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Teemu Reiman

Assessing Organizational Culture in Complex Sociotechnical Systems

Methodological Evidence from Studies in Nuclear Power Plant Maintenance Organizations

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Teemu Reiman

Academic Dissertation

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VTT, Bergsmansvägen 3, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 3, P.O.Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax + 358 20 722 4374

VTT, Tekniikantie 12, PL 1000, 02044 VTT
puh. vaihde 020 722 111, faksi 020 722 7046

VTT, Teknikvägen 12, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 7046

VTT Technical Research Centre of Finland, Tekniikantie 12, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 7046

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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.

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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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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,

[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).

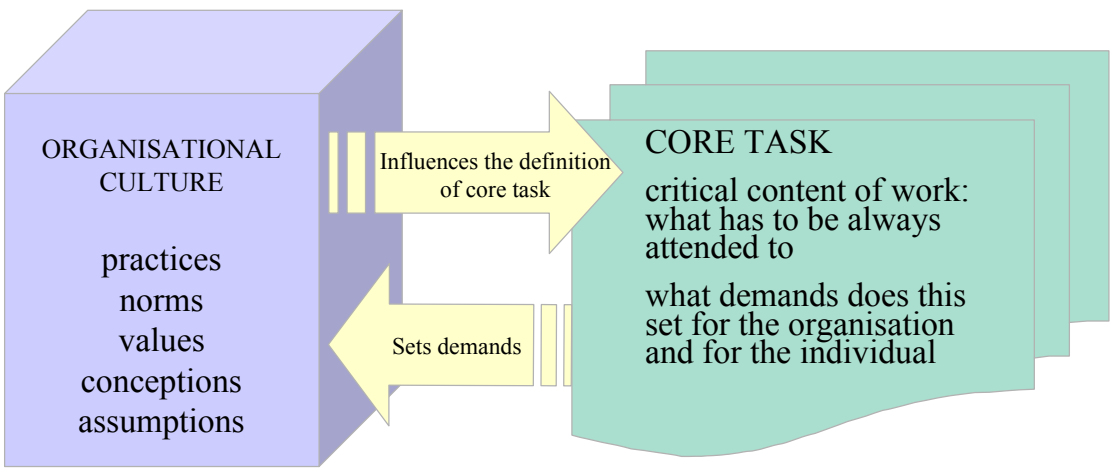


Figure 1. The central concepts of CAOC methodology, a preliminary model (Reiman & Oedewald, 2002b, p. 253).

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.

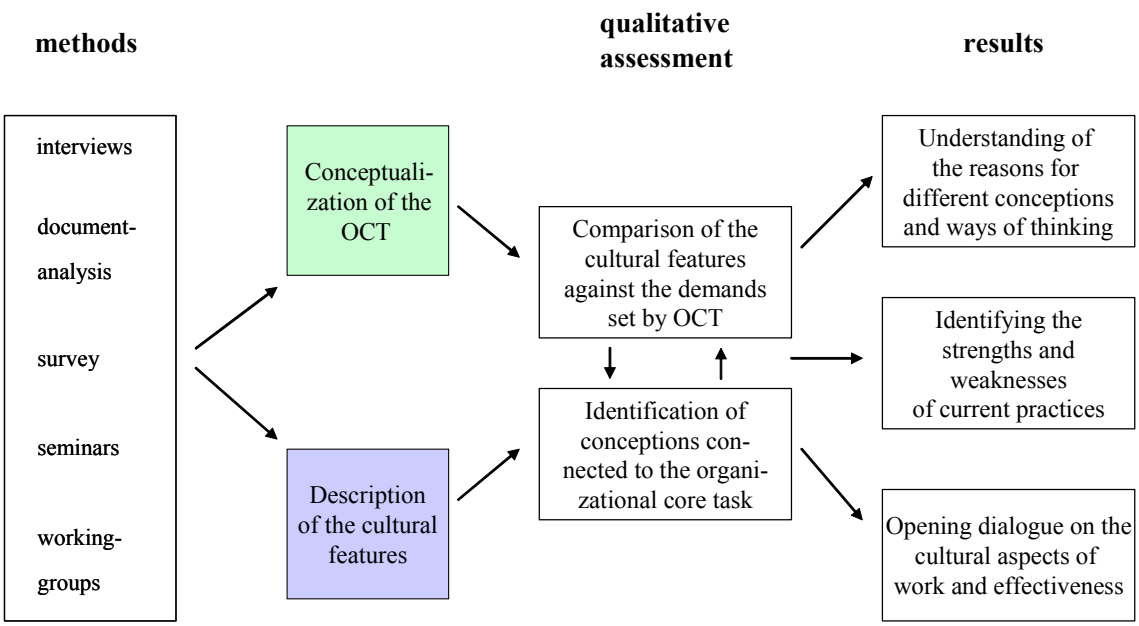


Figure 2. The analysis model of Contectual Assessment of Organizational Culture methodology.

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.

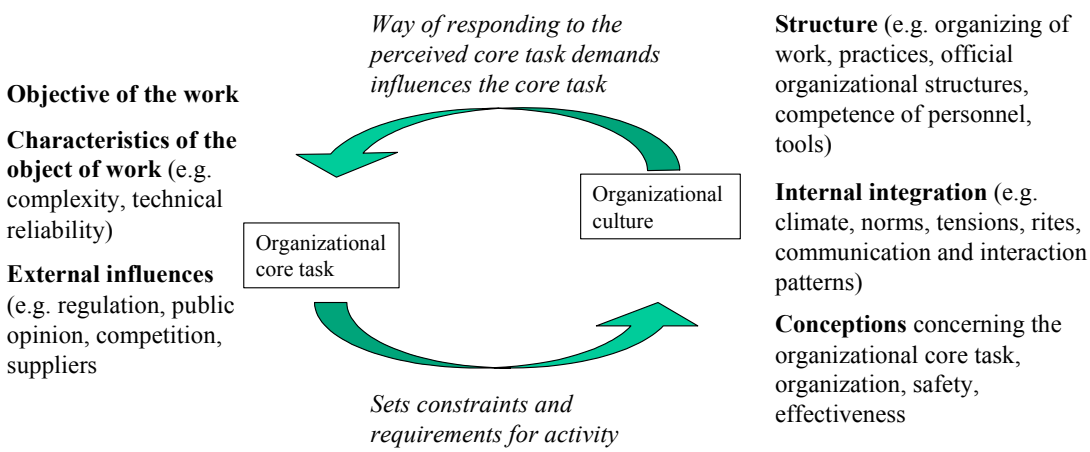


Figure 3. The central concepts and their interrelations.

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)

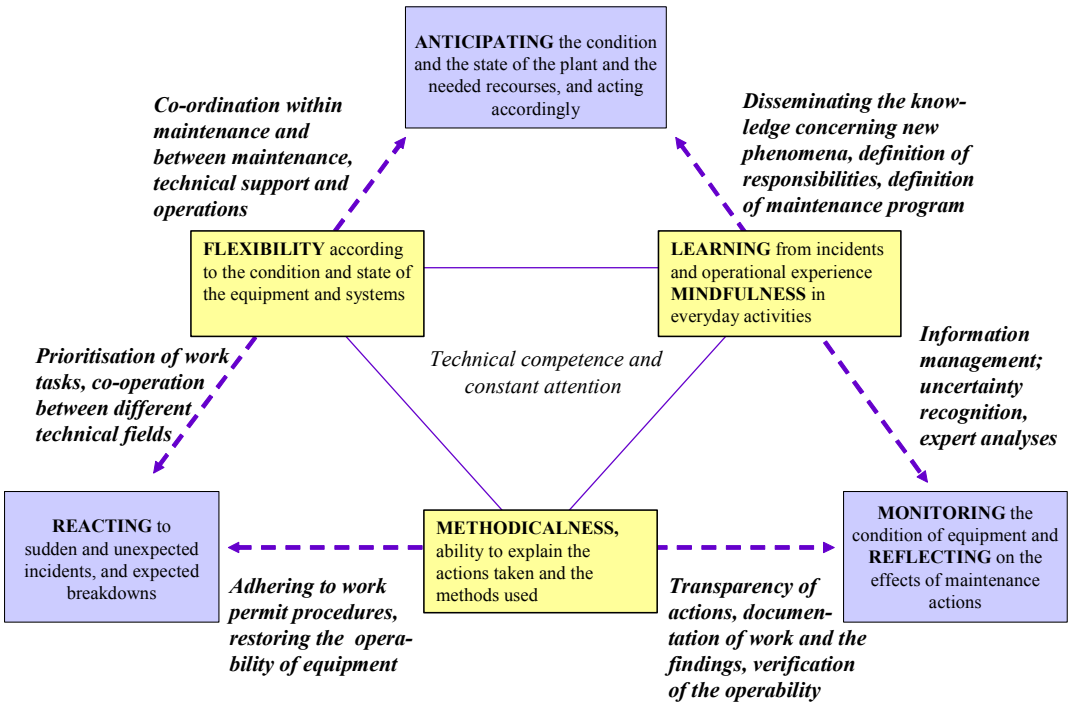


Figure 4. The model of the demands of the maintenance core task, adapted from Article I and III: critical demands (in the corners of the triangle), instrumental demands for the critical demands (between each critical demand), and demands for working practices (in italics, outside the triangle).

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
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
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

OBJECTIVES

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.

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)*.

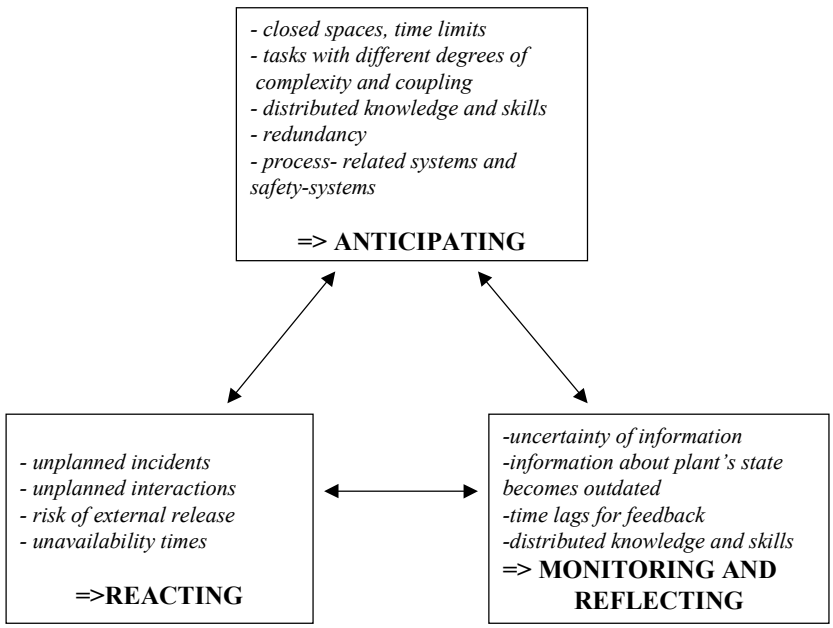


Figure 6. The critical demands of the maintenance core task and the associated constraints.

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).

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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

Section B. PLEASE READ THESE INSTRUCTIONS BEFORE ANSWERING.

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.

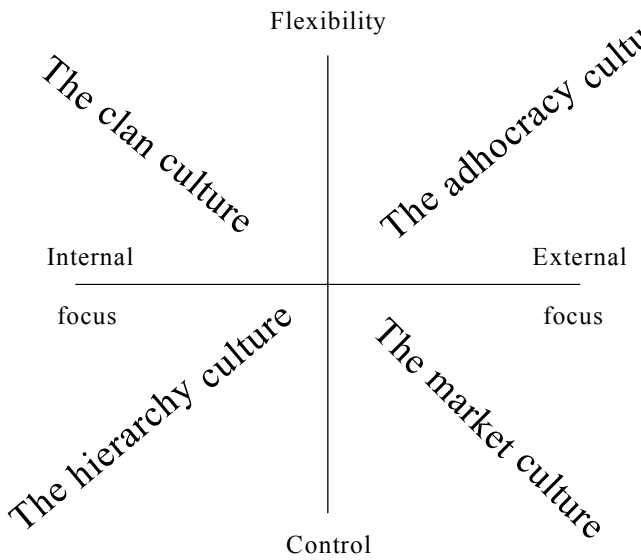


Figure D1. Cameron and Quinn's (1988, 1999) competing values framework.

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

Original publications are not included in the PDF version.
Please order the printed version to get the complete publication
(http://www.vtt.fi/publications/index.jsp)

Series title, number and report code of publication

VTT Publications 627
VTT-PUBS-627

Author(s)
Reiman, Teemu

Title

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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Keywords	Publisher
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Julkaisun sarja, numero ja raporttikoodi

VTT Publications 627
VTT-PUBS-627

Tekijä(t)
Reiman, Teemu

Nimeke

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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