scales of the larger sample are fully identical to the scales used in this study. The differences in the mean scores are thus indicative only, and no ANOVAs have been calculated to indicate the statistical significance of the differences.

Table 2 shows that the perceived change values (e.g. "questioning of the old practices") were lowest and the perceived safety values (e.g. "occupational safety", "carefulness") were highest (similar to the larger sample). The personnel did not consider the low change values as being a bad thing (except some younger personnel). Working in the NPP calls for conservatism. The low value of cohesiveness (e.g. "co-operation", "wellbeing of the

Table 2
Summated scales of the survey, adapted partly from Reiman and Oedewald (2004)

Variables	Items	α	Mean	SD	Mean at three units	Position $F(3, 83)$	Section $F(5, 83)$	Age $F(3, 122)$	Tenure $F(5, 83)$
Perceived values									
Financial and efficiency	4	0.75	3.87	0.98	4.03	1.19	1.75	2.35	1.47
Safety and deliberation	5	0.80	4.13	0.87	4.72	3.04*	2,20*	0.53	0.82
Change and development	4	0.81	2.77	0.93	3.91	3.35*	2,36*	1.78	3,88**
Hierarchy	3	0.63	3.68	0.96	4.42	1.90	2.40*	0.40	2.06
Autonomy and proficiency	6	0.88	3.48	0.96	4.20	4.41**	2,83*	0.44	2.66*
Cohesiveness	7	0.90	2.98	0.92	4.01	6.87***	2.43*	1.36	2.73*
Psychological characteristics									
Perceived feedback	4	0.75	3.47	0.96	4.03	4.55**	0.70	1.77	2.30
Meaningfulness	3	0.73	4.35	0.94	4.46	0.70	1.35	0.76	1.18
Sense of responsibility	4	0.62	4.42	0.71	4.47	1.84	1.42	0.61	1.56
Sense of control	4	0.52	4.28	0.74	3.34	3.74*	0.66	2.00	0.61
Individual perceptions									
Perception of management	5	0.72	2.77	0.82	–	7.25***	1.86	1.46	3.56**
Perception of climate	5	0.59	4.10	0.70	4.17	0.57	2.57*	0.32	0.42
Development orientation	5	0.61	4.15	0.63	4.44	2.56	2.11	3.11*	0.40

α = Cronbach's alpha efficient; SD = standard deviation; mean three units = mean score from three Nordic NPP maintenance units ($N = 316$).
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

personnel") was considered a problem, and a few employees complained in the interviews and the open question of the survey that financial (e.g. "cost-effectiveness") and hierarchy issues (e.g. "centralized decision making") are currently too highly valued by the managers.

One's own work was considered meaningful (Table 2) and according to the interviews maintenance work was seen important to the safe and reliable operation of the plant. The sense of control over one's work was very high. The job satisfaction was also good on the average ($M = 4.36$, SD = 1.07). When the result was presented at the final seminar and in the working groups (Table 1), the personnel were surprised that the others were so satisfied with their work. It had become a habit in the culture to complain about the organization and the work. This, what we call *emergent social dissatisfaction* with the work was reinstated with every publicly uttered complaint. Weeks (2004, p. 12) calls this kind of behavior "complaining about the culture in the culturally acceptable ways". We will return to the implications of this finding later and elaborate next the other conceptions concerning specifically the maintenance work and the maintenance organization.

3.1.3. Conceptions concerning the organization and the maintenance work

The interviewees were asked about the goals of maintenance, the critical things to be done in achieving them and about the demanding things in their work. The goal of maintenance was seen quite uniformly as keeping the equipment in good condition to allow safe (and efficient) production of electricity, but the view on the critical means to achieve the goal varied. The critical means were grouped into four classes; planning and preventive maintenance (4 respondents), proficient and motivated personnel (7 respondents), monitoring, identification of fault mechanisms and overview of the plant (3 respondents), and other issues such as money (2 respondents). At the project group (see Table 1) the goal of maintenance was defined as follows: "the goal is to keep the plant in such a condition that it can be operated, and take all the boundaries (safety, economy, public opinion) into account."

Many of the comments from the interviews concerning the maintenance task reflected the current situation of the plant, e.g. the talk about economy. For example, one interviewee who emphasized that the goal of maintenance is to "keep the plant in a safe state", responded to the question about what is critical in achieving it as follows:

> "The economy has come into the picture only recently, due to the privatization, it used to have no meaning to us. I mean that we did not devote our attention to it, but now money is important." (3)

The large variety of the tasks and the tasks with high safety significance or time pressure were experienced as demanding. Tasks involving fault situations and problem solving were mentioned as demanding by five persons. Other demanding issues that were mentioned by one or two interviewees were personnel issues, outage, variety of the tasks, coping with the bureaucracy and prioritization of work. A few persons could not think of any demanding things in their work. Safety was highlighted in most interviews, seven persons explicitly mentioned safety as an integral part of the maintenance task. Economy was usually added as an afterthought, or raised as something that is new to the plant (cf. citation 3). Some persons also mentioned economy as potentially threatening safety or the quality of the work. In the survey (Table 2), safety, efficiency and hierarchy values were differentiated. They were conceptualized as separate goals. The results implied that *safety was perceived as the primary criterion of effective maintenance* and financial and hierarchical aspects more as internal requirements or constraints.

The maintenance work was described as most meaningful when there were technical problems to solve. One interviewee (I&C technician) described the content of his job:

> "Most demanding thing is… finding the fault. The kind of fault that you can't inspect. You have to repair it, but it no longer exists, but it has existed, and you are supposed to repair it. Like a light bulb that goes off and then goes on again… Of course, these are also the most interesting tasks." (4)

The defining characteristics of expert were "steadiness", "deliberation", "self-confidence" and "initiative" (Question 5 in Appendix A). The personnel experienced themselves as very skilled but most interviewees noted that there are differences in the motivation and working habits of the employees. A foreman contemplated what differentiates an expert from novice in maintenance work:

> "Well it's a difficult question, I mean that some can be better than others… but still the end result might be quite the same. Well perhaps not exactly the same, I mean, if you think of the whole system… but if the system works and you look at the indicators, they have both been as good, but the thing is, that how you have done the job, it

> can have some impact on the future. The other fellow can take even that into account. I mean that he takes a kind of a larger perspective, not just a single task, an expert takes always the whole process, the whole picture, takes everything into account, and acts accordingly." (5)

The personnel identified strongly with the handicraft nature of the maintenance work. The opportunity to work with the machines and to be able to repair them motivated the personnel.

3.2. Assessment – the criteria and the main cultural conceptions

On the basis of the interviews and the project group (see Table 1), the overall goal of maintenance was conceptualized as guaranteeing safe, reliable and efficient production of electricity. The fulfilment of this goal was constrained by the complexity of the technology and its both tight and loose couplings, the ageing and physical changes, the mediated interaction with the equipment, and the presence of radiation. Also the need to control the risk of core damage affected the maintenance work in the form of a need for redundant safety systems, maximum unavailability times for critical equipment and the separation of process-related systems and safety systems (Oedewald and Reiman, 2003, p. 286).

Ten central demands of the maintenance task were extracted from these constraints and from the goals of the maintenance. Table 3 depicts the demands and the organizational practices and tools used to manage the demands. The third column shows our interpretation of the cultural conceptions embedded in the practices and tools. The conceptions can be either reasons for the practices, or the practice or a tool has generated the conception in the culture. Both influences are present in organizations. It is often impossible to reason whether some conceptions existed before the current tools were taken into use or whether the tools helped to create (and embed) the conception into the organization.

One of the central conceptions in the culture was that the *ability to react to sudden incidents is the most important requirement of effective maintenance* (see the sixth demand in Table 3 and citation 4). The conception also reinforces the other main conceptions, namely that *certainty is an ideal state* and that "*we are doing it right*", since any changes endanger the fulfilment of effective reacting. Work is carried out the way it has always been done. In that way the outcomes and the organizational obstacles are predictable. Safety was conceptualized as the primary criterion of effective maintenance.

3.3. Assessment – the main conceptions as embedded in the organizational practices

The current way of organizing activities into technically specialized sections within the maintenance unit was experienced as complicating the co-operation and co-ordination of the work. Subcultures that differentiated themselves from others by emphasizing their similarity and dissimilarity of others to them had formed. However, conceptions differed little as identified in this study. It was further pointed out that the organization is able to reach its (safety) goals, but the current practice was seen as somewhat ineffective and not always very motivating. Hierarchy and bureaucracy were seen as having good sides, as shown in this citation from a foreman:

Table 3
Assessment summary of the features of the culture at the maintenance unit

Working practice demand	Current practices and artifacts	Cultural meanings and conceptions embedded in the practices or artifacts
1. Co-ordinating timetables and resources within maintenance:	Maintenance unit is separated into several small quite independent groups on the basis of the type of work they are doing	*Conception of the norm of specialization*, long history of routine formation (over 20 years). One's own tasks were prioritized over other tasks
– communicating between technical fields	There were few common meetings between groups, no common access to PLIS that would indicate all the tasks currently in progress at the plant	Problems of sharing knowledge were acknowledged, but no solution was thought possible, *conception that employees are not willing to share their knowledge*
– intention to form an overall picture of the condition of the plant	Foremen of the groups co-ordinate the work done in that area The foreman is accountable for and in charge of the technicians working under him	*Foreman is responsible* for his technicians and the quality of their work
2. Co-ordinating work between maintenance and operations – approval to start working – information of the availability (state) of the equipment to operations – verification of system operability	The shift supervisor from operations approves all work permits that the maintenance foremen or the work planners have prepared with the PLIS. The foreman gives the approved permit to the technician who carries out the job. During the work the permit is fastened to the machinery under work. The foreman returns the permit to operations where the approval to restart the equipment is given	Co-operation embedded in routines and procedures, not in face-to-face interactions Maintenance is responsible for the availability of the equipment; operations are responsible for the operation of the plant
3. Co-ordinating work between technical support and maintenance – informing the condition of the equipment technical support – keeping up to date on forthcoming modification from technical support	Under normal operation, maintenance communicates little with technical support. Formal circulation of technical documents is done according to the area of specialty. Technical department plans the modifications, which the maintenance department implements	Norm of specialization existed also between the departments. *Maintenance was considered as handcraft work* requiring no abstract thinking. Thus a language barrier existed between technical department and maintenance
4. Definition of responsibility areas	Responsibility areas were quite narrow. Implicitly the responsibility areas were well known due to long history of the plant, but they were not very well documented formally. Plenty of "grey" areas, where the responsibilities are not clear and must be decided on a case-by-case basis, existed	*Conception of the norm of specialization* in responsibility areas. Narrow responsibility areas do not foster a need for an overall picture of the condition of the plant
5. Definition of the maintenance program	No formal maintenance program and strategy defined, except for safety critical equipment	"*The plant has worked well for over 20 years so we must be carrying out a good maintenance program*"

(*continued on next page*)

Table 3 (*continued*)

Working practice demand	Current practices and artifacts	Cultural meanings and conceptions embedded in the practices or artifacts
6. Prioritization of work task; urgent and non-urgent fault repairs, preventive aintenance modifications	Foremen prioritized their own tasks and their own resources, no comprehensive system for objective task prioritization Personal contacts and "hidden organization" used in order to react quickly when deemed necessary by the personnel otherwise the official route is followed, which takes more time	*Conception of the importance of reacting.* Safety is the main criterion of effective maintenance, reacting is effective when safety is in danger, but financial aspects not very salient; conception of inherently productive nature of nuclear power. "Trusted workers" are used, partly because foremen are considered responsible for the outcome
7. Co-operation between different technical fields within maintenance in concrete work situations	Work permit includes separate stages, the paper permit is manually carried to other units before they can begin their part of the job, the work is seldom done together	Low cohesiveness; different subcultures make co-operation harder,"electricians do not touch the spanner" The paper permit embeds the conception that only the one with the actual physical permit can work on the object in question
8. Adhering to work permit procedures and instructions	Nothing is done without a work permit. The work permit is directed at component in the equipment, different technical areas thus need a different permit. The work permit includes the necessary precautions to be taken. The work permit is signed by shift supervisor and issued by the foreman	*Work permit is the cultural carrier of both the collective responsibility over one's own work and the specialization to one area.* Safety-critical nature of NPP is emphasized, rules are used as means of coping with uncertainty
9. Transparency of actions and documentation of the work and its outcomes	Hard-to-use text-based computer system (PLIS) for planning and conducting the work, individual notes and "black booklets" used widely	Documentation is often considered as an extra-work, and not part of the maintenance task The assumptions underlying the PLIS-system development has been that it will not be used by many people, that only a few specialized people need the information stored in PLIS, *conception that one's actions need not be transparent to all the workers, only to the experts and QC control*
10. Information management	Uncertainty recognition is embedded in the culture of reacting, but the uncertainties are not explicitly discussed, or the uncertainties are addressed to the social organization	*Conception of certainty* as an ideal state, but also individual awareness of the technical uncertainties exists
– gathering and interpreting data concerning new phenomena	Complex social organization creates ambiguity	Safety-critical nature of a NPP is emphasized, rules are used as means of coping with the uncertainty, *conception of the norm of specialization*
– expert analyses	Expert analyses are done far from the field, but no necessarily utilized in daily activities	Prevalent norm of specialization, only the expert of the given subject needs to know
– disseminating information concerning new phenomena	Information written in reports which are circulated to whom it should concern	

> "This hierarchy in here, there are benefits in it…if I don't know something, I can always go to my superior… it is safe." (6)

The *need for certainty* was clearly emphasized in the organizational culture. This manifested e.g. in the norm of not accepting a job unless one was absolutely sure one had the competence to carry it out and in the tendency of the foremen to favor technicians who were known to "do a good job". Hierarchy, rules and procedures, expertise, and specialization were considered the primary means of achieving certainty and control. A technician responded to a question about the required competence in the work in a slightly exaggerating tone:

> "It is not necessary to know anything [in order to get by in here], if you say to some task that I don't know anything about that, the answer is 'ok, let's forget it', nobody takes the responsibility and requires anything." (7)

In the interviews, most employees spontaneously reflected on the norm of certainty. Nobody attributed the norm to himself; rather it was attributed as "everybody here says that you should not do anything unless you are absolutely certain". This assumption of certainty was thus an *emergent* property of the maintenance culture, reproduced and existing only in the interactions and communication patterns of the personnel. A technician replied to a question about expertise in the work:

> "Quite many people emphasize that if you are uncertain you should do nothing. People are afraid that something happens, perhaps it's got something to do with the fact that if the plant shuts down it's in the news instantly…. If a pump from the primary circuit stops, you have to report to the [nuclear regulatory authority] immediately." (8)

Certainty was especially emphasized by the managers. One line manager noted about his subordinates:

> "At a nuclear power plant you can't afford to mess around all by yourself, you have to know exactly what you are doing." (9)

Specialization to an exact area of expertise was considered to be safer than larger areas of responsibility, partly due to the emphasis on certainty (cf. citations 8 and 9). Another means of managing the complex organization was to proceduralize and create rules of conduct (cf. citations 10 and 11). The prevailing culture supported *generally applicable rules*, which would be non-interpretable and clear enough to be followed with basic technical training. On the other hand, it was acknowledged by many that the complexity of the maintenance work prevents the standardization of every task.

An underlying conception in the organizational culture seemed to be that *variance in human activity is harmful*. The conception about the appropriate means to control the variance differed. One of the technicians noted:

> "It is good that we have instructions, it guarantees that everybody does the job the same way." (10)

A foreman was more reflective on the role of rules in the organization (cf. Schulman, 1993, p. 363):

> "From the plant's point of view, it's good that we have instructions. If something happens you can always say that one didn't follow the instructions." (11)

Despite the strong cultural emphasis on proceduralization and hierarchy, differences existed in the working practices of the employees. This variance in human behavior was experienced as ambiguous. Many agreed that it was potentially harmful for the safety and effectiveness of maintenance, but the strong tendency to standardize and proceduralize was experienced as threatening job motivation, the meaningfulness of the work and the ability to carry out the daily work (cf. Hackman and Oldham, 1980, p. 75; Bourrier, 1996, p. 106; Dien, 1998; Dekker, 2003). The personnel were afraid of losing their professional identities as skilled craftsmen and becoming "a small cog in a big machine", but they felt this was the goal of the organization and also somewhat the daily reality. A technician commented in the interviews:

> "We are like robots in here, someone brings me an order, I carry it out, and return the paper to him, but nothing is said to each other." (12)

The importance of responsibility for the safety of maintenance was emphasized but the content of the term was rather vague. A technician responded to the question "what are your daily tasks and responsibilities":

> "Well, hard to say outright what I am responsible for. Of nothing all by myself I guess. (*Interviewer: on what level does the responsibility lay then? Is group responsible for…?*) Well, I am one part of this I&C group. In a way I am one… Let's say that if there is a cogwheel, I am one cog in that wheel. (13)

Collective responsibility was thus emphasized in the culture (cf. Rochlin, 1999; Schulman, 1996; Klein et al., 1995). Responsibility meant following the rules and doing your part of the job as defined in the work order. In that way responsibility was embedded in the work order procedure and the general rules of conduct (cf. Dien, 1998; Hirschhorn, 1993). Responsibility was proceduralized.

The central conceptions and their interrelations are depicted in Fig. 2. Both shared and emergent conceptions are shown, as well as lines indicating the interrelations between the conceptions. Dotted lines indicate contradictory conceptions. Emergent conceptions are conceptions that emerged in e.g. individual interviews, but as features that no one attributed to oneself but to the 'collective'. Both emergent conceptions had an effect on the behavior of the employees. For example, the personnel had an emergent conception that the *employees are not satisfied with their jobs*. On the other hand, the personnel thought that "*this is our plant, we are doing an important job by keeping it safe*", but they also felt that the *management considered personnel as replaceable, cogs in a large machine*. Thus, according to the personnel, the management does not need to focus on issues related to climate and cohesiveness since the personnel are not as important as procedures or technology in guaranteeing safety and production. The personnel themselves thought otherwise. The most influential conception was the conception about safety being the main criterion of effective maintenance of a nuclear power plant.

The main strengths of the culture were in the high safety commitment of the personnel, and in the high perceived meaningfulness of one's own work. Due to the complex and distributed nature of the maintenance work the achievement of a general view of the plant condition, and flexible co-operation between the technical fields are challenging. The lack of the overall picture was compensated by the high commitment of the personnel, situational flexibility and knowledge of "who might know".

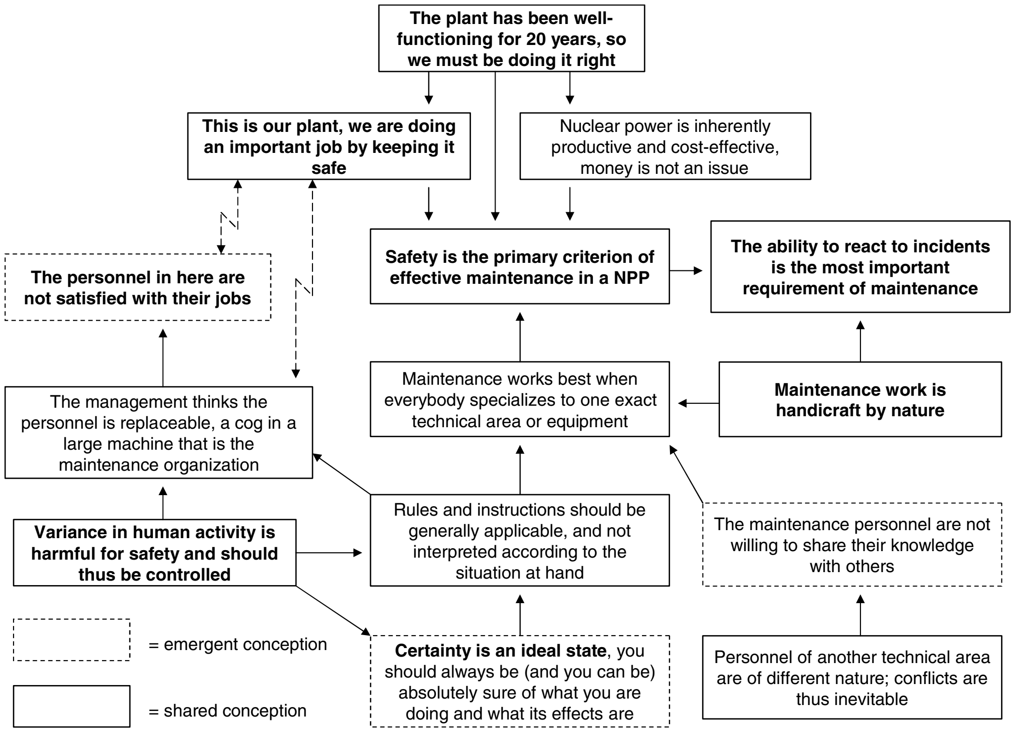

Fig. 2. The cultural conceptions of the personnel at the maintenance unit. Dotted lines between the conceptions indicate discrepancies in the conceptions. Dotted boxes indicate emergent conceptions and other boxes indicate shared conceptions. The bolded conceptions are the most widely shared and taken-for-granted conceptions in the culture, in the others more disagreements and debate existed.

3.4. Safety consequences of the main cultural conceptions

The plant is currently performing well (and has been so for 20 years). Objective indicators such as yearly load factors, number of incidents or occupational accidents indicate a steady improvement in the performance over the years. Nevertheless, on the basis of the assessment, we can argue that some of the cultural conceptions are not optimal in terms of the efficiency and long term effectiveness of maintenance. Indications were also found that the climate had been somewhat lowered due to inefficiency of the activities. Further, as argued by Vicente (1999), in order to be effective in the long-term, an organization has to be efficient, safe and healthy. Thus problems in e.g. efficiency or employee wellbeing might have also safety consequences. How the main cultural conceptions that were identified in this case study could affect safety? The following main conceptions were identified that are of special relevance in terms of long-term safety of the plant: the emphasis on specialization, the emphasis on certainty and the emphasis on safety as the only criterion of effective maintenance. These conceptions will be tackled next.

The narrowly defined responsibility areas and the emphasis of strict work procedures were interpreted by the personnel to mean that the organization tried to make sure that no person is irreplaceable (cf. citation 13). This interpretation was explicitly raised at the working groups when the preliminary results about the low cohesiveness values (Table 2) were presented. Nevertheless, due to the specific responsibility areas the organization has *drifted* to a situation were some tasks have been personified, which meant that only few (or one) persons knew how to carry out a particular task. The problems of this personification to e.g. flexibility and knowledge transfer to newcomers were acknowledged in the organization. Still, the importance of specialization for safe maintenance was not questioned. Another problem relating to the specialization was that according to the maintenance task modeling effective maintenance requires an overview of the condition of the plant. This is difficult to achieve since everyone had their own narrow job roles.

Problems in co-operation within the unit were one of the most frequently raised complaints by the personnel. As the personnel were very committed to the safety of the NPP it could be hypothesized that they would worry about the possible safety consequences of the lack of co-operation and extensive specialization. It seemed, however, that the personnel were not willing to extend their responsibility areas or change their routines, e.g. practice job rotation, in order to enhance co-operation. These propositions were experienced as directly endangering safety, whereas the lack of co-operation was something they had learned to cope with and compensate for. Thus, the current lack of co-operation was experienced as endangering safety less than a change in the current practices would.

The personnel had strong but sometimes quite narrow conceptions concerning safety. Despite their emphasis on the significance of safety in maintenance, they emphasized the importance of reacting to technical faults over e.g. preventive maintenance and condition monitoring. The fact that inflexible or inefficient maintenance could also be a safety risk was mostly denied. Furthermore, everything that was new and unfamiliar was taken as a potential threat to safety and was thus questioned in the culture. The emergent cultural emphasis on certainty also provided a legitimate reason to question all new ideas as potentially dangerous. Thus, the problems perceived in the e.g. organizing of work and in the division of labor (see Section 3.1) were not to be solved by *new* ways of organizing. Finally, the vagueness of the meaning of personal responsibility in the culture made change even more difficult, since responsibility was something that was based on a history of working together and it was embedded in the rules and procedures. Responsibility was a collective and emergent property of the system; when things were done the way they had always been done, also responsibilities were taken care of (cf. Rochlin, 1999, p. 1554). The personnel could feel certain that the big picture would be taken into account when everybody did their part accordingly.

The above-mentioned features of the culture make any change initiatives in a complex organization such as the given maintenance unit demanding; they either have to be justified from a perspective that fits into the prevalent cultural conception of the work or the conception of the work has to be changed (cf. Weeks, 2004, p. 104, 121). Financial goals that came with the privatization did not fit into the cultural picture and were thus neglected by the personnel. The *resistance to change* in the organization was actually at the same time *commitment to maintaining safety* and commitment to the practices that in their opinion were needed to guarantee safety.

The NPP's activities were reorganized after the data collection. The reorganization was not known by the personnel or by the researchers at the time of the data collection. In the reorganization, the instrumentation and control and electrical maintenance functions were merged into a single section. Many of the technical specialists were transferred to the technical department in order to give them resources to focus on the plant life time management issues (aka to specialize further). Furthermore, many of the issues in Table 3 that were connected to the maintenance strategies and the utilization of computer systems have subsequently been taken into consideration. The influence of these changes to the cultural conceptions is beyond the scope of this article and will be considered in a separate study.

4. Discussion

The aim of the case study was to assess the organizational culture of a NPP maintenance unit. On the basis of the results, three issues are discussed. Firstly, we will discuss the nature of the maintenance work as knowledge-intensive and complex industrial activity, the significance of which has previously been little acknowledged in safety science. Secondly, we will discuss the importance of considering the demands of the task of the organization as criteria in the assessment. Thirdly, we will argue that tensions, discrepancies and emergent conceptions in the organization are important elements of the organizational culture. Finally, we will discuss the validity of the results and further research needs.

4.1. The maintenance work

Maintenance has often been considered as mostly manual labour, which requires little or no mental work. This reflects also to maintenance being quite often at the bottom of the hierarchy (in comparison to e.g. technical support and operations) in terms of respect, influence and authority at the NPPs (Perin, 2005, p. 75; Mercier, 1988, p. 14). Mercier (1988, p. 14) argues that NPP maintenance work suffers from a "dirty hands" image. Perin (2005, p. 262) states that "given the significance of maintenance activities to risk reduction in all high hazard industries, in this 21st century a "dirty hands" image marks a cultural lag of "gigantic" proportions." The nature and significance of maintenance work should be better acknowledged by the maintenance workers themselves and by other parties (e.g. operations and technical groups). This study did not find evidence of an image problem at the case plant even though the manual labour requirement of maintenance was emphasized.

The demands of the maintenance task as abstracted in this case study and in Oedewald and Reiman (2003) resemble the demands of knowledge-intensive work, where knowledge acquisition, interpretation and sharing are central for maintaining a good situation awareness (see e.g. Endsley, 1995). Maintenance work is a synthesis of manual labour and knowledge intensive work (cf. Barley, 1996; Orr, 1996); it is about *maintaining* the complex technology by anticipating, monitoring, reflecting and reacting to it. In the case organization, the handicraft nature of maintenance work was emphasized. Still, some workers clearly saw the work as requiring more than manual labor, but they had trouble conceptualizing the nature of this knowledge (cf. citation 5).

The maintenance work produced a feeling of meaningfulness especially when there were technical problems to solve (cf. Reiman et al., 2005; Orr, 1996, pp. 95–97). The motivating aspect of the problems and fault situations is a paradox in the sense that one of the goals of maintenance is to avoid problems and keep the technology running reliably. This conception of maintenance work is not optimal in terms of fulfilling the maintenance task, where preventive maintenance, condition monitoring and analysis of the maintenance history of the equipment are important for keeping the production safe and reliable on the long run.

On the other hand, the results clearly imply that the opportunity to work with the machines motivates the maintenance workers. Cooke (2002, p. 983), who conducted an in-depth case study of maintenance workers in five manufacturing firms, noted that "most maintenance workers … expressed the view that their biggest source of job satisfaction was keeping the plant running and doing the best for the machine." The challenge is in finding the appropriate means for doing this in a manner where the significance of maintenance to operational reliability is clearly seen by all the parties.

The case study showed the strong influence of physical artifacts and tools on the cultural features of the organization. For example, the work permit procedure and the PLIS system embedded many of the central assumptions depicted in Fig. 2. Also, responsibility was largely embedded in the procedures and routines of the daily activity. This was one of the main reasons why the personnel felt they were only a small cog in a big machine. They had little actual personal responsibility although they had a high sense of responsibility. The prescriptions guiding the personnel's conduct (see Schlenker et al., 1994) were perceived to be so strong that the individual choice, which is needed for personal responsibility to be felt, was not perceived to be present (see also Hackman and Oldham, 1980, p. 75; Hirschhorn, 1993). On the other hand, the impossibility of proceduralizing all the aspects of the maintenance work and the inadequacy of the procedures to cope with the realities and surprises of daily work were acknowledged by many in the maintenance unit (cf. Bourrier, 1996, p. 106; Dekker, 2003; Dien, 1998).

4.2. Defining the criteria in the organizational assessment

The premise of the case study was that the features of the organizational culture should be assessed against the demands of the task the organization is carrying out. We approached this by modeling the demands of the maintenance work and by assessing how the features of the organizational culture supported the fulfilment of these demands. In safety critical domains, values that emphasize safety have traditionally been considered as taken-for-granted criteria for the assessment, an ideal model. Reflections of the ideal model -thinking can be seen in the emphasis on formal safety training and general safety attitudes (e.g. "always put safety first") as a means of fostering a "safety culture" (IAEA, 1991). For an overview of the safety culture field see e.g. Cox and Flin (1998), Guldenmund (2000), Sorensen (2002). As shown in our study, the meaning of "safety" is socially constructed, interpreted and embedded in the daily practices of the organization (see also Rochlin, 1999; Pidgeon, 1998). For example, specialization was considered safer than wider responsibility areas and general knowledge. They were thus "putting safety first" by resisting changes that endangered their ability to e.g. specialize. Specialization has pros and cons in terms of safety and effectiveness. Weick (1988, p. 311) writes that specialists "can do a few things well, which means that they search the world to see if it needs what they can do. If it doesn't, they do nothing else because they see nothing else". The modeling of the demands of the work aims at showing the larger picture (cf. Vicente, 1999; Norros and Nuutinen, 2002).

We have used a term *organizational core task* (OCT, see Reiman and Oedewald, 2006a,b; Reiman and Oedewald, submitted for publication) to denote the central demands of the work that the particular organization is carrying out (cf. Table 3). The fulfilment of the organizational core task should thus be the motive of all activity in the organization. The concept of OCT can offer a means for assessing the unique cultural features of an organization. The organizational core task sets demands (constraints and requirements) for the activity in the organization. The way of perceiving the demands shapes the culture of the organization and influences the practices, tools and conceptions in the organizational culture (cf. Fig. 1).

The organizational practices and cultural conceptions are evaluated against what the organization is trying to accomplish and what demands it has to fulfill in order to be effective. The aim of conceptualizing the OCT is to explicate the demands that the organization has to manage in its everyday activities. The demands can be fulfilled organizationally in many different ways. The organizing of the activity and the activity itself are assessed only on the basis of the requirements that they have to fulfill and the constraints that they have to take into account.

The focus of organizational assessment as we define it is thus on the OCT-related conceptions in the given organization. As shown in the case study, the conceptions are also embedded in the practices and tools of the organization. The current practices can maintain a false conception of the OCT if they work well enough in the normal daily work. Still some critical aspect of the OCT can be ignored because it does not manifests itself daily (e.g. bypassing radiation check at a NPP in a room where there has never been radiation), or its effects are long-term and difficult to perceive (e.g. monitoring the effect of corrosion on equipment), or it becomes relevant only in the case of exceptional conditions (e.g. the loss of the external grid at a NPP). Weick (1998, p. 74), drawing on the seminal work of Turner (1978), argues that "organizations are defined by what they ignore – ignorance that is embodied in assumptions – and by the extent to which people in them neglect the same kinds of considerations." In the case study the cultural assessment made the conceptions taken for granted explicit in the organization and thus facilitated their reflection and change.

4.3. Theoretical issues concerning organizational culture in safety-critical organizations

The view on culture used in this study was originally based closely on the integration and differentiation perspectives (Martin, 2002). The integration approach emphasizes the unity and consistency of cultural assumptions and the lack of ambiguity, whereas within the differentiation perspective consensus occurs within the boundaries of subcultures that might conflict with each other (Martin, 2002). The results showed various tensions and discrepancies in the attitudes and conceptions of the personnel in addition to the shared and emergent conceptions (cf. Fig. 2 and Table 3). These features were also important to take into account when considering the ability of the organization to fulfill the demands of the maintenance task. Thus if the aim of the research is to assess the organization, the concept of organizational culture should include the dysfunctional features and discrepancies, as well as the attempts to solve or cover these (Oedewald and Reiman, 2003, p. 292). Alvesson (2002, p. 164) points out that "the challenge [in cultural research] is to consider the frequently *simultaneous* existence of (a) relative clarity and common orientations associated with a degree of shared meanings across the organization, (b) diversity, conflict and multitude of overlapping group identifications, and (c) ambiguity and fragmentation on different levels" (see also Martin, 2002; Richter and Koch, 2004). In the case study, a difference was found between *shared collective conceptions* (shared by most or all the members of the organization) and *emergent collective conceptions* (existing in the collective culture but shared and accepted by only few or none of its members).

Managers of industrial organizations should pay more attention to the conceptions concerning the work that they and their employees have. They should also be attentive to discrepancies in these conceptions and aim at guaranteeing up-to-date conceptions of the task and the appropriate means to fulfill it in their organizations. For an effective (safety) management it is imperative to acknowledge the nature of organizational culture. In order to maintain internal cohesion, "culture" forms routines, preconceptions and rules of thumb, and hence it inherently resists outside change. Furthermore, inputs from the outside are interpreted within the existing cultural framework of thinking. Organizational culture acts as much a blindfold as an asset if not reflected upon actively. (Alvesson, 2002, p. 119; Kunda, 1992; Trice and Beyer, 1993; Weeks, 2004) Weick has also emphasized that "strong cultures can compromise safety if they provide strong social order that encourages the compounding of small failures" (Weick, 1998, p. 75). Thus the homogeneity of the culture (widely shared conceptions) is not always a good thing in terms of fulfilling the organizational core task (Reiman and Oedewald, submitted for publication).

The culture of an organization becomes especially evident in change situations, since culture influences how change is perceived and how the personnel respond to it. Sometimes change initiatives fail since no need for change in the organization is perceived by the personnel. In this case, we argue that the cultural conceptions of the organizational core task are not up to date, and they must first be challenged or changed if the working practices are to be changed.

The study also showed how the organizational structures, practices and tools embed the cultural conceptions (Table 3). These embedded conceptions are seldom reflected. Tools may thus maintain false or outdated conceptions of the task. More attention should be paid to the underlying conceptions that the various tools and technical solutions hold. For example, conceptions concerning responsibility were embedded in the work order procedure and the rules of conduct which emphasized collective responsibility over one's own work.

Managers are as much part of the culture as the workers are. Their ability to become aware of and question the cultural assumptions is thus limited. Actually, some characteristics of the culture may better be perceived at "lower" levels of the organization, were e.g., the financial pressures and outside influences do not "distort" the picture as much. Especially in the current (perceived) increase in economic pressures it is imperative for managers to better grasp the realities and constraints of the work at the shop-floor level. The concepts of organizational culture and OCT can be of help in this.

4.4. Validity, limitations and future research

We aimed at identifying the strengths and weaknesses of the culture in the case organization in relation to the demands of the maintenance task. The focus of the assessment was not on explaining causal relations to objective measures (e.g. occupational accidents or number of equipment failures). Instead, we strove to anticipate the consequences of the current practices and conceptions in the organization to their ability and willingness to fulfill the maintenance task. The results of the assessment were presented at the final seminar with about 100 participants from all the levels and tasks of the maintenance unit. The results were also used as a starting point in further development work in the organization.

At the final seminar the participants were asked to fill a feedback questionnaire on the study. Of the 100 participants, 67 filled out the questionnaire. In can be concluded from Table 4 that the personnel considered the case results as quite pertinent to their organiza-

Table 4
The views of the personnel about the results at the final seminar ($N = 67$)

Question	Yes	No	Do not know/empty
Were the results accurate?	95.5% (64)	4.5% (3)	–
Were the results interesting?	92.5% (62)	6% (4)	1.5% (1)
Were the results useful?	79% (53)	10.5% (7)	10.5% (7)

tion. There was some doubt, however, whether the results would actually lead to any changes in the culture (the usefulness of the results in Table 4). Of course, the table does not tell what the personnel thought would be "useful".

Table 4 indicates a good validity of the results in terms of credibility and plausibility (cf. Silverman, 1993). The model of the demands of the maintenance work was presented to the participants in the work shops and they were asked to attribute their daily tasks to different requirements (e.g. reflecting). The overall feeling at the workshops was that this kind of an exercise should be done to all the maintenance tasks, in order to e.g. get rid of the unnecessary tasks, or to make their contribution clearer. Thus the model also acted as a neutral tool for starting a dialogue on the content of the maintenance work at the plant. The model could be characterized as a "mirror" against which the personnel reflected on their tasks and their culture.

Due to practical reasons (mainly access to the NPP and their schedule) the data collection methods and their execution (e.g. the number of interviews) had to be planned well in advance. Thus the emerging themes and questions (cf. Charmaz, 1995, p. 31) could only be addressed within the constraints of the data collection plan, and the nature and extent of the data already collected. Group working and the development groups formed later acted as an important place for testing of the emerging themes and raising questions for discussion. Still, not all the principles of iterative data collection could be satisfied in this case study. Also the predictive validity of the extracted criteria (Table 3) of the maintenance work could not be tested in the case study. Further, the clarification of some emerging themes such as the significance of the problems of co-operation between the operations, maintenance and technical departments would have necessitated data collection in the other departments as well. This was, however, beyond the scope of this study.

The methodology that was used and developed in the case study was quite time-consuming. If an organization is committed to a development project that takes some months to complete and produces results gradually, the methodology piloted in this case study proved fruitful. A future challenge is to be able to carry out all the phases of the assessment more quickly without losing the depth of the analysis. Further research should aim to test and validate the criteria used to assess the maintenance work, and also validate the general results concerning the nature and unique challenges of maintenance work in safety critical organizations.

Appendix A. The interview questions utilized in the case study

One's own work

1. Tell us about your work. What is the central content of your work? What are your daily tasks and responsibilities?
2. What are the most demanding or difficult things in your work?

  - How do the difficulties manifest themselves?
  - Are there uncertainties in your tasks?
  - How do you cope with difficulties/uncertainties?
3. What motivates you in your job?
  - What is interesting in your job? What is dull?
4. What things do you have to know in order to get by in here?
5. How can you tell that somebody is an expert in your work?
6. How does one achieve expertise?
7. Tell us some event from your work that has been significant in some way (You have learned something, realized something etc.)
8. Has your job changed? In what way?
  - Have the tools you are utilizing changed? What computer systems do you utilize in your work?
9. How do you know you have done your job well? (What does 'good quality' mean in your work?)
  - How can you ensure it?
10. Is it easy to perceive why things are done in here the way they are?
11. What is the role of rules and instructions in your work?

The maintenance task
Instruction: think about the maintenance of a nuclear power plant in general

12. What is the goal of maintenance?
13. What is critical in achieving it?
  - What uncertainties are connected to its achievement? (On what things is it dependent?)
  - *How do you know how well the maintenance is functioning* (*department heads*)?
14. How are you personally able to influence that maintenance fulfils its goals?

The organization/organizing of work
Instruction: think about your own power plant

15. Is the organizing of the maintenance activities currently optimal?
  - If there are problems, how do they manifest themselves in practice?
16. What are the interfaces between the different sections of maintenance like? (clear/diffuse, stable/changing)
  - co-operation, communication, information flow?
  - appreciation or attitudes towards your section, your attitudes towards other sections.
17. Could some other way of organizing the maintenance activities be better than the current way?
  - How would the other way look like?
18. Tell us an example of some task. How do you receive it, what do you do, and how do you document it? Who receives information about the task? Do you receive feedback after you have finished?
  - What functions well? What are the typical problems?

19. What changes have taken place in the working environment of the [plant]?
    - Deregulation, outsourcing, the political climate towards nuclear power?

The organizational culture

20. How would you describe the organizational culture of [the maintenance unit]?
    - Are there subcultures? (different branches, age, occupational groups)?
    - In every organization there are plenty of stories or legends, e.g. about some heroic deeds, bad mistakes, the "good old times" or something that are e.g. told to newcomers. Do you remember one that is told here?
21. Final question, what are currently the most important targets for development in the maintenance activities at [the plant]?
    - Do you have something in mind that you would like to add or ask us?

References

Alvesson, M., 2002. Understanding Organizational Culture. Sage, London.

Alvesson, M., Berg, P.O., 1992. Corporate Culture and Organizational Symbolism. Walter De Gruyter, Berlin.

Barley, S.R., 1996. Technicians in the workplace: ethnographic evidence for bringing work into organization studies. Administrative Science Quarterly 41, 404–441.

Bourrier, M., 1996. Organizing maintenance work at two American nuclear power plants. Journal of Contingencies and Crisis Management 4, 104–112.

Bourrier, M., 1999. Constructing organisational reliability: the problem of embeddedness and duality. In: Misumi, J., Wilpert, B., Miller, R. (Eds.), Nuclear Safety: A Human Factors Perspective Taylor & Francis, London, pp. 25–48.

Cameron, K.S., Quinn, R.E., 1999. Diagnosing and Changing Organisational Culture: Based on the Competing Values Framework. Addison-Wesley, Massachusetts.

Charmaz, K., 1995. Grounded theory. In: Smith, J.A., Harré, R., Langenhove, L.V. (Eds.), Rethinking Methods in Psychology Sage, London, pp. 27–49.

Cooke, F.L., 2002. The important role of the maintenance workforce in technological change: a much neglected aspect. Human Relations 55, 963–988.

Cox, S., Flin, R., 1998. Safety culture: philosophers stone or man of straw? Work & Stress 12, 189–201.

Dekker, S., 2003. Failure to adapt or adaptations that fail: contrasting models on procedures and safety. Applied Ergonomics 34, 233–238.

Dien, Y., 1998. Safety and application of procedures, or 'how do 'they' have to use operating procedures in nuclear power plants?' Safety Science 29, 179–187.

Doniol-Shaw, G., 1997. Industrial maintenance, organizational design and workers' health. The example of nuclear power plants. In: IEA 1997, FROM Experience to Innovation. Of the 13th Triennial Congress of the International ergonomics association. Tampere, Finland.

Endsley, M.R., 1995. Toward a theory of situation awareness in dynamic systems. Human Factors 37, 32–64.

Enkvist, J., 2003. A human factors perspective on non-destructive testing (NDT). Detection and identification of cracks. Doctoral dissertation. Department of Psychology. Stockholm University.

Enkvist, J., Edland, A., Svenson, O., 1999. Human factors aspects of non-destructive testing in the nuclear power context. A review of research in the field. SKI Report 99:8.

Gauthereau, V., 2003. Work practice, safety and heedfulness: studies of organisational reliability in hospitals and nuclear power plants. Linköping Studies in Science and Technology Dissertation #842, Linköping, Sweden.

Geertz, C., 1973. Thick description: toward an interpretative theory of culture. In: Geertz, C. (Ed.), The Interpretation of Cultures Basic Books, New York, pp. 3–30.

Gherardi, S., Nicolini, D., 2002. Learning the trade: a culture of safety in practice. Organization 9, 191–223.

Guldenmund, F.W., 2000. The nature of safety culture: a review of theory and research. Safety Science 34, 215–257.

Hackman, J.R., Lawler, E.E., 1971. Employee reactions to job characteristics. Journal of Applied Psychology Monograph 55, 259–286.

Hackman, J.R., Oldham, G.R., 1980. Work Redesign. Addison-Wesley, Reading, Mass.

Hale, A.R., Heming, B.H.J., Smit, K., Rodenburg, F.G.Th., van Leeuwen, N.D., 1998. Evaluating safety in the management of maintenance activities in the chemical process industry. Safety Science 28, 21–44.

Hammersley, M., 1996. The relationship between qualitative and quantitative research: paradigm loyalty versus methodological eclecticism. In: Richardson, J.T.E. (Ed.), Handbook of Qualitative Research Methods for Psychology and the Social Sciences The British Psychological Society, Leicester, pp. 159–174.

Hirschhorn, L., 1993. Hierarchy versus bureaucracy: the case of a nuclear reactor. In: Roberts, K.H. (Ed.), New Challenges to Understanding Organizations. Macmillan, New York.

Hutchins, E., 1995. Cognition in the Wild. MIT Press, Massachusetts.

IAEA, Safety Series No. 75-INSAG-4. 1991. Safety Culture. International Atomic Energy Agency, Vienna.

Isobe, K., Shibuya, S., Tabata, N., 1999. Human factors in nuclear power plant maintenance – an empirical study. In: Misumi, J., Wilpert, B., Miller, R. (Eds.), Nuclear Safety: A Human Factors Perspective Taylor & Francis, London, pp. 331–340.

Jacobsson, L., Svenson, O., 1991. Psychosocial work strain of maintenance personnel during annual outage and normal operation in a nuclear power plant. In: Proceedings of the Human Factors Society 35th Annual Meeting.

Kecklund, L., 1998. Studies of safety and critical work situations in nuclear power plants: a human factors perspective. Doctoral dissertation. Department of Psychology. Stockholm University, Edsbruk, Akademitryck AB.

Klein, R.L., Bigley, G.A., Roberts, K.H., 1995. Organizational culture in high reliability organizations: an extension. Human Relations 48, 771–793.

Kunda, G., 1992. Engineering Culture: Control and Commitment in a High-Tech Corporation. Temple University Press, Philadelphia.

Laakso, K., Pyy, P., Reiman, L., 1998. Human errors related to maintenance and modifications. STUK-YTO-TR 139. Edita, Helsinki.

Martin, J., 2002. Organizational Culture Mapping the Terrain Sage, Thousand Oaks.

Mercier, J.-P., 1988. Nuclear Power Plant Maintenance second ed. English Adaptation of "La maintenance des centralés nucleaires" Published for Electricité de France 1987 Editions Kirk, Paris.

Norros, L., 2004. Acting under uncertainty. The Core-Task Analysis in Ecological Study of Work. VTT Publications 546. Technical Research Centre of Finland, Espoo.

Norros, L., Klemola, U.-M., 1999. Methodological considerations in analysing anaesthetists' habits of action in clinical situations. Ergonomics 42, 1521–1530.

Norros, L., Nuutinen, M., 2002. The concept of the core-task and the analysis of working practices. In: Borham, N., Samurcay, R., Fischer, M. (Eds.), Work Process Knowledge Routledge, London, pp. 25–39.

NRC. 1986. Human Reliability Impact on Inservice Inspection. NUREG/CR 4436. U.S. Nuclear Regulatory Commission.

Oedewald, P., Reiman, T., 2003. Core task modelling in cultural assessment – a case study in nuclear power plant maintenance. Cognition, Technology & Work 5, 283–293.

Orr, J.E., 1996. Talking About Machines: An Ethnography of a Modern Job. ILR Press, Ithaca, NY.

Paté-Cornell, M.E., 1993. Learning from the Piper Alpha accident: a post mortem analysis of technical and organizational factors. Risk Analysis 13, 215–232.

Perin, C., 2005. Shouldering Risks. The Culture of Control in the Nuclear Power Industry. Princeton University Press, New Jersey.

Pidgeon, N., 1998. Risk assessment, risk values and the social science programme: why we do need risk perception research. Reliability Engineering and System Safety 59, 5–15.

Pyy, P., 2001. An analysis of maintenance failures at a nuclear power plant. Reliability Engineering and System Safety 72, 293–302.

Rasmussen, J., 1997. Risk management in a dynamic society: a modelling problem. Safety Science 27, 183–213.

Reason, J., 1990. Human Error. Cambridge University Press, Cambridge.

Reason, J., 1997. Managing the Risks of Organizational Accidents. Ashgate, Aldershot.

Reason, J., Hobbs, A., 2003. Managing Maintenance Error. A Practical Guide. Ashgate, Hampshire.

Reiman, T., Norros, L., 2002. Regulatory culture: balancing the different demands of regulatory practice in the nuclear industry. In: Kirwan, B., Hale, A.R., Hopkins, A. (Eds.), Changing Regulation – Controlling Risks in Society Pergamon, Oxford, pp. 175–192.

Reiman, T., Oedewald, P., 2004. Measuring maintenance culture and maintenance core task with CULTURE-questionnaire – a case study in the power industry. Safety Science 42, 859–889.
Reiman, T., Oedewald, P., 2006a. Organizational culture and social construction of safety in industrial organizations. In: Svenson, O., Salo, I., Skjerve, A.B., Reiman, T., Oedewald, P. (Eds.), Nordic Perspectives on Safety Management in High Reliability Organizations: Theory and Applications Stockholm University Press, Stockholm, pp. 115–129.
Reiman, T., Oedewald, P., 2006b. Contextual assessment of organizational culture in complex sociotechnical systems. In: Proceedings of the Ninth International Symposium of the ISSA Research Section, 1–3 March 2006, Nice, France.
Reiman, T., Oedewald, P., submitted for publication. Assessment of complex sociotechnical systems – theoretical issues concerning the use of organizational culture and organizational core task concepts.
Reiman, T., Oedewald, P., Rollenhagen, C., 2005. Characteristics of organizational culture at the maintenance units of two Nordic nuclear power plants. Reliability Engineering and System Safety 89, 333–347.
Richter, A., Koch, C., 2004. Integration, differentiation and ambiguity in safety cultures. Safety Science 42, 703–722.
Rochlin, G.I., 1999. Safe operation as a social construct. Ergonomics 42, 1549–1560.
Sackmann, S.A., 1991. Uncovering culture in organizations. Journal of Applied Behavioral Science 27, 295–317.
Sandberg, J., 2000. Understanding human competence at work: an interpretative approach. Academy of Management Journal 43, 9–25.
Schein, E.H., 1985. Organizational Culture and Leadership. Jossey-Bass, San Francisco.
Schlenker, B.R., Britt, T.W., Pennington, J., Murphy, R., Doherty, K., 1994. The triangle model of responsibility. Psychological Review 101, 632–652.
Schulman, P.R., 1993. The negotiated order of organizational reliability. Administration & Society 25, 353–372.
Schulman, P.R., 1996. Heroes, organizations and high reliability. Journal of Contingencies and Crisis Management 4, 72–82.
Schultz, M., 1995. On Studying Organizational Cultures. Diagnosis and Understanding. Walter de Gruyter, Berlin.
Schultz, M., Hatch, M.J., 1996. Living with multiple paradigms: the case of paradigm interplay in organizational culture studies. Academy of Management Review 21, 529–557.
Silverman, D., 1993. Interpreting Qualitative Data. Methods for Analysing Talk, Text and Interaction Sage, London.
Smircich, L., 1983. Concepts of culture and organizational analysis. Administrative Science Quarterly 28, 339–358.
Smith, J.A., 1995. Semi-structured interviewing and qualitative analysis. In: Smith, J.A., Harré, R., Langenhove, L.V. (Eds.), Rethinking Methods in Psychology Sage, London, pp. 9–26.
Sorensen, J.N., 2002. Safety culture: a survey of the state-of-the-art. Reliability Engineering and System Safety 76, 189–204.
Strauss, A., Corbin, J., 1998. Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory, second ed. Sage, Thousand Oaks.
Svenson, O., Salo, I., 2001. Latency and mode of error detection in a process industry. Reliability Engineering and System Safety 73, 83–90.
Tabachnick, B.G., Fidell, L.S., 2001. Using Multivariate Statistics, fourth ed. Allyn & Bacon, Boston.
Toriizuka, T., 2001. Application of performance shaping factor (PSF) for work improvement in industrial plant maintenance tasks. International Journal of Industrial Ergonomics 28, 225–236.
Trice, H.M., Beyer, J.M., 1993. The Cultures of Work Organizations. Prentice-Hall, Englewood Cliffs, NJ.
Turner, B., 1978. Man-Made Disasters. Wykenham, London.
Turner, B.A., Pidgeon, N.F., 1997. Man-Made Disasters, second ed. Butterworth-Heinemann, Oxford.
Vaughan, D., 1996. The Challenger Launch Decision. University of Chicago Press, Chicago.
Vicente, K., 1999. Cognitive Work Analysis. Toward Safe, Productive, and Healthy Computer-Based Work. Lawrence Erlbaum, London.
Weeks, J., 2004. Unpopular Culture The Ritual of Complaint in a British Bank University of Chicago Press, Chicago.
Weick, K.E., 1988. Enacted sensemaking in crisis situations. Journal of Management Studies 25, 305–317.
Weick, K.E., 1995. Sensemaking in Organizations. Sage, Thousand Oaks.

Weick, K.E., 1998. Foresights of failure: an appreciation of Barry Turner. Journal of Contingencies and Crisis Management 6, 72–75.
Wright, C., 1994. A fallible safety system: institutionalised irrationality in the offshore oil and gas industry. The Sociological Review 38, 79–103.
Yin, R.K., 1994. Case Study Research. Design and Methods, second ed. Sage, Thousand Oaks.

ARTICLE V

Assessment of complex sociotechnical systems – Theoretical issues concerning the use of organizational culture and organizational core task concepts

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Assessment of complex sociotechnical systems – Theoretical issues concerning the use of organizational culture and organizational core task concepts

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Abstract

This article studies organizational assessment in complex sociotechnical systems. There is a practical need to monitor, anticipate and manage the safety and effectiveness of these systems. A failure to do so has resulted in various organizational accidents. Many theories of accidents and safety in industrial organizations are either based on a static and rational model of an organization or they are non-contextual. They are thus reactive in their search for errors and analysis of previous accidents and incidents, or they are disconnected from the actual work in the organization by their focus on general safety attitudes and values. A more proactive and predictive approach is needed, that is based on an accurate view on an organization and the demands of the work in question. This article presents and elaborates four statements: (1) the current models of safety management are largely based on either a rational or a non-contextual image of an organization, (2) complex sociotechnical systems are socially constructed and dynamic cultures, (3) in order to be able to assess complex sociotechnical systems an understanding of the organizational core task is required, and (4) effectiveness and safety depend on the cultural conceptions of the organizational core task. Finally, we will discuss the implications of the proposed concepts for safety research and development work in complex sociotechnical systems.

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Keywords: Organizational culture; Organizational core task; Task analysis; Assessment; Work psychology; Safety culture

1. Introduction

Assuring the safety and effectiveness of a complex industrial organization is demanding. Most safety management systems and theories of safety critical organizations emphasize the regular self-assessment and auditing of the activities. Rasmussen (1997, p. 183) notes that in spite of all the efforts to design safer systems, severe, large scale accidents still happen. He questions whether safety research has adequate models of accident causation (see also Pidgeon and O'Leary, 2000; Dekker, 2005). We argue that many theories of accidents and safety in industrial organizations are based on a static and rational model of an organization or they are non-contextual. They are thus reactive in their search for individual human errors and analysis of previous accidents and incidents, or they are disconnected from the actual work in the organization by their focus on general safety attitudes and values. At the same time, organization research has begun to increasingly emphasize the dynamic and interpretative aspects of organizations. Safety management approaches based on this interpretative view of the organization are still rare. We can thus raise the question of whether safety research has adequate models of complex industrial organizations. This article illustrates two concepts that can be used in understanding and assessing complex industrial organizations, namely the concepts of organizational core task and organizational culture. The aim of this article is to study organizational assessment and more specifically, the significance of organizational culture in assessing the safety and effectiveness of modern industrial organizations.

Industrial organizations of modern society are complex and dynamic sociotechnical systems (Rasmussen, 1997; Leveson, 2004; cf. Perrow, 1984). This is due to the following reasons. In addition to multiple goals (efficiency, safety, credibility, and employee wellbeing), multiple interacting parties (different technical disciplines, various tasks, outside contractors) and complex social structures, they encompass uncertainties in the tightly-coupled and complex technology and the environment (market pressures, political decisions, [de]regulation). The work itself is usually highly specialized, mediated via various tools and information systems, and potentially hazardous (to personnel and/or the environment) (Vicente, 1999, pp. 14–17; see also Perrow, 1984; Rasmussen, 1997; Kirwan, 2001; Orton and Weick, 1990).

Complex sociotechnical systems are uniquely dynamic and constantly changing and adapting. The premises of daily activity and strategic control and steering of these organizations are based on partly implicit norms, values and conceptions. The hierarchy as a control mechanism is undermined by an increasingly horizontal distribution of expertise (Barley, 1996, p. 437). Work in these organizations is becoming increasingly difficult to label as blue collar or white collar, or to dichotomise into mental versus manual labour (cf. Barley, 1996; Oedewald and Reiman, 2003). The complexities of the technology and the physical phenomena on which the work focuses (nuclear reaction, chemistry, etc.) require more and more abstract understanding. Furthermore, the tools themselves have become more complex and abstract (e.g. more computer systems and less hands-on-work, cf. Zuboff, 1988). The work requires specialization into some content areas, but at the same

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time the understanding of the entire system and the expertise of others becomes more difficult.

The difficulties of managing these complex sociotechnical systems have received a lot of attention in connection with various organizational accidents (e.g. the Challenger space shuttle accident, see Vaughan, 1996, Chernobyl nuclear accident or the Piper Alpha offshore platform accident, see Wright, 1994 and Paté-Cornell, 1993). In Turner's (1978) terms these events have been *disasters*. This means that the accidents have brought the previous approaches and assumptions about safety into question. A disaster is something that was not supposed to take place according to the existing framework of thinking, but it happened nevertheless. The event was thus in contradiction to the cultural conceptions about safety and the appropriate means for guaranteeing it (Turner, 1978; Turner and Pidgeon, 1997). These "false" conceptions had been gradually rooted in the culture of the organization as it was carrying on with its daily practices. These conceptions should thus be studied and their contribution to organizational effectiveness and safety should be assessed in advance. This should be done before or during the *incubation period* (Turner, 1978), when the preconditions of the accident are created. We argue that when the complexity of the work, technology and the social environment are increased, the significance of the most implicit features of organizational culture as a means of coordinating the work and achieving the safety and effectiveness of the activities also increases (cf. Perrow, 1986, p. 130; Weick, 1987, 1995, p. 117; Dekker, 2005, p. 37).

The aim of this article is to study organizational assessment in complex sociotechnical systems. Based on the above, we acknowledge the practical need to monitor, anticipate and manage the safety and effectiveness of the sociotechnical systems. This article builds on and elaborates four statements: (1) the current models of safety management are largely based on a rational or a non-contextual image of an organization, (2) complex sociotechnical systems are socially constructed and dynamic cultures, (3) in order to be able to assess complex sociotechnical systems an understanding of the organizational core task is required, and (4) effectiveness and safety depend on the cultural conceptions of the organizational core task. Finally, we will discuss the implications of the proposed concepts for organizational research and development work in complex sociotechnical systems.

2. Theoretical principles for organizational assessment in complex sociotechnical systems

2.1. Statement 1: current models of safety management are based on a rational or a non-contextual image of an organization

In this section we argue that most current models of safety management are based on a rational or a non-contextual image of an organization. They thus originate from a "traditional" mechanistic paradigm of organization science (Waring, 1996, p. 13; Dekker, 2005). This paradigm emphasizes the rationality and instrumentality of organizations. Organizations are considered as mechanistic. They are "set up to accomplish a specific task and to advance quite precise objectives, and they have a formalised structure which determines the distribution of authority and the division of labour" (Brunsson and Olsen, 1993, p. 2). The purpose of the organization is self-evident and explicit for everyone. Organizational routines are considered as well-defined, regular and stable forms of behaviour used to accomplish organizational goals. Procedures are used to define the appropriate behaviour. The role of management in supervising and directing the organizational behaviour is emphasized. This rational–instrumental theory of an organization is based on the assumption that people set explicit goals, make rational choices and act on the basis of objective facts (see also Etzioni, 1964; Williamson, 1975; Weber, 1978; cf. Scott, 2003). The theory can be claimed to be based on a positivist (cf. Hempel, 1965) image of a human conduct.

Another current model of safety management is the open systems model. This moved the focus beyond the mechanistic view to a more process-oriented view of organizations. This was an important addition, but we argue that these theories neglected the important issue of work context and the socially constructed and the sometimes dysfunctional sides of organizational reality. The open systems model of an organization gained prominence in the 50s and 60s, partly due to the Tavistock paradigm (see Rice, 1958; Miller and Rice, 1967), and partly due to the works of e.g. Simon (1957), Parsons (1951) and Selznick (1948). The mechanistic view of an organization was challenged. The organismic analogy and equilibrium as the ideal state of the system were the constituent characteristics of this approach. The system's ability to self-regulate based on the selection and interpretation of environmental inputs was emphasized. The interactions of the system and its environment were considered mostly linear and functionalistic (serving some specific purpose or need) (Burrell and Morgan, 1979; Scott, 2003). One of the most influential open systems models was that of Katz and Kahn (1966). Their work also laid "the most important theoretical foundation for later culture studies" (Schein, 1990, p. 11). Open systems models emphasized process over structure, and abstraction over description of the actual work (Burrell and Morgan, 1979; Barley and Kunda, 2001; Scott, 2003). Barley and Kunda (2001, p. 80) argue that "during the 1960s and 1970s… organization studies gradually drifted away from the study of work. The shift was associated with a number of trends in the discipline's development, including a turn to systems theory and greater levels of abstraction". The open systems model of an organization has been very prominent in safety science also (Rasmussen, 1997; Waring, 1996; Hale and Hovden, 1998).

The concept of *safety culture* has been derived from the open systems theory and its refinements (such as the organizational culture theory). The term was introduced after Chernobyl nuclear meltdown in 1986 (IAEA, 1991; cf. HSE, 1997). It was proposed that the main reasons for the disaster and the potential future accidents did not only include technical faults or individual human errors committed by the frontline workers. The management, organization and attitudes of the personnel were also noted to influence safety for better or for worse. A proper "safety culture" was quickly required by the regulatory authorities first in the nuclear area and gradually also in other safety critical domains in order to prevent accidents of any kind. The role of management in creating and sustaining a safety culture was emphasized. Safety culture studies and development programs have been conducted in e.g. nuclear industry (Lee, 1998; Lee and Harrison, 2000; Harvey et al., 2002), aviation (McDonald et al., 2000), offshore platforms (Mearns et al., 1998, 2003; Cox and Cheyne, 2000), chemical industry (Donald and Canter, 1994), manufacturing (Williamson et al., 1997; Cheyne et al., 1998), healthcare sector (Singer et al., 2003; Pronovost et al., 2003) and the transport sector, including railways (Clarke, 1998, 1999; Farrington-Darby et al., 2005). The sometimes careless and vague use of the term safety culture has resulted in criticism among academic organizational researchers (e.g. Guldenmund, 2000; Pidgeon, 1998; Cox and Flin, 1998; Reiman et al., 2005). According to them the concept of safety culture has become a catch-all concept for psychological and human factors issues in complex sociotechnical systems. The critique expresses a concern that safety culture is not

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seen as a contextual phenomenon, but as some kind of a general ideal model, without adequate consideration of the work itself that is being carried out in the organization in question. Reflections of the ideal model-thinking can be seen in the emphasis on formal safety training and general safety attitudes (e.g. "always put safety first") as a means of fostering a safety culture. This has limitations: "Safety is not a separable form of knowledge. It is not something that is learned as such… it is an aspect of practice" (Gherardi and Nicolini, 2002, p. 216). One could say that safety is as much an aspect of practice as is any element that makes a skilful worker. But what constitutes a skilful worker in different working environments? For this we cannot apply universal criteria, and the same applies to safety. Thus, it can be claimed that the safety culture concept does not describe the organizational reality sufficiently well. This can lead to definitions and measurements that are too abstract and non-contextual. They are thus disconnected from the *daily work* in a particular organization (cf. Barley and Kunda, 2001).

The roots of the safety culture concept lie in the wider concept of *organizational culture*. This concept also has a fairly recent history (see e.g. Schein, 1985, 1990; Meek, 1988; Alvesson, 2002; Denison, 1996) in organizational psychology. Meek (1988) has noted that the culture concept was borrowed from the structural–functional paradigm of the anthropological tradition. This paradigm relies heavily on the organism metaphor for the organization and on the social integration and equilibrium as goals of the system (Parsons, 1951; Durkheim, 1982; Radcliffe-Brown, 1958; cf. Schultz and Hatch, 1996). These characteristics were also found in most early theories of organizational culture (Baker, 1980; Schein, 1985; Barney, 1986). Only shared aspects in the organization where considered as part of the culture. Alvesson (2002, pp. 43–44) argues that these theories of organizational culture have a bias toward the positive functions of culture in addition to being functionalist, normative and instrumentally biased in thinking about organizational culture. Culture is considered a tool for the managers to control the organization. The safety culture concept seems to be derived from this tradition of organizational culture (cf. Cox and Flin, 1998; Richter and Koch, 2004).

The functionalistic view of an organization (and the human being) that is emphasized by both the rational–instrumental and open systems paradigm (cf. Burrell and Morgan, 1979; Hernes and Bakken, 2003, p. 1516), has been widely challenged (cf. Burrell and Morgan, 1979; Sandelands and Drazin, 1989; Scott, 2003). Waring and Glendon (1998, p. 175) criticize safety management systems that are based on a rational image of the organization and argue that they may be only partly effective while creating an illusion that the risks have been fully controlled (see also Waring, 1996, p. 46; Dekker, 2005, p. 2). The theories of organizational culture have also been revised to include more dynamic aspects (Smircich, 1983). These approaches will be tackled in the next section.

2.2. Statement 2: complex sociotechnical systems are socially constructed and dynamic cultures

In this section, we argue that complex sociotechnical systems are socially constructed and dynamic cultures. We draw on evidence from interpretive organizational theories and discuss the nature of organizations in light of these theories.

Theories of the organization have begun to increasingly centre on systems of meaning and the way these are constructed in action (Silverman, 1971; Scott, 1995; Czarniawska-Joerges, 1992; Weick, 1995). The concept of organizational culture has been redefined in

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less functionalistic terms (see Smircich, 1983; Alvesson, 2002; Martin, 2002). In contrast to the functionalistic theories of culture described in the previous section, the more interpretative-oriented theories of organizational culture emphasize the symbolic aspects of culture such as stories and rituals, and are interested in the interpretation of events and creation of meaning in the organization (cf. Geertz, 1973; see also Frost et al., 1985, p. 17; Turner, 1971). Also the power relations and politics prevalent in all organizations but neglected by the functionalistic and open systems theories have gained more attention in the interpretive tradition of organizational culture.

The image of an organization (cf. Morgan, 1997) has also gradually changed. Weick (1979, 1995) has emphasized that instead of speaking of *organization*, we should speak of *organizing*. What we perceive as an organization is the (temporary) outcome of an interactive *sense-making* process (Weick, 1979). Tsoukas (2001) states that an organization is an emerging pattern, and that stability and change as well as rules and improvisation are all necessary features of an organization (see also Tsoukas and Hatch, 2001; Feldman and Rafaeli, 2002). Feldman (2000, p. 613) describes organizational routines as "emergent accomplishments", and thus constantly changing and internally dynamic. Tsoukas and Chia (2002, p. 570) propose that "organization must be understood as an emergent property of change. Change is ontologically prior to organization – it is the condition of possibility for organization". Even heavily proceduralized safety critical organizations adapt and change their practices locally and constantly (cf. Bourrier, 1999; Snook, 2000; Dekker, 2005).

Weick (1995) has described the continual and collective reality-building process constantly taking place in the organization. In this process the meanings of various events are deliberated and a common view is formed based on perpetually incomplete information (Weick, 1995). The organization and its members create and recreate the context in which future behaviour occurs – which again shapes the context further (Weick, 1993a; Giddens, 1984; Hernes and Bakken, 2003). Organizational culture thus both influences and is influenced by the conceptions, meanings, and behaviours of the personnel. Creating meanings is not always a democratic process; power struggles and politics are also involved (Alvesson and Berg, 1992; cf. Gephart, 1984, p. 213; Weeks and Galunic, 2003, p. 1315; Pidgeon and O'Leary, 2000). Some persons have more cultural influence in the organization than others (cf. Weeks and Galunic, 2003, pp. 1336–1337).

Organizational culture, as we conceptualize it, is a "root metaphor" (Smircich, 1983) for the organization. Alvesson (2002, p. 25) points out that in the idea of culture as a root metaphor, "the social world is seen not as objective, tangible, and measurable but as constructed by people and reproduced by the networks of symbols and meanings that people share and make shared action possible". Organizations are thus socially constructed and constantly in process. Organizational reality is an ongoing accomplishment, not a stable outcome (Weick, 1993b).

Schultz (1995, p. 5) argues that the cultural way of studying organizations is to study the meanings and beliefs which members of organizations assign to organizational behaviour and how these assigned meanings influence the ways in which the members behave themselves (cf. Czarniawska-Joerges, 1992). Interpretation and *duality* (Giddens, 1984) of organizational structure including its technology were emphasized in both the theories of the organization and the organizational culture. Orlikowski (1992, p. 406) argues that "technology is physically constructed by actors working in a given social context, and technology is socially constructed by actors through the different meanings they attach to it". She

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also emphasises that “once developed and deployed, technology tends to become reified and institutionalized, losing its connection with the human agents that constructed it or gave it meaning, and it appears to be part of the objective, structural properties of the organization” (Orlikowski, 1992, p. 406).

Social scientists of mostly an anthropological or sociological background have described the nature and dynamics of “culture” and the social construction of the work in case studies (see e.g. Orr, 1996; Rochlin, 1999; Bourrier, 1999; Gherardi and Nicolini, 2002; Hutchins, 1995). Their findings illustrate the social and interactive nature of organizations. They have empirically shown how the central features of work and organization (including safety) are constructed in interaction in the daily work (cf. Geertz, 1973). Similar ideas have been proposed also by e.g. Weick (1987, 1995), Kunda (1992), and Barley (1996). Our approach to organizational culture derives strongly from the work of the above mentioned researchers. From the point of view of an organizational assessment, ethnographies produce interesting insight about the culture of the workplace, but that is not sufficient. The aim of the ethnographic research is not to extract criteria for organizational assessment, or evaluate the cultural features that they depict (cf. Geertz, 1973).

In safety critical fields and in safety science, more interpretative models of the organization were proposed in e.g. accident research (Vaughan, 1996; Snook, 2000; see also Waring and Glendon, 1998) and by researchers such as Weick (1987), Hutchins (1995), Turner and Pidgeon (1997), Rasmussen (1997), and Rochlin (1999). Especially the High Reliability Organization group (La Porte, 1996; Rochlin, 1999) at the University of Berkeley and the work of Weick and Roberts at the University of Michigan (Weick, 1987; Weick and Roberts, 1993) have been influential in focusing attention on the interpretative and cultural aspects of safety and reliability of the organizations. They have extracted many interesting general features and characteristics of high reliability organizations, such as redundancy in both organizational structures and technology, clear and accepted safety goals, hierarchical decision making in normal operations combined with flexibility and decentralized decision making in emergencies, constant preoccupation with the possibility for failure, continuous improvement and learning, reluctance to accept simplifications of reality, sensitivity to daily operations, deference to expertise, and commitment to resilience (La Porte, 1996; Roberts, 1993; Weick and Sutcliffe, 2001; Rochlin, 1999). On the other hand, the advocates of Normal Accidents Theory (NAT, Perrow, 1984; Sagan, 1993) have illustrated the potential dangers of interactive complexity and tight couplings prevalent in e.g. nuclear industry, modern weapons systems, aviation and chemical industry. More than the actual content of work these theories have concentrated on studying the process of organizing the work (Rochlin, 1999; Schulman, 1993), the structural features of these organizations (Perrow, 1984; Sagan, 1993; La Porte, 1996; Roberts, 1993), and the psychological requisites of the personnel working in HROs (Weick and Sutcliffe, 2001; Weick and Roberts, 1993). The approach described in this paper strives to be more contextual and evaluative than HRO and NAT research. Our aim is not to seek generalizations and common characteristics of high reliability organizations but to assess an individual organization against relevant criteria and give recommendations for appropriate measures. This is due to the fact that when working with safety critical organizations we acknowledge in addition to the advancement of scientific theory the need of research to contribute to the practical development of safety at the particular organization. These ideas will be elaborated in the next two sections.

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2.3. Statement 3: in order to be able to assess complex sociotechnical systems an understanding of the organizational core task is required

Thirdly, we will argue that in order to be able to assess complex sociotechnical systems an understanding of the organizational core task is required. The features of the organizational culture can be functional, dysfunctional or irrelevant in terms of fulfilling the task requirements (safety, efficiency, employee wellbeing). These features should be assessed against relevant criteria; what the organization is trying to accomplish, and what constraints and requirements this sets for the organizational culture. We will introduce a concept of organizational core task which we will argue should be used as a basis for organizational assessment in complex sociotechnical systems. In order to make the theories of accidents and safety more contextual, understanding of the normal daily work, its objectives and its socially constructed nature are needed.

Norros and Nuutinen (2002) (see also Reiman and Norros, 2002; Norros, 2004; Norros and Nuutinen, 2005; Nuutinen, 2005) have introduced a concept termed "core task" for modelling the "outcome-critical content" of process control work in various complex, dynamic and technologically mediated environments (such as air traffic control and nuclear power plant control room). They have assessed working practices and personal work orientations in relation to the core task demands. We will illustrate the collective motive of the work in the organization by extending and redefining the concept of core task to the organizational level.

We propose the term *organizational core task* (OCT), which refers to the shared objective or purpose of organizational activity. Activity means action in a social context with a shared objective. This shared objective is called the collective motive of the activity (Engeström, 1999; Leontiev, 1975). According to psychologist Alexei Leontiev (1975), a proponent of the cultural–historical theory of activity, the constituent characteristic of the activity is its orientation to its object. He states that the concept of activity implicitly includes a conception of its motive. He further distinguishes between activity (which has a motive), action (which has a goal) and operations (which are carried out under certain conditions) (Leontiev, 1975). The differentiation between activity and action is of special importance in understanding work in complex sociotechnical systems. Action has a specific goal (such as repairing a leaking valve), but the repairing of the valve is also governed by a wider motive of maintaining the production of a power plant, thus making it a part of the maintenance activity. OCT thus refers to the collective motive of activity in the organization.

The OCT-concept strives to avoid a purely cognitivistic or error-focused approach in assessing the individuals' action in complex work settings (cf. Hutchins, 1995; Norros and Nuutinen, 2002; Norros, 2004). The focus is not on the specific tasks, single acts or individual cognitive processes but on the boundaries and requirements of the activity in the entire sociotechnical system. The OCT frames the motive of the activity and the shared constraints and requirements that all the workers have to take into account in all their tasks (actions). OCT is neither an aggregate of all the tasks the organization has to perform nor a single key-task performed by some critical members of the organization. The OCT is influenced by three interrelated components (see Fig. 1):

(1) the physical object of the work and its characteristics (such as a certain type of power plant),

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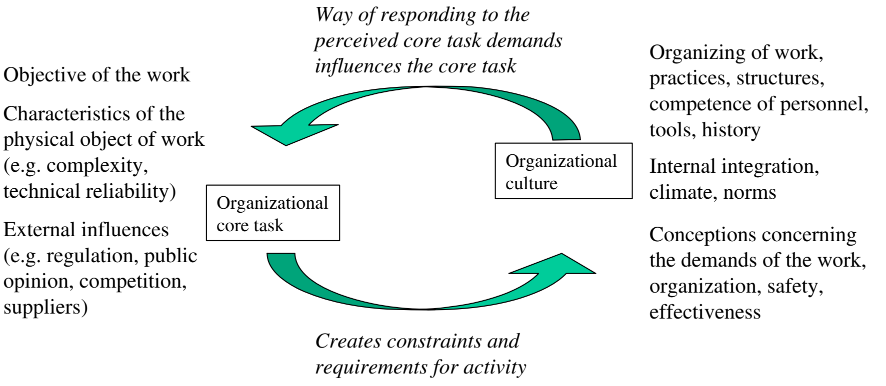

Fig. 1. The central concepts and their interrelations.

(2) objective of the work (e.g. to produce electricity safely and efficiently at a competitive price), and
(3) the society and the environment (e.g. regulation, political climate).

The physical object of the work activity (e.g. particular power plant, manufacturing plant, offshore platform), the objective of the work and the society and environment (e.g. deregulated electricity market, harsh winter weather) set constraints and requirements for the fulfilment of the organizational core task (e.g. producing electricity safely and efficiently by light boiling water nuclear reactor to the electricity market at a competitive price). These constraints and requirements influence the formation and development of organizational culture (Fig. 1).

Organizational culture includes three interrelated elements of *structure* (organizing of work, tools, etc.), *internal integration* (climate, norms), and *conceptions* (cf. Sandberg, 2000) concerning the work and the organizational core task (Fig. 1). As illustrated in Fig. 1, the OCT sets demands (constraints and requirements) for the activity in the organization. Activity in turn is an aspect of the organizational culture resulting from the interaction of the cultural features (see also Fig. 2). For example, how the demands of the work are perceived shapes the other features of the organizational culture and thus influences the organization's way of responding to the OCT. As illustrated by the upper arrow in Fig. 1, the activity in turn influences the components of the organizational core task (e.g. by changing the characteristics of the physical object, or by drawing more regulatory and public attention by increased incidents or accidents).

Organizational culture – as we define it – includes the process of formation and reformation of the conceptions concerning the organizational core task and the means to fulfil it. This process of collective sense-making and (re)interpretation of events is the essence of an organizational culture (Weick, 1995; cf. Giddens, 1984; Weeks and Galunic, 2003). This means that the organizational culture includes the dysfunctional solutions and discrepancies, as well as the attempts to solve or cover these (Oedewald and Reiman, 2003, p. 292). According to Martin (2002, p. 155) "what people disagree about and what they find ambiguous are just as much a part of culture as what they share" (cf. Kunda, 1992, p. 222; Alvesson, 2002, p. 164). That is why the purely functionalistic view of the organization (see Section 2.1) is limited if the aim is to assess the culture and to explain its significance to the

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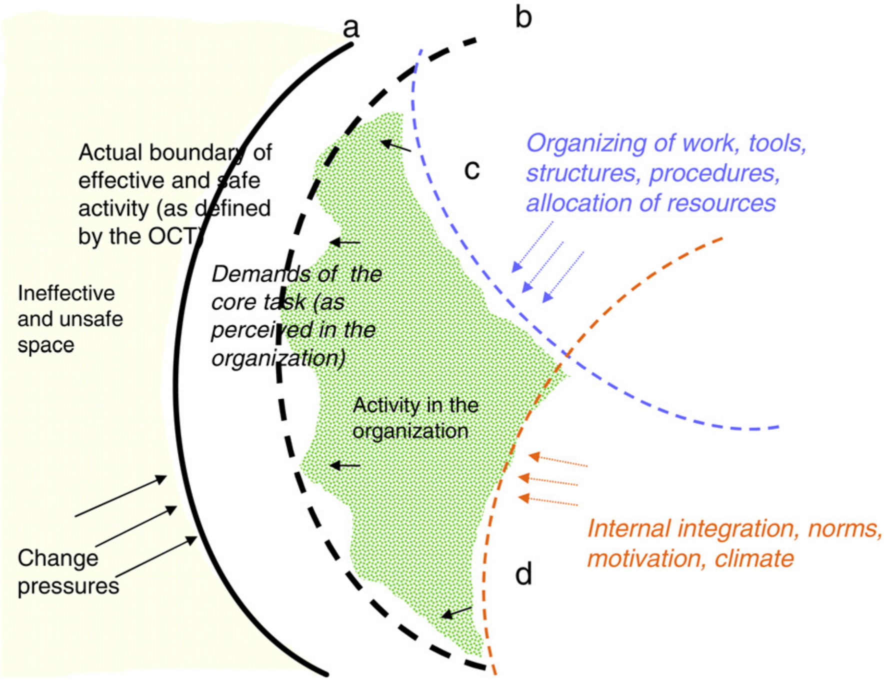

Fig. 2. The dynamics of organizational culture and organizational core task. Activity in the organization is influenced by three cultural dimensions; perceptions of the core task demands (line b), organizing of the work (line c) and internal integration (line d). The boundary of effective and safe activity is illustrated by line a. None of the lines are static and the arrows indicate pressures that are gradually and constantly changing the system.

organizational effectiveness. What are crucial to identify are the issues that should be shared, e.g. the core task conceptions, their content, and the extent to which these are actually shared in the culture.

To summarize, the rationale for introducing the OCT concept is to understand and assess the aspects of organizational culture that either prevent or allow the organizations to function safely and effectively (to function as HROs, that is). Understanding the organizational life and its dynamics is not enough. The work of the organization and its requirements also has to be understood in order to develop the organizational behaviour and enhance the safety of the sociotechnical system in question. If we are able to define the demands set by the organizational core task, we also get the appropriate criteria for the assessment of the features of the organizational culture. This will be elaborated in the next section.

2.4. Statement 4: effectiveness and safety depend on the cultural conceptions of the organizational core task

Last, we will argue that the effectiveness and safety of complex sociotechnical systems depend on the cultural conceptions of the organizational core task prevalent in the organization. Organizational safety and effectiveness is achieved when the cultural way of responding to the core task demands is adequate and based on an accurate conception of

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the OCT (Fig. 1). Furthermore, the organization needs to maintain reflectivity toward the possible changes in the requirements of its core task, and toward a "practical drift" (Snook, 2000) of the practices and the organizational activity. Practical drift means a gradual local optimization of working practices that does not necessarily take the entire OCT into account (cf. Rasmussen, 1997; Leveson, 2004, p. 247; Dekker, 2005). A theory that would be able to anticipate and prevent accidents should be "sensitive to the creation of deficiencies, not just to their eventual presence" (Dekker, 2005, p. 34). We will illustrate how inaccurate conceptions can gradually create deficiencies, direct the organizational adaptation in daily work (drift), and create and maintain unsafe practices and associated tools.

Schein (1985) has proposed that one of the functions of organizational culture is the adaptation to its external environment. He also uses the term basic (or alternatively core) mission, but he has not operationalized the concept and he does not question the problem of the definition of the basic mission of the organization. Schein (1985, 1990) also considers the problem of internal integration of the culture as a somewhat separate challenge from external adaptation. We argue that many of the characteristics of organizational culture that deal with internal integration stem from the nature of the particular work and conceptions of the organizational core task or they can have an effect on those. Hence, internal characteristics, such as norms, the climate or conflicts and power relations, should be viewed in relation to the task the organization should fulfil, aka the OCT. For example, norms influence what is considered as the right or appropriate way of talking about safety and about the risks that are perceived in one's own work.

The dynamics of organizational culture and OCT are illustrated in Fig. 2 using the graphical presentation format that resembles visually the format that Rasmussen (1997, p. 190) has used to model the migration of human performance toward the boundary of "functionally acceptable performance". Contrary to Rasmussen, our model depicts the institutional and cultural factors influencing the activity in the organization and strives to illustrate how the activity in the organization results from the interaction of the three elements of the organizational culture (cf. Fig. 1). Furthermore, our model shows the relation of the current activity of the organization to the boundary of safe and effective activity as defined by the OCT. Thus our model has only one boundary of safe and effective activity, that created by the demands of the organizational core task. The other lines represent the elements of the culture that affect the activity of the organization either by pushing it toward the boundary or allowing it to stay within acceptable limits and a safe margin from the boundary defined by the OCT (Fig. 2).

In Fig. 2, line A represents the actual boundary of effective and safe activity as dictated by the OCT. Line B represents the demands of the OCT as they are perceived in the organizational culture (the perceived boundary). Line C indicates the influence of resources, tools, organizational structures and procedures on the activity. Line D indicates the influence of the internal integration of the culture (norms, motivation, and climate) on the organizational activity. The space between lines B, C and D defines the area of normal organizational activity. In other words, activity in the organization is dictated by the culturally formed conceptions concerning the demands of the OCT (cf. Fig. 1), organizing of the work (including tools and procedures), and internal integration (including norms and climate) of the organization. These three elements form the organizational culture and thus have an effect on its ability to fulfil the OCT. The elements (lines B,C and D) are not outside pressures affecting the system, rather they are aspects of the organizational culture created and maintained by the organization. As depicted in Section 2.2, the organization and its members create and recreate the context in which future behaviour occurs. The conceptions concerning the OCT are of crucial importance in directing this process. Inaccurate conceptions of OCT can lead to a selection of inappropriate criteria for activity. Even errorless conduct by the personnel can thus lead to an accident if they are acting on the basis of flawed conceptions of the constraints and requirements of the organizational core task prevalent in the organizational culture (cf. Dekker, 2005). It must be emphasized that the three elements are cultural features that influence but never fully determine individual action.

The three elements of organizational culture (Fig. 2) define the normal space of activities of the organization. This space tends to gradually change through drift in practices, normalization of deviance, formation of shortcuts and norms, local optimization and discrepancies in the conceptions concerning the work (cf. Snook, 2000; Vaughan, 1996; Rasmussen, 1997; Leveson, 2004; Dekker, 2005). The activities in the organization "cross the borders" created by lines B, C and D from time to time and if this crossing is frequent enough, the borders move (since they are created, maintained and changed through the same activity as described above, see Section 2.1 and Weick, 1995). Furthermore, the elements are interrelated; change in one element of culture affects the other elements. For example, when small changes in practices (drift) do not lead to an accident, the organization will "begin to believe that past success is a guarantee of future safety" (Dekker, 2005, p. 63). Their conceptions of the OCT (line B) thus move closer to or cross the actual boundary of safe and effective activity. The introduction of new information systems or other technologies can also direct attention to certain aspects of the core task and gradually change the conception of what is critical in the work (cf. Zuboff, 1988; Hutchins, 1995). Unsafe or ineffective practices are thus made legitimate and seemingly safe in the culture.

The strength of the three elements of culture (the amount of influence they have on the actual behaviour of the individuals in the organization) varies according to the degree of which they are shared in the culture. Strong cultures exhibit less "border crossing". This is a good thing if the cultural conceptions are based on an accurate image of OCT. Border crossing can thus also result from an accurate perception of the OCT and a corresponding realization that e.g. the current way of organizing is not adequate for fulfilling the OCT (due to gradual change in either the OCT or in the culture). Then the border is crossed in order to be able to fulfil the requirements of the OCT. For example, some norm about the appropriate conduct can be broken in order to alert the organization of impending danger or the official procedures are not followed since they would be inadequate in some exceptional situation. This is "normal" organizational adaptation to unanticipated conditions (cf. Dekker, 2003, p. 235). For this adaptation to be successful and safe, awareness of the OCT and its demands is crucial.

Differentiating between the organizational culture and the organizational core task thus allows us to consider organizations as units striving for rationality and to define the boundaries of this rational action (the OCT), but at the same time consider organizations as inherently dynamic, ambiguous and emergent cultural phenomena (see Section 2.2). In the words of Sayer, the personnel's conceptions of the requirements of their core task can be "real [in the sense of existing in their mind] but nevertheless false [from the perspective of fulfilling the OCT]" (Sayer, 1992, p. 42). It must be emphasized that organizational culture as a phenomenon does not have an inherent function per se (cf. open systems theories of culture in Section 2.1). Still, the organizational culture can be studied from the perspective of how the

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given culture contributes to or hinders organizational effectiveness (defined as productivity, safety and employee wellbeing, cf. Vicente, 1999). Thus, when assessing complex sociotechnical systems from the perspective of the OCT, the central "function" of the organizational culture is to produce, maintain, and reproduce shared conceptions (cf. Sandberg, 2000, p. 12) of the organizational core task that work well enough in the daily tasks and thus lead to the creation and use of applicable tools, procedures, and routines.

To summarize, the organization creates and recreates its own constraints which may or may not correspond with the demands of the OCT. Outside pressures are always interpreted in the organization. The organization thus defines the significance of and the appropriate response to these pressures. These definitions and organizational solutions are not fixed. Rather safety and effectiveness are emergent properties of organizational dynamics, with conceptions of OCT playing a central role in directing the dynamics. In the next section we will elaborate on these issues with more concrete examples and we will also describe the basis of a methodology that can be used to model the OCT and assess the organizational culture.

3. Application of the proposed concepts to the research and development of complex sociotechnical systems

3.1. Procedure for organizational assessment utilizing the concepts of OCT and organizational culture

A methodology called Contextual Assessment of Organizational Culture (CAOC) has been developed around the principles depicted in this article. The methodology has been applied in e.g. nuclear power plant maintenance units (Oedewald and Reiman, 2003; Reiman et al., 2005; Reiman and Oedewald, in press), regulatory authority (Reiman and Norros, 2002), metal manufacturing, NPP engineering organization and hospital settings. The cultural assessment consists of three phases (Fig. 3):

1. Characterizing the culture of the organization according to the three elements of organizational culture (cf. Fig. 1).
2. Modelling the OCT in order to get appropriate criteria for the assessment of the organizational culture.
3. Explaining the effect of the culture on organizational effectiveness by qualitative assessment based on the OCT model and the extracted cultural features.

The methods that have been utilized in the assessment include questionnaire (Reiman and Oedewald, 2004), interviews, group working, and personnel seminars (Oedewald and Reiman, 2003; Reiman et al., 2005). The specific methods are not elaborated here since the focus is on the logic of organizational assessment.

The purpose of the cultural analysis (phase 1) is not to aggregate the data until a "common view" or an average opinion is found. The aim is to exemplify the personnel's multiple ways of making sense of and interacting in the organizational context (cf. Sackmann, 1991; Rochlin, 1999; Weick, 1995) and to inspect what type of conceptions are shared among the personnel, and to what extent. The mode of analysis is interpretative (cf. Schultz and Hatch, 1996, p. 538) in its search for the creation of meaning and conceptions in the organization.

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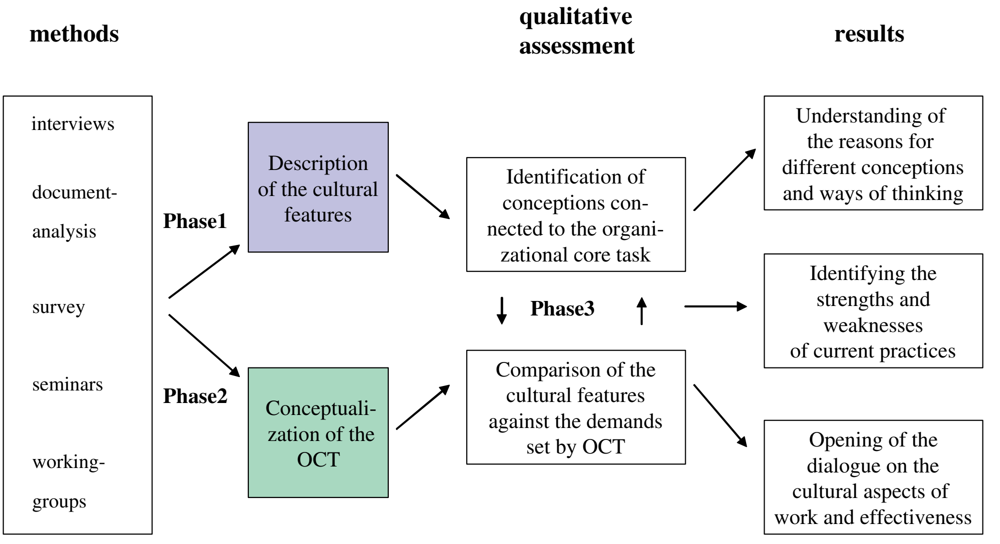

Fig. 3. The analysis model in cultural assessment made according to the principles of CAOC.

The focus of organizational core task modelling is on the boundaries and requirements of the activity in the entire sociotechnical system. In the OCT analysis, the objective of the activity, the physical object, and the external influences are defined first broadly (e.g. "guaranteeing the power production in a PWR-type nuclear power plant in an open electricity market") and then more specifically (e.g. the characteristics of the physical object such as technical complexity, safety systems, radiation). Then the requirements and constraints that these set for the activity are modelled together with the domain experts (cf. Norros and Nuutinen, 2002; Vicente, 1999; Oedewald and Reiman, 2003). The domain experts are personnel who have the most extensive technical knowledge of the sociotechnical system in question. Also experts outside the organization in question are consulted in order to decrease the influence of cultural biases on the core task modelling.

The aim of the core task modelling is to extract demands of the work that apply to all the personnel. When analyzing the OCT, discrepancies in the conceptions of the organizational core task are considered to reflect the different aspects of the demands and the different angle from which the personnel perceive their organization and its core task. For example, managers typically have a better overview of the OCT, but they lack a picture of the discrepancies and conflicts that manifest themselves better at the sharp end of the operations (cf. Corley, 2004, p. 1159).

The aim of conceptualizing the OCT should not be to prescribe the structures (e.g. network organization or matrix organization with particular processes) or practices needed to accomplish the organizational core task. Instead, the aim should be to explicate the demands that the organization has to manage in its everyday activities. The demands can be fulfilled organizationally in many different ways. In this sense, our approach is not normative but formative (see Vicente, 1999, p. 110). The organizing of the activity and the activity itself are assessed principally on the basis of the requirements that the organization has to fulfil and the constraints that the personnel have to take into account. This is elaborated in the next section.

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3.2. Using conceptions of OCT to assess and predict organizational safety and effectiveness

A central challenge in terms of the safety and effectiveness of the sociotechnical system is that the demands of the OCT (line A in Fig. 2) are not always obvious to the personnel at every level of the organization or to the outside observer (Oedewald and Reiman, 2003; Norros and Nuutinen, 2002; cf. Rasmussen, 1997). The culture influences the personnel's definition of the organizational core task (or, to phrase it more accurately, the personnel's definitions of the OCT are one element of the culture itself, see Fig. 1). The personnel's conceptions of the organizational core task are thus historically constructed and rooted in the culture of the organization and as stated, they are not inevitably uniform. The history of the organization is physically present in the tools, practices and organizational structures that are currently utilized. For example, outdated tools can maintain a false image of the present core task or its demands (cf. Hutchins, 1995). The current tools and technology both facilitate and constrain organizational performance (Orlikowski, 1992, p. 411). Outdated work practices or tools can also gradually change the conceptions concerning the OCT and thus make legitimate activities that are no longer actually safe (they are outside line e in Fig. 4). Changes in the operating environment and the new operational demands caused by the changes do not automatically lead to changes in the personnel's understanding of the core task of their organization. This is especially so if the cultural conceptions are not actively reflected upon.

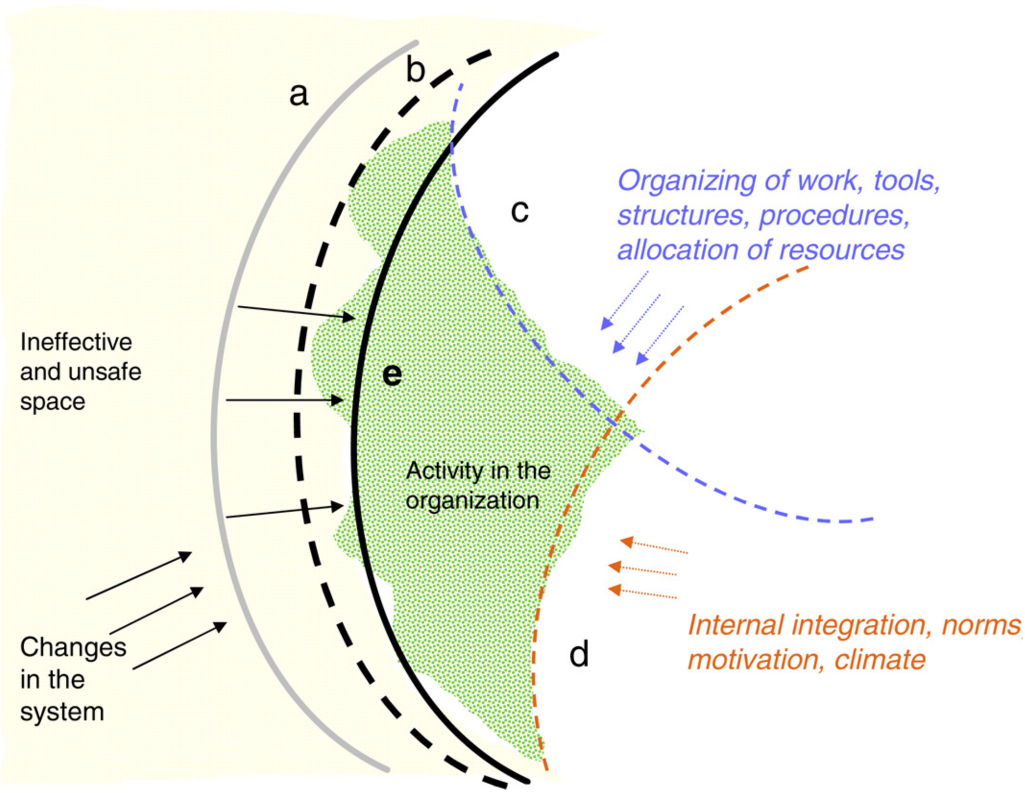

Fig. 4. Change in the requirements of the OCT. Line E indicates the new boundary of safe activity, which has moved "inside" the activity in the organization making it unsafe.

Furthermore, the organizational core task is not static (cf. Nuutinen, 2005). For example, a nuclear power plant sets the same technical constraints (e.g. radiation, redundant safety systems, time lags on feedback of activities) to the activity but the environment might change (e.g. deregulation of the electricity markets, political pressure and regulations) and set new demands for organizational safety and effectiveness. Another aspect is that the constraints and requirements that stem from the concrete object of the work might also change. For example the aging of the technical infrastructure generates new phenomena (e.g. corrosion or increase in the frequency of technical faults). Thus, the appropriate means to fulfil the OCT also change (see Fig. 4).

The line E in Fig. 4 indicates the new changed boundary of safe and effective activity. This gradual shift of the boundary is hard to notice in the daily activities of the organization. The outdated cultural conceptions of the OCT should be identified in the organization and changed to correspond with the new reality before the current activity leads to a disaster (which finally "awakes" the organization to its preconceptions, cf. Turner and Pidgeon, 1997).

Conceptualizing the OCT demands offers a way to assess the safety and effectiveness of the feature of a particular culture. Concrete working practices and the cultural conceptions concerning the work can be evaluated against the general constraints and requirements. For example, in the maintenance of a nuclear power plant one central demand of the OCT was defined as balancing between anticipating the plant condition (and the needed resources) beforehand and reacting efficiently to unforeseen faults in the equipment (Oedewald and Reiman, 2003, pp. 286–287). This requires flexible organizing of the maintenance work. The need for flexibility was illustrated with examples of coordinating the timetables for jobs that require multiple areas of expertise or coordinating the resources and prioritizing the daily tasks in a case of a sudden equipment failure. However, the way of organizing activities at the case organization was highly specialized and distributed according to technical areas (line C in Fig. 2). It thus provided little help for coordinating the daily activities. In addition, delays in fault repairs were not monitored at the organizational level, but every foreman had to report the delays in his own area. This resulted in organizational activity where everyone prioritized tasks that were in their own area of responsibility, even though in theory all technicians should be available to do jobs where most urgently needed. Their ability to fulfil the OCT was thus hindered by the extensive specialization (Reiman and Oedewald, in press).

Another example of a cultural assessment is a study by Reiman and Norros (2002). They utilized core task analysis at the Finnish Nuclear Regulatory Authority and identified three critical demands of the core task of the regulator: achieving and retaining public trust and credibility, maintaining expertise and using authority effectively toward the nuclear power plants. The objective of work was defined as securing a safe use of nuclear power in Finland. The authors differentiated three partly conflicting roles of the regulator that require different competence. According to Reiman and Norros (2002), the authority role requires perceiving safety relevant cues and practising mediated control toward the power plants. The inspectors must use different indicators and inspections for indirect observations of the status of the plant operation, and act through safety regulations and decisions. The public role requires informing openly to the public and successful balancing of fairness and firmness in relationships with the operating plants on the one hand and openness and confidentiality in relationships with the public on the other hand. The expert role requires dialogue with other experts and self-criticism toward one's own expertise.

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It also requires acknowledgement of the uncertainty connected to all information and all decisions. In its activity, the organization was currently emphasizing the authority role at the expense of the other roles.

The main point of the above examples is that by modelling the organizational core task it becomes possible to explain why certain practices and routines are currently hindering effective and safe activity or can lead to ineffective activity (or accidents) in the future. The conceptualization of the OCT also helps to understand why certain situations and tasks are experienced as frustrating or stressful by the personnel. Further and importantly, it is also possible to show that certain practices and routines may be either based on a presently inadequate conception of the OCT, or they may in the long run lead to false conceptions. These flawed conceptions and underlying assumptions can lead to creation of artefacts (procedures, practices, rules) that maintain and recreate this imperfect mental representation of the OCT. The incubation period (Turner, 1978) of an organizational accident has thus been started.

In fact, many detailed accident analyses seem to be based on quite similar ideas to ours, even though the concepts that are used differ (see e.g. Wright, 1994; Vaughan, 1996; Snook, 2000; cf. Dekker, 2002, 2005). Rasmussen (1997, p. 189) writes that "court reports from several accidents such as Bhopal, Flixborough, Zeebrugge, and Chernobyl demonstrate that they have not been caused by a coincidence of independent failures and human errors, but by a *systematic migration of organizational behaviour toward accident* under the influence of pressure toward cost-effectiveness in an aggressive, competitive environment" (italics added). Snook concludes his detailed accident analysis of the friendly fire incident at Iraq in 1994 where two US Air Force F-15C Eagle fighters accidentally shot down two US Army UH-60 Black Hawk helicopters by proposing that the fundamental question to be considered in an attempt to reduce the chance of future accidents is: "What are the critical design features of a hyper-complex, multilevel, multitask, organizational system that will increase the likelihood of accomplishing the "total task" consistently?" (Snook, 2000, p. 235) We propose that the concepts of organizational culture and OCT as defined in this article could be of use in the prevention of these kinds of incidents from recurring also in different sociotechnical systems with different demands placed on the culture.

The focus of organizational assessment as we define it should thus be on the OCT-related conceptions in the given organization. To simplify, poor formal organizational practices and tools combined with adequate conceptions of the OCT are better than currently functioning tools and practices combined with deficient or outdated conceptions of the OCT. For example, this can mean a situation where current practices maintain a false conception of the OCT since they work well enough in normal daily work, but some critical aspect of the OCT tends to be ignored because it does not manifests itself daily (e.g. bypassing a radiation check at a NPP in a room where there has never before been radiation), or its effects are long-term and difficult to perceive (e.g. monitoring the effect of corrosion on machinery), or it becomes relevant only in a case of exceptional conditions (e.g. the loss of electricity in a hospital emergency room). The focus on conceptions gives us a better chance to predict the drift in the practices beforehand and to identify practices and conceptions that are no longer adequate.

Despite the well known problems of prediction in social sciences (see e.g. Sayer, 1992, p. 134) we strive to anticipate the consequences of the current conceptions and practices in the given organization also over a longer time span. One of the main problems of prediction in social sciences is the problem of self-fulfilling prediction. This concern is not as

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salient for our approach, since as we will depict in the next section, intervention is one of the goals of the safety research and self-fulfilling predictions can serve as an important aid for it. Actually, "self-invalidating predictions" of future incidents – in the case that the current cultural conceptions would not change – could be considered a tool in the development work.

3.3. Opening of internal dialogue in the organization and facilitating change

The aim of the safety research is not only to assess the organization, but also to give the personnel and the management new concepts and new tools for reflecting on their organization, their work and on the appropriate working practices. The personnel's conceptions concerning these issues have to be made explicit so that constructive discussion about the development needs and possible new solutions is achievable. Otherwise, this conversation can turn overemotional and be oversensitive to issues too close to the conversationalists' own preconceptions about the "right and wrong" ways of doing things. Then the conversation is no longer in the form of a dialogue (Schein, 1999), where assumptions can be confronted and a common understanding can be built. This, in turn hinders any development activities.

Furthermore, core task modelling together with the researchers prompts the personnel to discuss and make explicit the aspects taken for granted in their daily work. Thus, it can be used as a research-tool for revealing the underlying, core task-related conceptions of the given culture. The core task model also provides the organization with a tool for critically considering the daily activities and routines. Especially important is the identification of reasons behind the current routines and whether or not these reasons are connected to the OCT. The current reason for the existence of some routine might differ from its originally designed function due to a drift in practices or a change in the requirements of the OCT (see Sections 2.4 and 3.2).

In the maintenance organization mentioned above, the conception of specialization as the appropriate means to guarantee safety was so deeply rooted in the culture that no other solution was even thought of. The danger of over-emphasized specialization was pointed out with the OCT model indicating the prerequisite of an overview of the functioning of the plant for anticipation and flexible activity. The danger of strict adherence to one's own areas of responsibility and concentration on a narrow area of technical competence was that the personnel lose the overall picture of the plant over time. Hence, they would be unable to fulfil one of the critical demands: anticipating the condition of the plant and the needed resources accurately. As a consequence, the importance of effective reacting (to e.g. technical faults) was emphasized over the anticipation of the plant condition in the prevailing culture (Oedewald and Reiman, 2003; Reiman and Oedewald, in press).

When considering organizational culture, one should take into account that contradictions and different points of view may exist within the organization (Alvesson, 2002; Martin, 2002; cf. Richter and Koch, 2004). Another premise is that these differences are not a priori "bad". Homogeneity of the culture (widely shared conceptions and assumptions) as such is not always a criterion for safe and effective culture. The starting point of all evaluation is the demands of the work, i.e. the core task of the organization. Thus, the demands of the OCT dictate whether certain cultural features (e.g. differences in opinion) are good, bad or insignificant for the effectiveness of the organization. For example, in safety critical organizations, different opinions can facilitate discussion and be adaptive in fulfilling the

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demands of safety and reliability (Reiman et al., 2005, cf. Weick, 1998, p. 75). On the other hand, contradictions and different points of view stemming from politics and power conflicts inside the organization may lead to withholding of information or to decisions based not on “synthesis of the most powerful arguments” but on “the arguments of the most powerful” (Waring, 1996, p. 52, see also Pidgeon and O’Leary, 2000). In this case, modelling the demands of the work might help in assessing the arguments more objectively.

Even though the aim of the assessment is to point out practices and conceptions that facilitate or hinder OCT, in terms of development it is not sufficient to concentrate purely on the work activities and cultural assumptions directly related to the core task. When developing the activities and striving to enhance the productivity, safety, and well-being of the employees (cf. Vicente, 1999), it is necessary to take into account also all the other characteristics of the culture, such as work values, the climate, individual traits and skills of the personnel, the physical and mental workload of the tasks, and general work satisfaction (cf. Richter and Koch, 2004, p. 719). These are all aspects of the organizational culture (cf. Fig. 1). The initiatives for change should still primarily aim at changing the conceptions of the core task in addition to merely changing the organizational practices. Furthermore, it could be worthwhile to use the change in the personnel’s conceptions of the organizational core task as one indicator of organizational change. The ideas presented in this article are thus meant to improve, not replace, the methods such as task analysis (Kirwan and Ainsworth, 1992), safety (culture) auditing and organizational assessment. Also the tradition of descriptive organizational culture research (see e.g. Smircich, 1983; Sackmann, 1991; Kunda, 1992; Schumacher, 1997; Parker, 2000; cf. Geertz, 1973) might be more applicable in safety critical domains if they would devote more attention to the demands of the work the organization is carrying out.

4. Conclusions

The aim of this article was to study organizational assessment in complex sociotechnical systems. We introduced the concept of organizational core task (OCT). We proposed that together with a dynamic view of the complex sociotechnical system as an organizational culture, OCT can be used in assessing the central features of a particular culture. We then discussed the implications of the concepts for behavioural scientific research and development work at complex sociotechnical systems.

In order to create appropriate criteria for organizational effectiveness we have in this article emphasized the need to integrate ideas from work psychology and cultural studies to human factors research. The concept of OCT was proposed to denote the constraints and requirements of a particular work. Uncertainty and complexity are the defining characteristics of modern industrial work. Nevertheless, we agree with Barley’s (1996) worry that concepts such as complexity and uncertainty are not sufficient to understand the activity in the given organization. Barley criticizes the goal of comparing dissimilar complex tasks (such as management and medicine) in order to “discover relations that would hold across contexts” (Barley, 1996, p. 405; see also Orton and Weick, 1990, p. 219). We argue that our methodology is applicable in various contexts, but the methodology does not include a conception of an ideal sociotechnical system a priori. The criteria for assessment are created on a case by case basis.

The OCT concept is related to the concepts of primary task (Rice, 1958; Miller and Rice, 1967) and basic mission (Schein, 1985). The main difference is that OCT is a normative

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concept that sets constraints and requirements for the organizational culture, whereas primary task and basic mission are more descriptive concepts of the current goals of the organization. In our framework, effectiveness and safety of the organization depend on the cultural conceptions of the OCT prevalent in the given organization. Our approach has also connections to the High Reliability Organizations research. When conducting organizational core task analysis in different domains, many of the extracted constraints and requirements resemble the general characteristics of HROs (see Section 2.3), but also more contextual requirements and constraints emerge. Further, also the general challenges, such as the need to anticipate the unexpected, are easier to communicate to the case organization and utilize in development initiatives if they are more contextualised to the specific work and its uncertainties.

The central challenge in terms of validity of the cultural assessment is how the cultural features relate to the demands of the OCT and how researcher-dependent this qualitative evaluation is. In other words, the challenge is how to conceptualize the objective demands of the organizational core task and the prevailing subjective cultural features in such a manner that the researcher is able to reliably assess their "fit". The results are thus always incomplete and remain as hypotheses (cf. Sayer, 1992, p. 67), a fact, which has to be taken into account when using the results in the development work, and when reporting the results to the scientific community.

The most genuine and far-reaching idea in the safety culture concept is its preventive nature (IAEA, 1991). With (safety) cultural thinking, you do not wait until the organization is "sick", and then cure it by some form of intervention. The "sick organization" metaphor is the usual approach in many consultancy approaches (cf. Levinson, 2002; Schein, 1985, 1999). With (safety) cultural thinking, development initiatives can be made without any visible signs of degradation in the safety or effectiveness. The underlying assumption is that it is always possible to enhance the safety, hence the motive for assessing and developing the culture regularly. Minding this, it is disadvantageous that the indicators currently used for safety culture so often come from the number of accidents, and the criteria for good safety culture are the lack of accidents or incidents along a certain time span in the history of the organization. We have proposed that in complex sociotechnical systems it is both necessary and possible to analyze the safety and effectiveness of the organization by assessing the organizational culture.

The concepts of organizational culture and OCT as depicted in this article can be of help in identifying warning signs in organizations before they lead to accidents or incidents. Especially due to the potential dysfunctional sides of the organizational culture, the concept of OCT is needed to identify the central features of culture and contemplate on their potential effects on safety and effectiveness of the organization. The concepts strive to offer a model for organizational assessment that takes into account on the one hand the interpretive and socially constructed nature of organization and on the other hand the constraints and requirements of the work that the organization is carrying out.

References

Alvesson, M., 2002. Understanding Organizational Culture. Sage, London.
Alvesson, M., Berg, P.O., 1992. Corporate Culture and Organizational Symbolism. Walter de Gruyter, Berlin.
Baker, E., 1980. Managing organizational culture. Management Review 69, 8–13.

Barley, S.R., 1996. Technicians in the workplace: ethnographic evidence for bringing work into organization studies. Administrative Science Quarterly 41, 404–441.

Barley, S.R., Kunda, G., 2001. Bringing work back in. Organization Science 12, 76–95.

Barney, J., 1986. Organizational culture: can it be a source of sustained competitive advantage? Academy of Management Review 11, 656–665.

Bourrier, M., 1999. Constructing organisational reliability: the problem of embeddedness and duality. In: Misumi, J., Wilpert, B., Miller, R. (Eds.), Nuclear Safety: A Human Factors Perspective. Taylor & Francis, London, pp. 25–48.

Brunsson, N., Olsen, J.P., 1993. The Reforming Organization. Routledge, London.

Burrell, G., Morgan, G., 1979. Sociological Paradigms and Organizational Analysis. Heinemann, London.

Cheyne, A., Cox, S., Oliver, A., Tomás, J.M., 1998. Modelling safety climate in the prediction of levels of safety activity. Work & Stress 12, 255–271.

Clarke, S., 1998. Safety culture on the UK railway network. Work & Stress 12, 285–292.

Clarke, S., 1999. Perceptions of organizational safety: implications for the development of safety culture. Journal of Organizational Behavior 20, 185–198.

Corley, K.G., 2004. Defined by our strategy or our culture? Hierarchical differences in perceptions of organizational identity and change. Human Relations 57, 1145–1177.

Cox, S.J., Cheyne, A.J.T., 2000. Assessing safety culture in offshore environments. Safety Science 34, 111–129.

Cox, S., Flin, R., 1998. Safety culture: philosophers stone or man of straw? Work & Stress 12, 189–201.

Czarniawska-Joerges, B., 1992. Exploring Complex Organizations. A Cultural Approach. Sage, Newbury Park, CA.

Dekker, S.W.A., 2002. Reconstructing human contributions to accidents: the new view on error and performance. Journal of Safety Research 33, 371–385.

Dekker, S., 2003. Failure to adapt or adaptations that fail: contrasting models on procedures and safety. Applied Ergonomics 34, 233–238.

Dekker, S.W.A., 2005. Ten Questions about Human Error. A New View of Human Factors and System Safety. Lawrence Erlbaum, New Jersey.

Denison, D.R., 1996. What is the difference between organizational culture and organizational climate? A native's point of view on a decade of paradigm wars. Academy of Management Review 21, 619–654.

Donald, I., Canter, D., 1994. Employee attitudes and safety in the chemical industry. Journal of Loss Prevention in the Process Industries 7, 203–208.

Durkheim, E., 1982. The rules of sociological method. Free Press, New York (First published in 1895).

Engeström, Y., 1999. Activity theory and individual and social transformation. In: Engeström, Y., Miettinen, R., Punamäki, R.-L. (Eds.), Perspectives in Activity Theory. Cambridge University Press, Cambridge, pp. 19–38.

Etzioni, A., 1964. Modern Organizations. Prentice-Hall, Englewood Cliffs, NJ.

Farrington-Darby, T., Pickup, L., Wilson, J.R., 2005. Safety culture in railway maintenance. Safety Science 43, 39–60.

Feldman, M.S., 2000. Organizational routines as a source of continuous change. Organization Science 11, 611–629.

Feldman, M.S., Rafaeli, A., 2002. Organizational routines as sources of connections and understandings. Journal of Management Studies 39, 309–331.

Frost, P.J., Moore, L.F., Louis, M.R., Lundberg, C.C., Martin, J. (Eds.), 1985. Reframing Organizational Culture. Sage, Newbury Park, CA.

Geertz, C., 1973. Thick description: toward an interpretative theory of culture. In: Geertz, C. (Ed.), The Interpretation of Cultures. Basic Books, New York, pp. 3–30.

Gephart Jr., R.P., 1984. Making sense of organizationally based environmental disasters. Journal of Management 10, 205–225.

Gherardi, S., Nicolini, D., 2002. Learning the trade: a culture of safety in practice. Organization 9, 191–223.

Giddens, A., 1984. The Constitution of Society: Outline of the Theory of Structure. University of California Press, Berkeley, CA.

Guldenmund, F.W., 2000. The nature of safety culture: a review of theory and research. Safety Science 34, 215–257.

Hale, A.R., Hovden, J., 1998. Management and culture: the third age of safety. A review of approaches to organizational aspects of safety, health and environment. In: Feyer, A.-M., Williamson, A. (Eds.), Occupational Injury. Risk, Prevention and Intervention. Taylor & Francis, London.

Harvey, J., Erdos, G., Bolam, H., Cox, M.A.A., Kennedy, J.N.P., Gregory, D.T., 2002. An analysis of safety culture attitudes in a highly regulated environment. Work & Stress 16, 18–36.

Please cite this article in press as: Reiman, T., Oedewald, P., Assessment of complex sociotechnical systems – ..., Safety Sci. (2006), doi:10.1016/j.ssci.2006.07.010

Hempel, C.G., 1965. Aspects of Scientific Explanation. Free Press, New York.
Hernes, T., Bakken, T., 2003. Implications of self-reference: Niklas Luhmann's autopoiesis and organization theory. Organization Studies 24, 1511–1535.
HSE, 1997. Successful Health and Safety Management. Health and Safety Executive, HMSO, London.
Hutchins, E., 1995. Cognition in the Wild. MIT Press, Massachusetts.
IAEA, Safety Series No. 75-INSAG-4, 1991. Safety Culture. International Atomic Energy Agency, Vienna.
Katz, D., Kahn, R.L., 1966. The Social Psychology of Organizations. John Wiley, New York.
Kirwan, B., 2001. Coping with accelerating socio-technical systems. Safety Science 37, 77–107.
Kirwan, B., Ainsworth, L.K., 1992. A Guide to Task Analysis. Taylor & Francis, London.
Kunda, G., 1992. Engineering Culture: Control and Commitment in a High-Tech Corporation. Temple University Press, Philadelphia.
La Porte, T.R., 1996. High reliability organizations: unlikely, demanding and at risk. Journal of Contingencies and Crisis Management 4, 60–71.
Lee, T., 1998. Assessment of safety culture at a nuclear reprocessing plant. Work & Stress 12, 217–237.
Lee, T., Harrison, K., 2000. Assessing safety culture in nuclear power stations. Safety Science 34, 61–97.
Leontiev, A.N. 1975. Dejatelnost. Coznanie. Litšnost (Activity, Consciousness, Personality). A Finnish Translation. KOY, Kuopio.
Leveson, N., 2004. A new accident model for engineering safer systems. Safety Science 42, 237–270.
Levinson, H., 2002. Organizational Assessment. A Step-by-Step Guide to Effective Consulting. American Psychological Association, Washington.
Martin, J., 2002. Organizational Culture. Mapping the Terrain. Sage, Thousand Oaks.
McDonald, N., Corrigan, S., Daly, C., Cromie, S., 2000. Safety management systems and safety culture in aircraft maintenance organisations. Safety Science 34, 151–176.
Mearns, K., Flin, R., Gordon, R., Fleming, M., 1998. Measuring safety climate on offshore installations. Work & Stress 12, 238–254.
Mearns, K., Whitaker, S.M., Flin, R., 2003. Safety climate, safety management practice and safety performance in offshore environments. Safety Science 41, 641–680.
Meek, V.L., 1988. Organizational culture: origins and weaknesses. Organization Studies 9, 453–473.
Miller, E., Rice, A.K., 1967. Systems of Organization: Task and Sentient Systems and their Boundary Control. Tavistock, London.
Morgan, G., 1997. Images of Organization, second ed. Sage, Thousand Oaks, CA.
Norros, L. 2004. Acting Under Uncertainty. The Core-Task Analysis in Ecological Study of Work. VTT Publications 546, Technical Research Centre of Finland, Espoo.
Norros, L., Nuutinen, M., 2002. The concept of the core-task and the analysis of working practices. In: Borham, N., Samurcay, R., Fischer, M. (Eds.), Work Process Knowledge. Routledge, London, pp. 25–39.
Norros, L., Nuutinen, M., 2005. Performance-based usability evaluation of a safety information and alarm system. International Journal of Human–Computer Studies 63, 328–361.
Nuutinen, M., 2005. Contextual assessment of working practices in changing work. International Journal of Industrial Ergonomics 35, 905–930.
Oedewald, P., Reiman, T., 2003. Core task modelling in cultural assessment – a case study in nuclear power plant maintenance. Cognition, Technology & Work 5, 283–293.
Orlikowski, W.J., 1992. The duality of technology: rethinking the concept of technology in organizations. Organization Science 3, 398–427.
Orr, J.E., 1996. Talking about Machines. An Ethnography of a Modern Job. ILR Press, New York.
Orton, J.D., Weick, K.E., 1990. Loosely coupled systems: a reconceptualization. Academy of Management Review 15, 203–223.
Parker, M., 2000. Organizational Culture and Identity. Sage, London.
Parsons, T., 1951. The Social System. Routledge & Kegan Paul, London.
Paté-Cornell, M.E., 1993. Learning from the Piper Alpha accident: a post mortem analysis of technical and organizational factors. Risk Analysis 13, 215–232.
Perrow, C., 1984. Normal Accidents: Living with High-Risk Technologies. Basic Books, New York.
Perrow, C., 1986. Complex Organizations, third ed. Random House, New York.
Pidgeon, N., 1998. Safety culture: key theoretical issues. Work & Stress 12, 202–216.
Pidgeon, N., O'Leary, M., 2000. Man-made disasters: why technology and organizations (sometimes) fail. Safety Science 34, 15–30.

Please cite this article in press as: Reiman, T., Oedewald, P., Assessment of complex sociotechnical systems – ..., Safety Sci. (2006), doi:10.1016/j.ssci.2006.07.010

Pronovost, P.J., Weast, B., Holzmueller, C.G., Rosenstein, B.J., Kidwell, R.P., Haller, K.B., Feroli, E.R., Sexton, J.B., Rubin, H.R., 2003. Evaluation of the culture of safety: survey of clinicians and managers in an academic medical center. Quality and Safety in Health Care 12, 405–410.

Radcliffe-Brown, A.R., 1958. Method in Social Anthropology. University of Chicago Press, Chicago.

Rasmussen, J., 1997. Risk management in a dynamic society: a modelling problem. Safety Science 27, 183–213.

Reiman, T., Norros, L., 2002. Regulatory culture: balancing the different demands of regulatory practice in the nuclear industry. In: Kirwan, B., Hale, A.R., Hopkins, A. (Eds.), Changing Regulation – Controlling Risks in Society. Pergamon, Oxford, pp. 175–192.

Reiman, T., Oedewald, P., 2004. Measuring maintenance culture and maintenance core task with CULTURE-questionnaire – a case study in the power industry. Safety Science 42, 859–889.

Reiman, T., Oedewald, P., in press. Assessing the maintenance unit of a nuclear power plant – identifying the cultural conceptions concerning the maintenance work and the maintenance organization. Safety Science 44, 821–850.

Reiman, T., Oedewald, P., Rollenhagen, C., 2005. Characteristics of organizational culture at the maintenance units of two Nordic nuclear power plants. Reliability Engineering and System Safety 89, 333–347.

Rice, A.K., 1958. Productivity and Social Organisation: The Ahmedabad Experiment. Tavistock Publications, London.

Richter, A., Koch, C., 2004. Integration, differentiation and ambiguity in safety cultures. Safety Science 42, 703–722.

Roberts, K.H. (Ed.), 1993. New Challenges to Understanding Organizations. Macmillan, New York.

Rochlin, G.I., 1999. Safe operation as a social construct. Ergonomics 42, 1549–1560.

Sackmann, S.A., 1991. Uncovering culture in organizations. Journal of Applied Behavioral Science 27, 295–317.

Sagan, S.D., 1993. The Limits of Safety. Organizations, Accidents, and Nuclear Weapons. Princeton University Press, New Jersey.

Sandberg, J., 2000. Understanding human competence at work: an interpretative approach. Academy of Management Journal 43, 9–25.

Sandelands, L., Drazin, R., 1989. On the language of organization theory. Organization Studies 10, 457–478.

Sayer, A., 1992. Method in Social Science. A Realist Approach, second ed. Routledge, London.

Schein, E.H., 1985. Organizational Culture and Leadership. Jossey-Bass, San Francisco.

Schein, E.H., 1990. Organizational culture. American Psychologist 45, 109–119.

Schein, E.H., 1999. Process Consultation Revisited. Building the Helping Relationship. Addison-Wesley, Reading, MA.

Schulman, P.R., 1993. The negotiated order of organizational reliability. Administration & Society 25, 353–372.

Schultz, M., 1995. On Studying Organizational Cultures. Diagnosis and Understanding. Walter de Gruyter, Berlin.

Schultz, M., Hatch, M.J., 1996. Living with multiple paradigms: the case of paradigm interplay in organizational culture studies. Academy of Management Review 21, 529–557.

Schumacher, T., 1997. West Coast Camelot. The rise and fall of an organizational culture. In: Sackmann, S.A. (Ed.), Cultural complexity in organizations. Inherent contrasts and contradictions. Sage, Thousand Oaks, pp. 107–132.

Scott, W.R., 1995. Institutions and Organizations. Sage, Thousand Oaks.

Scott, W.R., 2003. Organizations. Rational, Natural, and Open Systems, fifth ed. Printice-Hall, New Jersey.

Selznick, P., 1948. Foundations of the theory of organization. American Sociological Review 13, 25–35.

Silverman, D., 1971. The Theory of Organizations: A Sociological Framework. Basic Books, New York.

Simon, H.A., 1957. Administrative Behavior: A Study of Decision Making Processes in Administrative Organisation. Macmillan, New York.

Singer, S.J., Gaba, D.M., Geppert, J.J., Sinaiko, A.D., Howard, S.K., Park, K.C., 2003. The culture of safety: results of an organization-wide survey in 15 California hospitals. Quality and Safety in Health Care 12, 112–118.

Smircich, L., 1983. Concepts of culture and organizational analysis. Administrative Science Quarterly 28, 339–358.

Snook, S.A., 2000. Friendly Fire. The Accidental Shootdown of US Black Hawks over Northern Iraq. Princeton University Press, New Jersey.

Tsoukas, H., 2001. Re-viewing organization. Human Relations 54, 7–12.

Tsoukas, H., Chia, R., 2002. On organizational becoming: rethinking organizational change. Organization Science 13, 567–582.

Please cite this article in press as: Reiman, T., Oedewald, P., Assessment of complex sociotechnical systems – ..., Safety Sci. (2006), doi:10.1016/j.ssci.2006.07.010

Tsoukas, H., Hatch, M.J., 2001. Complex thinking, complex practice: the case for a narrative approach to organizational complexity. Human Relations 54, 979–1014.

Turner, B.A., 1971. Exploring the Industrial Subculture. Macmillan, London.

Turner, B., 1978. Man-Made Disasters. Wykenham, London.

Turner, B.A., Pidgeon, N.F., 1997. Man-Made Disasters, second ed. Butterworth-Heinemann, Oxford.

Vaughan, D., 1996. The Challenger Launch Decision. University of Chicago Press, Chicago.

Vicente, K., 1999. Cognitive Work Analysis. Toward Safe, Productive, and Healthy Computer-Based Work. Lawrence Erlbaum, London.

Waring, A., 1996. Safety Management Systems. Chapman & Hall, London.

Waring, A.E., Glendon, A.I., 1998. Managing risk. Thomson.

Weber, M., 1978. Economy and Society. University of California Press, Berkeley CA.

Weeks, J., Galunic, C., 2003. A theory of the cultural evolution of the firm: the intra-organizational ecology of memes. Organization Studies 24, 1309–1352.

Weick, K.E., 1979. The Social Psychology of Organizing, second ed. Addison-Wesley, Reading, MA.

Weick, K.E., 1987. Organizational culture as a source of high reliability. California Management Review 29, 112–127.

Weick, K.E., 1993a. Sensemaking in organizations: small structures with large consequences. In: Murnigham, J.K. (Ed.), Social Psychology in Organizations: Advances in Theory and Research. Prentice-Hall, Englewood Cliffs, NJ, pp. 10–37.

Weick, K.E., 1993b. Organizational redesign as improvisation. In: Huber, G.P., Glick, W.H. (Eds.), Organizational Change and Redesign: Ideas and Insights for Improving Performance. Oxford University Press, Oxford, pp. 346–379.

Weick, K.E., 1995. Sensemaking in Organizations. Sage, Thousand Oaks.

Weick, K.E., 1998. Foresights of failure: an appreciation of Barry Turner. Journal of Contingencies and Crisis Management 6, 72–75.

Weick, K.E., Roberts, K.H., 1993. Collective mind and organizational reliability: the case of flight operations on an aircraft carrier deck. Administrative Science Quarterly 38, 357–381.

Weick, K.E., Sutcliffe, K.M., 2001. Managing the Unexpected. Assuring High Performance in an Age of Complexity. Jossey-Bass, San Francisco.

Williamson, O.E., 1975. Markets and Hierarchies: Analyses and Anti-Trust Implications. Free Press, New York.

Williamson, A.M., Feyer, A.-M., Cairns, D., Biancotti, D., 1997. The development of a measure of safety climate: the role of safety perceptions and attitudes. Safety Science 25, 15–27.

Wright, C., 1994. A fallible safety system: institutionalised irrationality in the offshore oil and gas industry. The Sociological Review 38, 79–103.

Zuboff, S., 1988. In the Age of the Smart Machine: The Future of Work and Power. Basic Books.

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Assessing Organizational Culture in Complex Sociotechnical Systems
Methodological Evidence from Studies in Nuclear Power Plant Maintenance Organizations

Abstract

Failures in industrial organizations dealing with hazardous technologies can have widespread consequences for the safety of the workers and the general population. Psychology can have a major role in contributing to the safe and reliable operation of these technologies. Most current models of safety management in complex sociotechnical systems such as nuclear power plant maintenance are either non-contextual or based on an overly-rational image of an organization. Thus, they fail to grasp either the actual requirements of the work or the socially-constructed nature of the work in question.

The general aim of the present study is to develop and test a methodology for contextual assessment of organizational culture in complex sociotechnical systems. This is done by demonstrating the findings that the application of the emerging methodology produces in the domain of maintenance of a nuclear power plant (NPP). The concepts of organizational culture and organizational core task (OCT) are operationalized and tested in the case studies. We argue that when the complexity of the work, technology and social environment is increased, the significance of the most implicit features of organizational culture as a means of coordinating the work and achieving safety and effectiveness of the activities also increases. For this reason a cultural perspective could provide additional insight into the problem of safety management. The present study aims to determine; (1) the elements of the organizational culture in complex sociotechnical systems; (2) the demands the maintenance task sets for the organizational culture; (3) how the current organizational culture at the case organizations supports the perception and fulfilment of the demands of the maintenance work; (4) the similarities and differences between the maintenance cultures at the case organizations, and (5) the necessary assessment of the organizational culture in complex sociotechnical systems.

Three in-depth case studies were carried out at the maintenance units of three Nordic NPPs. The case studies employed an iterative and multimethod research strategy. The following methods were used: interviews, CULTURE-survey, seminars, document analysis and group work. Both cultural analysis and task modelling were carried out. The results indicate that organizational culture in complex sociotechnical systems can be characterised according to three qualitatively different elements: structure, internal integration and conceptions. All three of these elements of culture as well as their interrelations have to be considered in organizational assessments or important aspects of the organizational dynamics will be overlooked. On the basis of OCT modelling, the maintenance core task was defined as balancing between three critical demands: anticipating the condition of the plant and conducting preventive maintenance accordingly, reacting to unexpected technical faults and monitoring and reflecting on the effects of maintenance actions and the condition of the plant. The results indicate that safety was highly valued at all three plants, and in that sense they all had strong safety cultures. In other respects the cultural features were quite different, and thus the culturally-accepted means of maintaining high safety also differed. The handicraft nature of maintenance work was emphasised as a source of identity at the NPPs. Overall, the importance of safety was taken for granted, but the cultural norms concerning the appropriate means to guarantee it were little reflected. A sense of control, personal responsibility and organizational changes emerged as challenging issues at all the plants.

The study shows that in complex sociotechnical systems it is both necessary and possible to analyse the safety and effectiveness of the organizational culture. Safety in complex sociotechnical systems cannot be understood or managed without understanding the demands of the organizational core task and managing the dynamics between the three elements of the organizational culture.

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Organisaatiokulttuurin arviointi monimutkaisissa sosioteknisissä järjestelmissä
Metodologinen tutkimus pohjautuen kolmen pohjoismaisen ydinvoimalaitoksen kunnossapito-organisaation arviointiin

Tiivistelmä

Onnettomuuksilla vaarallisten teknologioiden kanssa työskentelevissä teollisissa organisaatioissa voi olla kauaskantoisia seurauksia niin työntekijöiden kuin yhteiskunnan turvallisuudelle. Psykologialla on keskeinen rooli näiden teknologioiden turvallisen käytön varmistamisessa. Kunnossapitotyötä on tutkittu työpsykologian kentässä vähän huolimatta sen merkityksellisyydestä laitoksen turvallisuudelle ja käytettävyydelle. Lisäksi useimmat nykyiset teoriat turvallisuudesta monimutkaisissa sosioteknisissä järjestelmissä (kuten kunnossapito-organisaatiot) perustuvat joko ylirationaaliselle ihmiskuvalle tai sitten ne ovat epäkontekstuaalisia. Tämän takia ne eivät joko tavoita kyseisen työn sosiaalisesti rakentunutta luonnetta tai kyseisen työn todellisia vaatimuksia. Tutkimuksen yleisenä tavoitteena on kehittää ja kokeilla metodologiaa organisaatiokulttuurin kontekstuaaliseksi arvioimiseksi monimutkaisissa sosioteknisissä järjestelmissä. Tämä toteutetaan osoittamalla minkälaisia tuloksia kehitettävällä menetelmällä saadaan ydinvoimalaitoksen kunnossapitotyöstä. Organisaatiokulttuurin ja organisatorisen perustehtävän käsitteet määritellään ja testataan tapaustutkimuksissa. Tutkimuksessa lähtökohtana on oletus, että työn, teknologian ja sosiaalisen ympäristön monimutkaistuessa kasvaa organisaation kulttuurin merkitys organisaation turvallisuudelle ja tehokkuudelle. Tämän takia kulttuurisen lähestymistavan monimutkaisiin sosioteknisiin järjestelmiin voidaan olettaa tarjoavan täydentävää käsitystä näiden järjestelmien turvallisuuden hallinnasta. Tutkimuksessa tarkastellaan (1) mitkä ovat monimutkaisten sosioteknisten järjestelmien organisaatiokulttuurin keskeiset osatekijät, (2) mitä vaatimuksia kunnossapitotehtävä asettaa organisaatiokulttuurille, (3) miten kohdeorganisaatioiden nykyinen kulttuuri tukee kunnossapitotehtävän vaatimusten havaitsemista ja täyttämistä, (4) mitä yhtäläisyyksiä ja eroja kohdeorganisaatioiden kulttuurissa on, ja (5) miten arvioida monimutkaisten sosioteknisten järjestelmien kulttuuria. Tutkimus muodostui kolmesta tapaustutkimuksesta Pohjoismaisten ydinvoimalaitosten kunnossapito-organisaatioissa. Tapaustutkimusten erityinen tavoite oli kyseisten organisaatioiden kulttuurien arviointi. Tutkimuksissa käytetyt menetelmät olivat: henkilöstöhaastattelut, CULTURE-kysely, seminaarit, dokumenttianalyysi ja ryhmätyöskentely. Menetelmillä analysoitiin sekä kulttuuria että kunnossapitotehtävää. Tulosten perusteella organisaatiokulttuuria monimutkaisissa sosioteknisissä järjestelmissä voidaan kuvata kolmen laadullisesti erilaisen elementin vuorovaikutuksena: rakenteelliset piirteet, sisäinen yhteneväisyys ja kulttuuriset käsitykset. Nämä kolme elementtiä keskinäisine vuorovaikutuksineen on otettava huomioon organisaatioarvioinneissa. Muuten tärkeitä puolia organisaatioiden toiminnan dynamiikasta jää huomioimatta. Perustehtävämallinnuksen perusteella määriteltiin kolme kunnossapitotehtävän kriittistä vaatimusta: (1) laitoksen kunnon ennakointi ja ennakkohuollon suorittaminen sen mukaisesti, (2) ennakoimattomiin teknisiin vikoihin reagoiminen, ja (3) laitoksen kunnon monitorointi ja tehtyjen kunnossapitotoimenpiteiden reflektointi. Tulokset osoittavat että turvallisuutta arvostettiin jokaisella laitoksella, ja siinä mielessä he jakoivat vahvan turvallisuuskulttuurin. Muut kulttuurin piirteet sen sijaan erosivat laitoksien välillä, ja näin ollen kulttuurisesti hyväksytyt tavat ylläpitää turvallisuutta erosivat. Myös käsityksissä kunnossapitotyöstä oli eroja laitoksien välillä. Kaikilla laitoksilla vikakorjaukset ja tekniset haasteet koettiin motivoivana ja kunnossapidon käsityömäistä luonnetta korostettiin. Kaiken kaikkiaan turvallisuuden tärkeyttä pidettiin itsestään selvänä, mutta vallitsevia kulttuurisia normeja tarkoituksenmukaisista keinoista turvallisuuden varmistamiseksi ei juuri reflektoitu. Hallinnan tunne, henkilökohtaisen vastuun kokemus ja organisatoriset muutokset nousivat esille psykologisina erityiskysymyksinä. Tutkimuksessa esitetään että on sekä mahdollista että tarpeen arvioida monimutkaisten sosioteknisten järjestelmien turvallisuutta ja tehokkuutta arvioimalla niiden organisaatiokulttuuria. Turvallisuutta ei voida ymmärtää ja hallita ilman ymmärrystä organisaation perustehtävän vaatimuksista ja kulttuurin osa-alueiden ja niiden välisten vuorovaikutusten hallintaa.

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