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Safe Operation of Nuclear Power Plants – Is Safety Culture an Adequate Management Method?

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ABSTRACT

One of the characteristics of a good safety culture is a definable commitment to the improvement of safety behaviours and attitudes at all organisational levels. A second characteristic of an organisation with excellent safety culture is free and open communication. The general understanding has been that safety culture is a part of organisation culture.

In addition to safety culture thinking, proactive programmes and displays of proactive work to improve safety are required. This work needs to include, at a minimum, actions aiming at reducing human errors, the development of human error prevention tools, improvements in training, and the development of working methods and the organisation's activities. Safety depends not only on the technical systems, but also on the people and the organisation. There is a need for better methods and tools for organisational assessment and development.

Today there is universal acceptance of the significant impact that management and organisational factors have over the safety significance of complex industrial installations such as nuclear power plants. Many events with significant economic and public impact had causes that have been traced to management deficiencies.

The objective of this study is development of new methods to increase safety of nuclear power plant operation. The research has been limited to commercial nuclear power plants that are intended for electrical power generation in Finland. Their production activities, especially operation and maintenance, are primarily reviewed from a safety point of view, as well as human performance and organisational factors perspective. This defines the scope and focus of the study.

The research includes studies related to knowledge management and tacit knowledge in the project management context and specific studies related to transfer of tacit knowledge in the maintenance organization and transfer of tacit knowledge between workers of old generation and young generation.

The empirical results of the research are presented in research papers which are enclosed in this thesis.

Keywords: Nuclear Safety, Safety Culture, Safety Management, Knowledge Management, Organisational Culture, Co-Evolute Methodology

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This research started in 2000 and it summarises 12 years of research activities and also my experience of 36 years in nuclear power plant operation in several management and leadership positions.

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Rauma 19.11.2012

Antti Piirto

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IX Kantola, J., Vanharanta, H., Paajanen, P. & Piirto, A. *Showing asymmetries in knowledge creation and learning through proactive vision.* Theoretical Issues in Ergonomics Science, Vol. 13, No. 5, September October 2012, 570 585

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ABBREVIATIONS

IAEA	The International Atomic Energy Agency (IAEA) is the world´s center of cooperation in the nuclear field. It was set up as the world´s "Atoms for Peace" organisation in 1957 within the United Nations family. The Agency works with its Member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies.
INPO	The Institute of Nuclear Power Operations is a not-for-profit organisation headquartered in Atlanta established by the nuclear power industry in December 1979.
Management system	A set of interrelated or interacting elements (system) for establishing policies and objectives and enabling the objectives to be achieved in an efficient and effective manner.
NRC	The U.S. Nuclear Regulatory Commission (NRC) was created as an independent agency by Congress in 1974 to enable the nation to safely use radioactive materials for beneficial civilian purposes while ensuring that people and the environment are protected. The NRC regulates commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine, through licensing, inspection and enforcement of its requirements.
Nuclear safety	The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards.
OECD/NEA	The Nuclear Energy Agency (NEA) is a specialised agency within the Organisation for Economic Co-operation and Development (OECD), an intergovernmental organisation of industrialised countries, based in Paris, France.

Organisation Dynamic, multi-faceted human system that operate in dynamic environments in which what exactly suits at one time and one place cannot be generalised into a detailed universal truth (Dawson 1996, p. 162).

Performance indicator Characteristic of a process that can be observed, measured or trended to infer or directly indicate the current and future performance of the process, with particular emphasis on satisfactory performance for safety.

Periodic safety review A systematic reassessment of the safety of an existing facility (or activity) carried out at regular intervals to deal with the cumulative effects of ageing, modifications, operating experience, technical developments and siting aspects, and aimed at ensuring a high level of safety throughout the service life of the facility (or activity).

Safety culture The assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance (IAEA's definition).

Safety indicator A quantity used in assessments as a measure of the radiological impact of a source or practice, or of the performance of protection and safety provisions, other than a prediction of dose or risk.

Self-assessment A routine and continuing process conducted by senior management and management at other levels to evaluate the effectiveness of performance in all areas of their responsibility.Self-assessment activities include review, surveillance and discrete checks, which are focused on preventing, or identifying and correcting, management problems that hinder the achievement of the organisation's objectives, particularly safety objectives. Self-assessment provides an overall view of the performance of the organisation and the degree of maturity of the management system. It also helps to identify areas for improvement

	in the organisation, to determine priorities, and to set a baseline for further improvement.
WANO	The World Association of Nuclear Operators (WANO) is an organisation created to improve safety at every nuclear power plant in the world.

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1. INTRODUCTION

One factor connecting utility companies and nuclear power plants, contractors, regulators, and researchers working in the field of nuclear power is the recognition of the paramount importance of safety. This is manifested in the form of extensive and conservative norms, procedures, and laws that control nuclear power-related activities worldwide. The safety of nuclear plants has been developed and refined over a period of more than 35 years. A report by the International Nuclear Safety Advisory Group contains fifty specific safety principles (INSAG-3, 1988). Until the Chernobyl accident, no commercial nuclear power plant had ever had an accident causing radiation injury to members of the public or to the workers at the plant. However, when analysing the causes of the accident, it was established that the role of plant management cannot be underestimated because formal requirements alone do not guarantee safe operations. This is why active safety management is needed (OECD/NEA 1999a; OECD/NEA 1999b).

1.1. Background

V. C. Marshall has presented a historical review of the development of the management of hazards and risks in the energy-generating and distribution industries. In its early history, energy generation or, more strictly, the transformation of primary sources of energy into a form that is utilisable by the manufacturing industry, took place close to the point of use. This was no doubt due to an instinctive appreciation of the need to minimise transmission losses. Both water mills and wind mills had generating capacities of up to about 10 kW per unit. Factories, mainly for the manufacture of textiles, came into existence in the UK long before there was any system of centrally generated power and thus power had to be generated on the spot. Eventually some water-powered factories generated up to 150 kW. When steam power replaced water power the same basic system of energy transmission was used. However, the scale was larger, with some power houses developing up to 1500 kW (Marshall 1992, pp. 63-85).

These changes were accompanied by a corresponding increase in the hazards associated with the mechanical systems involved. Although statistics are lacking, there seems little doubt that these developments brought about a heavy toll of death and injury. This was reflected in the introduction of factory legislation which enacted, inter alia, that prime movers, flywheels, and transmission machinery must be securely fenced and that provision must be made for power to be shut off from the workplace in the case of an emergency. The introduction of steam power brought about the widespread use of steam

boilers of the shell type. This brought into existence the hazard of steam-boiler explosions which had the capability of injuring not only employees but also the members of the public living nearby. The first Act of Parliament to regulate boilers on land was the Boiler Explosions Act of 1882 which still remains in force. Eventually, scientific input began to come from boiler insurance companies, which were started in order to provide this service in the middle of the century. Insurance inspectors noted that on their rounds they found many examples of boiler safety valves which had been deliberately disabled. There was no specialist safety management as a staff function; safety management and line management were one and the same thing (Marshall 1992, pp. 63-85).

1.1.1. Development of safety management

The inauguration of public electricity-supply systems around 1880 was the beginning of a new era. Electricity was able to provide power, heat, light and, eventually, the means of operation of systems of communication such as the telegraph. One effect was to sweep away locally generated power for driving factory machinery with a consequent reduction in risk to factory workers who were no longer exposed to danger from steam power and mechanical transmission systems. From its inception, the supply industry had to come to terms with the dangers arising from electric shock (the first fatality from electric shock was recorded in 1879 in France) or from the overheating of conductors of inadequate capacity. Such inventions as fuses and circuit breakers came early. Conductors had to be either insulated or out of reach. Thus, management had to be in the hands of technically competent staff; the Institution of Electrical Engineers in its present form dates from 1888. This high level of managerial skill must have contributed to the good record of the industry (Marshall 1992, pp. 63-85).

The introduction of nuclear power for generating electricity after 1956 produced a major change in the responsibilities of management. Before this time, the hazard of steam-boiler explosions existed but these were unlikely to give rise to danger to life outside of a radius of, say, 0.5 km which for most large generating stations would confine the hazard to the factory site. With the coming nuclear power, the hazard radius was greatly increased and thus there came into being a major public dimension. As a consequence, the responsibilities of management also greatly increased. This was because a new technical dimension had appeared. The hazards of steam-raising plants remained, but now the far more serious hazards of nuclear reactors were added to them. This required a major upgrading of managerial skills and knowledge (Marshall 1992, pp. 63-85).

Safety culture, or safety climate as it can also be called, represents the flesh and blood and nerves and sinews where the skeleton is the formal structure of safety. Safety culture also represents, and perhaps even more importantly, the *spirit* of safety management in any organisation. For no matter how well worked-out the structures and procedures may be, they cannot be fully effective unless there is a spirit of co-operation between all of those concerned. Top managers must also set a personal example. Criticism of organisations for deficiencies in their safety culture has been a constant theme in the reports of inquiries into disasters, although in the past this term was not used. There was such criticism in the reports on the Flixborough disaster (Parker 1976), the Clapham rail disaster (Hidden 1989) and the Piper Alpha disaster (Cullen 1990), (Marshall 1992, pp. 63-85).

On the basis of this historical review by Marshall, corrective actions to enhance safety have often been reactive. They should be proactive to avoid the catastrophic consequences of accidents. Nuclear industry and other high risk industries should take care of the development of risk management methods in such a way that they are compatible with the increased risk of developed technology.

1.1.2. Management and organisational factors

Today, there is universal acceptance of the significant impact that management and organisational factors have over the safety significance of complex industrial installations such as nuclear power plants. Many events with significant economic and public impact had causes that have been traced to management deficiencies. The Rogovin report on the TMI-2 accident underlined the importance of problems associated with the management, organization, and institutional structure (Rogovin 1980). The Chernobyl accident is an example of multiple institutional, organizational, and management flaws, identified as determining contributors to the accident (Martin 1999).

In developing safety management methodologies they should be based on scientific analyses to identify and understand the individual causes involved and their effects. We should focus on the importance of this approach to safety management using the potential of human behaviour and management sciences (Martin 1999). While technical performance at nuclear power plants has benefitted from the significant improvement in the knowledge of materials, equipment and systems performance, etc. there has not been a similar general improvement of management practices. For many years it has been considered that managing a nuclear power plant was mostly a matter of high technical competence and basic managerial skills. The field of nuclear technology has been dominated by hard sciences while individual, organizational, and

managerial factors were considered in the realm of “soft sciences” whose potential contribution lasted to gain the acceptance needed. Some degree of frustration also became apparent after earlier research efforts (Martin 2002).

In high risk industrial environments such as nuclear power plants, chemical factories, railways or the aircraft industry, people in charge of work organisation tend to be engineer-technicians of a very homogeneous scientific background. For a number of decades, engineers have structured the organisation of high-risk industries. This has been achieved in a highly technical-bureaucratic fashion through successive reforms and as a result of fairly unilateral thinking. The resulting organisational innovations are hardly ever submitted to external criticism, let alone reliability assessments (of the organisation itself). No diagnosis is ever attempted. Organisations are generally modified, adjusted, and amended, without any prior justification or debate. Most of these changes are implemented top-down and yet the way they reach the bottom suggests that there is much variety in the way reforms are received, understood, and really implemented (Bourrier 2005).

In addition, many companies have observed differences in the actual working practices from one plant to another. This reality suggests there is a limit to homogeneous managerial rhetoric and in reality a great diversity of organisational practices exists, both on paper and on site. However, there appear to be few analyses and comparisons, or much questioning of this variety, not necessarily to determine the “best model”, but at least to try to assess each individual model in order to better understand its own logic and forecast its possible evolution. Designing work organisation in high-risk industries has rarely been a subject matter for organisation science – despite interest in these questions over the years (Bourrier 2005).

1.1.3. Safety culture

From a research point of view, safety culture is a challenging concept. Safety essentially depends on how people perform in their work. Is safety valued in general? How is it visible? Safety culture has been shown to be a difficult concept. It is especially vague to those carrying out practical safety work. Those involved in practical safety work require explanations concerning how safety culture will alter their work, and how it relates to any earlier means of promoting safety in a company. There are also many different definitions and emphasis areas in research. Researchers are still involved in the analysis of the concept and its neighbouring concepts (Ruuhilehto & Vilppola 2000).

During the past decade, it has been widely recognised that different factors controlled by the organisation of a nuclear power plant have an important

influence on the safety attitudes and the safe behaviour of individuals. With the development of the concepts of safety culture and quality management, interest in these influences started to increase. The importance of organisational performance has been demonstrated when some nuclear power plants were shut down due to significant organisational problems. The increasing focus on organisational factors led to the consequence that event analyses more frequently identified organisational factors as root causes and contributing causes of events (Ruuhilehto & Vilppola 2000).

In nuclear power plants, various versions of the functional organisation model are usual. There are some weaknesses which are inherent in the functional organisation. These are connected to processes and behaviours that cross organisational boundaries and that address organisational integration and interfaces.

1.1.4. Knowledge management

Today, increased attention is being given to phenomena such as learning organisations, human and organisational performance improvement, change management; knowledge management, and integrated management systems. As companies are increasingly recognising employees as being their most valuable assets, increased focus is being put on the critical roles that humans play in each of these phenomena. The increasing recognition of the invaluable nuclear power plant asset known as human or intellectual capital is having an enormous impact on the attention being paid to knowledge management (IAEA 2006).

Some of the knowledge management challenges that are faced by the nuclear industry include a complex technology base with a design basis as well as operation and management infrastructure. The nuclear power plant life cycle is very long, and there is a dependence on multidisciplinary technologies and extensive expertise. Stringent requirements for safety, nuclear quality assurance, and equipment and design configuration management must be maintained and achieved. A further question arises on how knowledge should be transferred to the younger generation. Knowledge transfer must be encouraged. National governments and also nuclear power companies should ensure that adequate education and training is made available in the nuclear industry (IAEA 2005).

1.2. Research objective and propositions

The objective of this study is the development of new methods to increase the safety of nuclear power plant operation. The research has been limited to

commercial nuclear power plants that are intended for electrical power generation in Finland. Their production activities, especially operation and maintenance, are primarily reviewed from a safety point of view, as well as human performance and organisational factors perspective. This defines the scope and focus of the study.

When analysing the root causes of major accidents, including nuclear power plant accidents, it has been established that factors related to the organisation have often been significant. As the number and generation power of nuclear power plants increase, the risk of accidents also increases. In addition to the nearby areas, the effects of recent major nuclear power plant accidents have spread far into other countries' territories. The general public is worried about the catastrophic outcomes of a nuclear power accident. The design basis of nuclear power plants will need to be adjusted, since earlier criteria have not been sufficient to ensure safety. Changes are especially required in areas related to human performance and organisational factors. Safety management at nuclear power plants needs to become more transparent in order to enable us to ensure that issues are managed correctly. Ensuring the safety of the nearby population is the best type of corporate responsibility. Answers to these questions are sought on a general level.

In 1984, Charles Perrow, an organisational theorist, published a highly influential book, *Normal Accidents: Living with High-Risk Technologies*, in which he advanced the bleak proposition that accidents are inevitable in complex, tightly-coupled systems like nuclear power plants – regardless of the skills of the operators and managers. Hence the title: accidents in such systems are "normal" (Perrow 1984; cf. also Kharbanda & Stallworthy, 1988).

Reason (1997) lists as examples of organisational accidents and maintenance failures:

- *Apollo 13*
- *Flixborough*
- *Three Mile Island*
- *American Airlines Flight 191 at Chicago O'Hare*
- *Bhopal*
- *Japan Airlines Flight JL 123 at Mount Osutaka*
- *Piper Alpha*
- *Clapham Junction.*

Two more can be added to the list:

- *Texas City refinery explosion*
- *The Deepwater Horizon oil spill.*

We can conclude that as technology develops, the analysis, methods, and procedures to ensure safety must also be developed accordingly. Earlier, the human-machine interface has been a central object of study for control room design. The emphasis has mainly been on the control room operator's technical means of receiving information about the production process and controlling it. As the analogue technology in the reactor protection and control systems is converted to digital technology, this brings about changes to the organisation of the activities. A more abstract I&C environment requires quality assurance methods and quality control that are similar to more concrete machine technology. The human-machine interface also needs to become a more generic human-organisation-machine interface, which is not limited to the control room, but rather refers to the entire operating organisation. However, this is only one of the future challenges. In general, new thinking and new methods are required to provide a versatile approach to ensuring safety. This is the goal for this research. The study has developed some methods that can in part aim to bring about improvements in safety.

The starting point of the research is the definition of safety culture that IAEA has adopted (INSAG-4, 1991):

"Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance."

The general starting point has been that safety culture is a part of organisation culture. The concept-analytical part of the study discusses the background of the safety culture concept in order to understand how safety culture can be deduced from the basic principles of organisation culture. Cooper states that "Unless safety is the dominating characteristic of corporate culture, which arguably it should be in high-risk industries, safety culture is a sub-component of corporate culture, which alludes to individual, job, and organisational features that affect and influence health and safety" (Cooper 2000). According to this, safety culture should have more emphasis on high-risk industries. This study proposes that safety culture is a necessary condition, but not a sufficient condition in itself in order to ensure the safety of nuclear power plant operation.

In addition to safety culture thinking, proactive programmes and displays of proactive work to improve safety are required. This work needs to include, at a minimum, actions aiming at reducing human errors, the development of human error prevention tools, improvements in training, and the development of working methods and the organisation's activities. Safety depends not only on the technical systems, but also on the people and the organisation. There is a

need for better methods and tools for organisational assessment and development.

This study presents knowledge management issues broadly, based on Nonaka's model. The idea is that, as an analogous counterpart to the Japanese "quality circles", a "safety circle" should be introduced; this would allow for having discussions on safety issues related to the work, and for making improvement proposals related to them. A second analogy that should be followed is the "Systematic Approach to Training" that is used for training activities; as a result of the development, the nuclear power plant would have a documented "Systematic Approach to Safety". This documentation would describe how safety is related to practical work. This would turn safety culture into a concrete tool. Documented safety thinking provides the organisation with a common starting point for future development.

It follows from the definition of safety culture that the organisation's competence is of great importance. The issues important for safety must be identified, and the correct actions must be taken. Training must be renewed because society no longer provides a sufficient amount of trained personnel through its universities. As an advanced business, the nuclear industry must use its own training to ensure that the power plant organisation has sufficient qualifications for its duties. The nuclear power plant organisation has a large amount of information that needs to be preserved, developed, and utilised. Therefore, traditional training must become knowledge management.

Technology has been the main focus from the very beginning, while the enhancement of human performance has mainly been a concern in reporting and analysing human errors. The United Kingdom has been a pioneer in the development of human error prevention tools and techniques.

A depth-oriented defence with consecutive barriers has been the starting point for nuclear power plant design. Administrative actions have been seen to supplement these barriers. However, since a safety analysis in its purest form has not credited administrative protections, its development has been sidelined. Such administrative actions should form a similar system of consecutive barriers. If such a system has not been analysed or described, and the different actions have not been placed in order of priority, the personnel cannot have a mental image of the system structure, and the development of the common cause cannot proceed.

This research has been carried out over twelve years. The research has been closely connected with master's theses, in which the researcher has been

involved in the design, implementation, guidance and results analysis. These master's theses are:

- Liikamaa (2000): Activated use of tacit knowledge in project management
- Isotalo (2002): Competence development through the transfer of formal and tacit knowledge
- Alatolonen (2000): Conceptions of safety among nuclear power plant employees
- Nurminen (2003): Deltoid – competencies of nuclear power plant operators
- Nirhamo (2002): Towards human-oriented computerised maintenance management system
- Saarela (2002): Decision-making in maintenance with the help of multimedia
- Paajanen (2003): Lituus – a system for the evaluation of learning and knowledge creation in a business context
- Mäkiniemi (2004): Conchoid – self-evaluation system for maintenance personnel's competencies
- Rinne Päivi (2008): Ontology of maintenance

They form an area of research where the central themes are safety culture, competence, tacit knowledge, data systems supporting activities, and participation in the development of the Co-Evolute methodology as well as developing applications related to methodology. The empirical material is included in the attached ten research papers. They are joined together by the researcher's own experience and tacit knowledge from a total of 36 years in different management and supervision tasks in a nuclear power plant organisation. This experience was gathered from the following areas: reactor physics, reactor technology, reactor operational supervision, nuclear fuel handling, nuclear safety supervision, deterministic safety assessments, probabilistic safety assessments, nuclear power plant operation and maintenance, general training, and simulator training.

The researcher has worked for twelve years as the Manager of Operation for the Olkiluoto nuclear power plant, and as the substitute for the responsible director who is referred to in the Nuclear Energy Act. From this time, he has experience in co-operation with all of the nuclear power plants in Sweden, Germany, and Switzerland, and with the boiling water reactor plants in Japan. Other types of co-operation have existed with some of the nuclear power plants in the United States, Spain, Belgium, the Netherlands, and China. During the last ten years, the researcher has worked as a Project Manager for the

European Commission's On-Site Assistance projects at three Russian power plants and the Bulgarian nuclear power plant, and participated in the co-operation of nearby regions funded by the Government of Finland. This co-operation has consisted of annual workshops with the Kola and Leningrad NPPs, where the methods of Finnish nuclear power plants, related to control room personnel training programmes, licensing, safety culture, and maintenance activities, have been presented. Different language versions of the Co-Evolute applications have been created, and they have been tested at the Russian nuclear power plants, for example.

The objective of this research can be divided into the following two goals:

- Goal 1. The first goal is to explore the theories related to the organisational culture, safety culture, and nuclear safety culture.

- Goal 2. The second goal is to construct the ontologies for assessing competencies of operation and maintenance personnel.

The following five propositions have been identified:

- Proposition 1. Safety culture as a management tool does not work unless in the task analysis safety relevance of each task is specified in advance

- Proposition 2. Human performance related training should be more adequately taken into account in the training programme of nuclear power plant operators

- Proposition 3. Importance of nuclear power plant maintenance to safety should be more adequately taken into account in the training programme

- Proposition 4. In the design of work organisation, also learning from experience should be taken into account to prevent risks of organisational accidents

- Proposition 5. Knowledge management, knowledge transfer, and knowledge creation is integrated part of safety management

This research is limited to review nuclear power plant operating organisations only from the viewpoint of nuclear safety.

1.3. Research strategy

The research in the field of Industrial Engineering and Management often seeks to answer the question of what the world should be and it also emphasises the relevance of the research problem instead of methods. As a result – various approaches, research methods, and explaining mechanisms are used in different research themes.

In this research, a conceptual approach is used to define the concepts, which are included in the framework of organisational culture, safety culture, and safety management. In the context of the nuclear power plant's operation, these concepts have been analysed from the safety point of view.

A constructive research approach is used when building assessment systems for nuclear power plant operation personnel and maintenance personnel. It is assumed that developed constructs can contribute to the enhancement of an organisation's operating competence and thus also enhance the safety of operation. Several case studies are used to demonstrate how constructs work in practice.

1.4. Content of thesis

Chapter 1 contains an introduction to the research. This chapter also deals with the background of the research, research objectives, problem formulation, and research strategy. The content of the thesis is also presented in this chapter.

Chapter 2 deals with the theoretical framework of the research. Chapter 2 outlines the concepts related to organisational culture, safety culture, safety management, and knowledge management.

Chapter 3 presents the results of the research covering safety culture, knowledge management, competencies of control room operators and competencies of maintenance personnel. It also presents a summary of the research papers. Research papers deal with different case studies and methods to review evaluation results. This chapter also presents the results of the discussion related to operation, maintenance, and safety management and presents how well the research objective was realised.

Chapter 4 presents the theoretical contribution of the research and proposes topics for further research.

Appendix. Ten research papers are attached to this thesis. The author's contribution in each publication is also presented.

2. THEORETICAL FRAMEWORK

This chapter is based on a literature review related to organisational culture, safety culture, and knowledge management.

2.1. Organisational culture

Many of the debates about organisational culture are caused by people's use of different concepts and definitions. This chapter seeks to clarify matters by examining just what organisational culture is (Ott 1989, p. 49).

2.1.1. Concepts and definitions

There are two very basic ways to go about defining complex concepts (Ott 1989, p. 49):

- Inductively building a generalised theoretical definition from one's experiences, preferences, and assumptions; and
- Working deductively from a generalised theory, analysing realities to see how they fit with theory, and modifying theory based on the results of analyses.

While this chapter uses both deductive and inductive approaches, deduction predominates. Keesing (1974) and Schein (1981, 1984, 1985, 2010) provide the theory for creating an initial classification system, or a typology of organisational culture elements (Miles & Huberman 1984), which is then used to analyse and compare a wide array of concepts of organisational culture that has been proposed by writers. The typology is used as the analytical framework for understanding different aspects of organisational culture, such as the relationships between organisational culture, leadership, change strategies, and research methodologies (Ott 1989, p. 49).

Organisational culture can be characterised as follows (Ott 1989):

- Organisational culture is the culture that exists in an organisation, something akin to the societal culture.
- It is made up such things as values, beliefs, assumptions, perceptions, behavioural norms, artefacts, and patterns of behaviour.
- It is a socially constructed, unseen, and unobservable force behind organisational activities.
- It is a social energy that moves organisation members to act.
- It is a unifying theme that provides meaning, direction, and mobilisation for organisation members.

- It functions as an organisational control mechanism, informally approving or prohibiting behaviours.

There is no consensus about organisational culture and the unanimity of concepts among proponents of the organisational culture perspective. There are very important substantive disagreements. The most fundamental of these involves the contents or composition of an organisational culture: what are the elements, constructs, and attributes of an organisational culture? The differences are more than semantic debates. They reflect serious disagreements about how one views, investigates, manages, and changes organisations (Ott 1989, p. 50).

The first step towards understanding the essence of organisational culture is to appreciate that it is a concept rather than a thing. This distinction is crucial. A thing can be discovered and truths established about it, for example, through empirical research. Unlike a thing, however, a concept is created in people's minds – that is, it must be conjured up, defined, and refined. Thus, ultimate truths about organisational culture cannot be found or discovered. There is no final authoritative source or experiment to settle disagreements about what it is or what comprises it (Ott 1989, p. 51). Therefore, when someone claims to have identified an organisational culture, that discovery represents nothing more than the results obtained from applying that person's concept of organisational culture in a given organisation. Another discoverer who uses a different concept-driven deciphering process will find a different culture in the same organisation (Van Maanen 1979, 1983; Herbert 1987).

The second important thing to remember is that how one looks at organisational culture largely determines what it is. When we start thinking about organisational culture structurally, we create structural typologies that, in turn, cause us to forget that organisational culture is not just structural elements. It also is a dynamic process – a social construction that is undergoing continual reconstruction.

Organisational culture's definitional problems mirror longstanding arguments in anthropology, archaeology, and cultural anthropology about the general concept of culture. In 1952, the cultural anthropologists Kroeber and Kluckhohn identified 164 different definitions of culture existing in their search of the literature (Kroeber & Kluckhohn 1952).

As recently as 1982, Ian Hodder described and bemoaned the problems caused by continuing debate between anthropologically oriented and materially oriented archaeologists over what culture is. The situation is perhaps even less clear relative to organisational culture.

There are very few areas of general consensus about organisational culture. They include the five assumptions stated earlier in this chapter:

- Organisational cultures exist
- Each organisational culture is relatively unique
- Organisational culture is a socially constructed concept (Berger & Luckmann 1966; Holzner & Marx 1979; Mead 1934)
- Organisational culture provides organisation members with a way of understanding and making sense of events and symbols
- Organisational culture is a powerful lever for guiding organisational behaviour. It functions as “organisational control mechanisms, informally approving or prohibiting some patterns of behaviour” (Martin & Siehl 1983).

However, beyond these five basic points, agreement is very limited, and the points say nothing about what organisational culture is. Consensus is restricted to its existence, relative uniqueness, and a few functions that it performs. In a summary, there are seventy-three words or phrases used to define organisational culture from the fifty-eight different published sources. It is easy to see why Kroeber and Kluckhohn (1952) found 164 definitions of culture. Clearly the concept has not been clarified very much since 1952, at least not by those who have written about organisational culture.

The study of organisational culture has become one of the major domains of organisational research. The rise of research on organisational culture came about because Japanese firms were, during the late 1970s and the early 1980s, widely considered to have superior operating characteristics, but the forms of organisational research that were dominant emphasised a formal structure and so they failed to uncover any difference between Japanese and Western firms. As a consequence, scholars began to examine the possibility that the different national cultures might have penetrated modern corporate forms, thus creating differences in organisational culture. Several early studies gave credence to this approach, which led next to the possibility that even within a single national culture there might be local differences in the culture of firms.

A casual inspection of the contemporary literature suggests that most of those who study organisational culture trace their intellectual roots to a few key anthropologists. Both the point of view and the method of the anthropologist might seem to have been heavily borrowed by the respective researcher of organisation. It is undeniable that anthropological style and method have been a great, perhaps the single greatest, influence on contemporary studies.

The contemporary study of organisational culture may be best understood as a continuation of the main line of organisational sociology, which has always focused on the normative bases and the shared understandings that, through subtle and complex expression, regulate social life in organisations (Ouchi & Wilkins 1985).

2.1.2. The intellectual foundations of organisational culture

The contemporary study of organisational culture appears to amalgamate several points of view, rather than to constitute one branch of a single disciplinary family of scholarship. There is no single dominant point of view or method but rather a rich mixture of ideas and approaches. In 1983, three collections of articles on organisational culture appeared: an anthology on Organizational Symbolism (Pondy et al. 1983) and special issues of Administrative Science Quarterly (Vol. 28, No. 3) and of Organizational Dynamics (Vol. 12, No. 2). In all, these comprise 32 articles. Of the seven most frequently cited works, one was written by an anthropologist; three were authored or co-authored by sociologists, and three by management scholars. Most frequently cited works were (Ouchi & Wilkins 1985):

- Geertz 1973, *The Interpretation of Cultures* – ten citations;
- Berger & Luckman 1966, *The Social Construction of Reality: A Treatise in the Sociology of Knowledge* – seven citations;
- Clark 1970, *The Distinctive College: Antioch, Reed, and Swarthmore* – seven citations;
- Deal & Kennedy 1982, *Corporate Cultures* – seven citations;
- Ouchi 1981, *Theory Z* – six citations;
- Pettigrew 1979, *On Studying Organizational Culture* – six citations;
- Weick 1979, *The Social Psychology of Organizing* – six citations.

2.1.3. The concept of corporate culture

Much management thinking in recent decades has focused on the concept of corporate culture. Some of the writings on the topic (e.g. Peters & Waterman 1982, Ouchi 1981, Pascale & Athos 1981, Deal & Kennedy 1982, Hofstede 1990) have been extremely influential among practising managers, mainly via its assumed relationship with organisational performance. It is generally thought that a well-developed and business-specific culture into which managers and employees are thoroughly socialised will lead to stronger organisational commitment, more efficient performance and generally higher productivity (Deal & Kennedy 1982, Graves 1986, Hampden-Turner 1990).

Usually based upon a blend of visionary ideas, corporate culture appears to reflect shared behaviours, beliefs, attitudes, and values regarding organisational goals, functions, and procedures which are seen to characterise particular organisations (Furnham & Gunter 1993). The maintenance of the dominating corporate culture within any organisation, therefore, is supported by on-going analyses of organisational systems, goal-directed behaviour, attitudes, and performance outcomes (Fry & Killing 1989). However, due to a general lack of information on how culture works, or how it can be shaped, changed, or otherwise managed in practice (Furnham & Gunter 1993), there is no consistent definition of what corporate culture might be (Williams et al. 1989).

Williams et al. (1989) take the issue with the notion that organisational culture reflects shared behaviours, beliefs, attitudes and values. They argue that not all organisational members respond in the same way in any given situation. Beliefs, attitudes and values about the organisation, its function or purpose can vary from division to division, department to department, workgroup to workgroup, and from individual to individual. Several different sub-cultures will emerge from, or form around, functional groups, hierarchical levels and organisational roles, with very few behaviours, beliefs, attitudes or values being commonly shared by the whole of the organisation's membership.

2.1.4. The influence of anthropology on organisational culture

Most of the current work on organisational culture draws upon the spirit, if not details, of the functionalist tradition in anthropology. This influence can be further divided between two rather distinct forms of contemporary work.

Radcliffe-Brown (1952) and Malinowski (1961) represent a school of thought in anthropology that encourages the scholar to consider a group or society as a whole and see how its practices, beliefs, and other cultural elements function to maintain social structure.

A second school of thought in anthropology is perhaps best represented by Clifford Geertz (1973). Along with other contemporary anthropologists, such as Goodenough and Lévi-Strauss, Geertz emphasises the importance of discovering the "native point of view". This approach has been called "semiotic" for its focus on language and symbols as the principal tools for apprehending the native's perspective. Geertz (1973, p. 24) suggests that "the whole point of a semiotic approach to culture is to aid us in gaining access to the conceptual world in which our subjects live so that we can, in some extended sense of the term, converse with them".

Goodenough (1971) and others have developed an approach labelled “ethnoscience”, “componential analysis”, or “cognitive anthropology”. While their aim is similar to that expressed by Geertz, they differ considerably in method. Culture for ethnoscientists is the system of standards or rules for perceiving, believing, and acting that one needs to know in order to operate in a manner acceptable to the members of the culture. Anthropologists in this tradition have been strongly influenced by linguists (e.g. Chomsky 1972). They have in mind that just as a learnt, and usually implicit, grammar helps people generate acceptable sentences, cultural rules and categories and principles also help people to generate acceptable behaviour. The methods suggested by Geertz require a great deal of artistic ability and intuition while Goodenough’s methods are more systematic and thus easier to learn.

2.1.5. The influence of organisational sociology on organisational culture

The review of Ouchi and Wilkins (1985) suggests both that the study of large firms is in a period of experimentation and that it draws upon many insights that anthropologists, sociologists, and psychologists have developed in the study of other forms of social organisation. Several points of view are now in active contention for dominance among researchers of organisational culture. One contest is over whether culture is a *dependent* or an *independent* variable (Ouchi & Wilkins 1985).

Among those who prefer to study organisational culture as a *dependent* variable, some take a natural-systems point of view and conclude that the culture of a firm is the natural outgrowth of its particular time and place and is not subject to human attempts at manipulation, while others assert that critical features of organisational culture may be systematically altered by a determined management (Ouchi & Wilkins 1985).

Those who view culture as an *independent* variable tend to ignore these possibilities and instead seek to explicate the variety of forms through which the subtle and implicit features of organisation influence the thoughts, feelings, and behaviour of individual participants (Ouchi & Wilkins 1985).

A second contest is over the appropriate *methods of study*. Some hold that the method of lengthy field observation must be employed, while others assert that the whole point of contemporary study of organisational culture is to go beyond the method of the anthropologist by applying multivariate statistical analysis to these issues (Ouchi & Wilkins 1985).

2.2. Safety culture

In 1991, the International Nuclear Safety Advisory Group (INSAG) introduced the concept of safety culture in its report (INSAG-4, 1991). Since then, many papers have been written on safety culture, as it relates to organisations and individuals, its improvement and its underpinning prerequisites. Variations in national cultures mean that what constitutes a good approach to enhancing safety culture in one country may not be the best approach in another. However, INSAG seeks to provide pragmatic and practical advice of wide applicability in the principles and issues presented in the report INSAG-15 (INSAG-15, 2002).

2.2.1. The concept of safety culture

The concept of safety culture was initially introduced in the “Summary Report on the Post-Accident Meeting on the Chernobyl Accident” (INSAG-1, 1986). The concept was further expanded in the report “Basic Safety Principles for Nuclear Power Plants” (INSAG-3, 1988, later replaced by INSAG-12, 1999) and finally in the report, “Safety Culture” (INSAG-4, 1991).

It is loosely used to describe the corporate atmosphere or culture in which safety is understood to be, and is accepted as, the number one priority (Cullen 1990). Unless safety is the dominating characteristic of corporate culture, which arguably it should be in high-risk industries, safety culture is a sub-component of corporate culture, which alludes to individual, job, and organisational features that affect and influence health and safety (Cooper 2000).

IAEA definition*: “Safety culture is that assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance”* (INSAG-4, 1991).

In all types of activities, for organisations and for individuals at all levels, attention to safety involves many elements:

- Individual awareness of the importance of safety.
- Knowledge and competence, conferred by training and instruction of personnel and by their self-education.
- Commitment, requiring demonstration at the senior management level of the high priority of safety and adoption by individuals of the common goal of safety.
- Motivation, through leadership, the setting of objectives, systems of rewards and sanctions and through individuals’ self-generated attitudes.

- Supervision, including audit and review practices, with readiness to respond to individuals' questioning attitudes.
- Responsibility, through formal assignment and description of duties and their understanding by individuals.

Safety Culture has two general components. The first is the necessary framework within an organisation and the responsibility of the management hierarchy. The second is the attitude of the staff at all levels in responding to and benefiting from the framework.

The concept of safety culture that is defined in INSAG-4 emerged from discussions of the Chernobyl Accident (cf. INSAG-7), and understandably has a strong nuclear connotation. Another definition by the ACSNI Human Factors Study Group in the UK that is similar in spirit, but which also describes more explicitly the characteristics of an organisation that has a positive safety culture is:

"Safety culture is the product of individual and group values, attitudes, competencies and patterns of behaviour that determine the commitment to, and the style and proficiency of an organisation's health and safety programmes. Organisations with a positive safety culture are characterised by communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of preventive measures."

The Nuclear Regulatory Commission defined safety culture in a somewhat similar but more succinct way:

"A good safety culture in a nuclear installation is a reflection of the values, which are shared throughout all levels of the organisation and which are based on the belief that safety is important and that it is everyone's responsibility."

Anyone interested in analysing safety culture can refer to these definitions or apply the Three Level model by Schein (IAEA 2002).

2.2.2. A review of the literature

Gadd and Collins (2002) review the literature on safety culture, focusing particularly on research carried out from 1998 onwards. The objectives were to review the main features of safety culture and safety climate within the existing academic and applied literature and to explore the links between safety culture and safety performance. The main findings were the following:

- Culture can be seen as a concept that describes the shared corporate values within an organisation which influences the attitudes and

behaviours of its members. Safety culture is a part of the overall culture of the organisation and is seen as affecting the attitudes and beliefs of members in terms of health and safety performance (Cooper 2000). Safety climate is a distinct yet related concept which can be seen as the current surface features of safety culture which are discerned from the employee's attitudes and perceptions (Flin et al. 2000). However, in reality, the terms are not so clear cut and many writers use the terms safety culture and safety climate interchangeably.

- From the literature it emerged that management was the key influence of an organisation's safety culture. A review of the safety climate literature revealed that employees' perceptions of management's attitudes and behaviours towards safety, production and issues, such as planning, discipline etc. was the most useful measurement of an organisation's safety climate. The research indicated that different levels of management may influence health and safety in different ways, for example managers through communication and supervisors by how fairly they interact with workers (Thompson 1998). Thus, the key area for any intervention of an organisation's health and safety policy should be management's commitment and actions towards safety. Ultimately management's attitudes and behaviour in terms of safety influence many aspects of safety behaviour.
- Many definitions of safety culture (e.g. ACSNI 1993) present a view of employees having a shared set of safety values and beliefs. However, a number of studies have found the presence of subcultures within an organisation which suggest an absence of a cohesive safety culture. Subcultures are likely to develop when employees within the same organisation experience different working conditions. Work groups within an organisation are likely to view risk differently depending on the type of work they do. In general, subcultures are not seen as undesirable and it can be argued that they provide useful contextual insight into the different risk and hazards experienced by workgroups.
- The literature on bonus schemes suggests that financial incentives to improve productivity or to compensate for working in hazardous conditions can lead to safety being compromised. Employees who were eligible for hazard pay were found to be at greater risk of having an accident, and it may be seen as an inducement to take risks (Sawacha et al. 1999). Productivity bonus schemes have been found to act as an incentive to work faster and thus to commit unsafe acts (Sawacha et al. 1999). Collective bonus schemes can lead to workers being pressured to not report an accident by colleagues who are unwilling to lose their bonus (Collinson 1999).

2.2.3. Three main directions in research

Safety culture has been shown to be a difficult concept. The word is used commonly and fluently, but it still remains vague. There are also many different definitions and emphasis areas in research. Ruuhilehto & Vilppola (2000) summarise three main directions which can be found in organisation safety culture research. These include 1) case studies, 2) comparative studies, and 3) psychometric surveys (Cox & Flin 1998). In the following, these three directions are connected to the present theories.

Case studies

Case studies consist of qualitative research using in-depth interviews and observation that is often participatory in nature. The research often focuses on a) companies where a major accident has occurred, b) companies operating in high-risk fields with a low accident frequency, or c) companies undergoing extensive changes.

The most common finding from case studies performed on accident companies is the lack of visible management commitment. There have also been clues of an approaching accident, clear symptoms that have gone unnoticed due to shortcomings in information transfer, or ambiguities in task distribution, for example. The problem with these “post hoc” studies, however, is that they cannot demonstrate direct relationships between the characteristics of the organisation and the accident. It is difficult to say for sure as to whether the organisation’s characteristics and conditions are a consequence of the accident or its cause.

Companies with low accident frequencies have been studied in order to receive further information for establishing the cause and effect relationship. These “good” companies have been studied using observations, interviews, survey forms, and document analysis. The research of companies with low accident frequencies can be criticised for the fact that the explicable factor has been considered to be accident statistics, which are poorly compatible with the culture by nature. An additional problem has been said to be that low accident figures can also be due to low reporting. In other words, a cause and effect relationship is similarly difficult to demonstrate using this research method (Ruuhilehto & Vilppola 2000).

The third case study type relates to change processes in companies. The current state of safety culture is established in companies undergoing change, and recommendations for improvement during the change are made. Usually, the methods used include interviews, surveys, and document analysis. A result

of this study direction is that personnel participation has been found to be an essential requirement for success (Ruuhilehto & Vilppola 2000).

Comparative studies

Another main direction of research, comparative study, usually compares companies with high and low accident frequencies (as the name implies). The literature presents several combined lists of features for “good” and “bad” companies. The features have been interpreted to be indicative of safety culture. Low accident rates have been used as a benchmark for good safety. Companies with a good safety level have the following features (Lee 1998):

- Plentiful, good communication between the different levels and task areas of the organisation. Changes occur frequently and they are performed flexibly. Safety aspects are brought up during the discussions. The managers make field tours, both to signal their interest in safety issues and to observe the situation and encourage better performance.
- The learning of organisations has been arranged well: they identify the needs for change and can respond to them.
- Safety issues have a central role in the minds of all the organisation members, and in the activities of the organisation.
- Senior management is heavily committed to safety, prioritises safety highly, appoints the necessary resources, and aims to actively promote safety.
- Management methods are democratic, cooperative, participatory, and they value individuals.
- A large amount of high-quality training related to safety and quality is available. In addition to separate safety training, safety issues are also emphasised during work induction and other work task related training.
- Good cleanliness and order, good working conditions
- High level of work satisfaction. Basis for human resource decisions (promotions, temporary layoffs, rewards) is considered justified.
- Safe working, not only peak productivity, is taken into account when recruiting and rewarding personnel.

The problem with comparative studies is that it is often difficult to eliminate the effects of confusing factors. Most often, the only benefits received from such studies are development activities for the companies involved. Commonly usable information is not really achieved (Ruuhilehto & Vilppola 2000).

Psychometric surveys

A research direction that is quickly gaining popularity is called psychometric surveys. Here, the material received from a survey is processed using statistical

methods. The regularly repeated opinion or attitude surveys are common when monitoring the development of work satisfaction or the organisation's atmosphere. Many safety researchers also prefer the term "safety atmosphere" to "safety culture" during psychometric surveys. Atmosphere is considered an indicator of culture (Ruuhilehto & Vilppola 2000).

Surveys related to safety can be compared to condition monitoring for equipment. For a company, monitoring the condition of equipment and preventing damage is much cheaper than observing the problems only after an accident has occurred. Likewise, surveys can be used to monitor the "condition" of safety, such as people's ideas, attitudes, and behaviour. Usually, the questions cover the attitudes and behaviour of colleagues, supervisors, and managers in addition to those of the interviewee. For the surveys to be useful, they would need to reliably identify the critical factors that affect the "condition". Most often, collections of questions or statements from earlier research are repeated in the studies, with very little variation (Ruuhilehto & Vilppola 2000).

So far, little evidence exists for the predicting abilities of the question batteries. Usually, the comparison variable has been the reported number of accidents; due to low frequencies, this is a very problematic benchmark for safety. The number of questions or statements usually ranges from a few dozen to a couple hundred. During the analysis of the documentation, individual questions are compiled into unified structures and factors. The number of factors and factor structures vary between studies. Recurrent themes of the surveys include leadership, management commitment, safety system, risk-taking, workload, qualification, working methods and procedures, and the role of work management (Ruuhilehto & Vilppola 2000).

Further study

The results of case studies, comparative studies, and psychometric surveys have been used to determine that it might be possible to determine a core group of factors, variables, and for the assessment of an organisation's safety culture. At present, there is very little evidence to either confirm or dismiss this. What is open to further research is the question of whether one field of business can only have a single, best possible way for safety management or whether there can be several ways. That is, can there be several different, successful safety cultures (Ruuhilehto & Vilppola 2000)?

It can also be deduced that a safety culture means merely applying good management practices in the field of safety. By doing so, we are limiting our understanding of culture to the outward appearance of culture, and the cognitive structures that manifest themselves in the attitudes of people. According to some research approaches, operating at such "superficial" levels does not

actually qualify as cultural research. However, the more in-depth means of researching organisation culture are expensive and time-consuming. Company executives want quick results and changes. These two views are incompatible. Therefore, it can be expected – and indeed, seen – that practical method development and scientific research will take different paths (Ruuhilehto & Vilppola 2000).

The challenges for the scientific research of safety culture include introducing methods from more in-depth cultural research, a closer connection to management research, reviewing accumulated individual research, meta-analysis (especially as regards the factor structure of attitude surveys), and cultural studies in multinational corporations (Cox & Flin 1998).

The largest challenge is how research can assist company executives in their work towards changing and developing safety culture, i.e. change management and leadership. The open questions related to this include, for example, if there exists only one, unified safety culture that can achieve a high level of safety culture, or if different organisations and fields of business have different safety cultures that provide good results (Hale & Hovden 1996).

According to the different schools, there are two options for change: culture either changes or it is changed. Those who feel that the culture itself changes, consider the underlying structure of culture to be so complex and deep that it cannot be consciously led or changed. It can only change by itself, over time. The changes are slow. Those who feel that organisation culture can be changed have presented different types of means. On the surface level, the goal is to change management, then to change the value system and, on the deepest level, the goal is to change the symbolic field and basic assumptions of organisation culture, cf. leadership and knowledge creation (Ruuhilehto & Vilppola 2000).

Choudhry et al. (2007) have examined a number of past studies, in order to better understand safety culture. It is thought that a summary of safety culture research undertaken since 1998, twenty-seven (27) selected studies, constitute a true representation of the concept. A major shortcoming with most of these safety culture models is the lack of their integration into general models of organisational culture. Most investigators (Thompson et al. 1998; Sawacha et al. 1999; Flin et al. 2000; Sorensen 2002) appear to agree that the elements of safety culture include senior management’s commitment to safety, good communications, organisational learning, a working environment that rewards identifying safety issues, and participative management leadership style (Choudhry et al. 2007).

2.2.4. Organisational factors related to safety

During the past decade, it has been widely recognised that different factors controlled by the organisation of a nuclear power plant have an important influence on the safety attitudes and safe behaviour of individuals. Interest in these influences began to increase with the development of the concepts of safety culture and quality management. The increasing focus on organisational factors has led to the consequence that event analyses more frequently have identified organisational factors as root causes and contributing causes of events (OECD/NEA 1999a).

The removal of an organisational problem is only the reactive part of the problem solving process. However, it is important to detect early signs of deteriorating safety performance in order to prevent the degradation of the safety of nuclear power plants. In order to be proactive, the links between the organisational factors and the safe behaviour of individuals have to be identified, as well as the mechanisms which increase the reliability of the organisation to manage safety. The objective of the report is to identify the organisational factors, their links to the individual and their influence on human performance, as well as the mechanisms important for organisational reliability (OECD/NEA 1999a).

The various approaches discussed in the report reflect the perspective of people with different profiles (i.e. organisational behaviour and sociology researchers, utility representatives, regulators or technical support organisation representatives, coming from 12 countries). They searched in a predictive or proactive manner in order to identify effective methods for determining reliability in organisations. Organisational factors have been defined in the area of organisational and behavioural sciences but the results are not widely known outside the research community. Furthermore, only a few research results were developed into assessment methods. The report presents an overview of the organisational factors regarded as important to safety. Some factors are well known and could be well defined, whereas other factors, such as “organisational culture”, “organisational knowledge”, and “organisational learning”, have slightly different interpretations and will need further discussions to reach a common definition. The report identifies twelve major organisational factors. The order of the factors does not reflect their level of importance. The twelve factors are (OECD/NEA 1999a):

- External influences
- Goals and strategies
- Management functions and overview
- Resource allocation
- Human resources management

- Training
- Co-ordination of work
- Organisational knowledge
- Proceduralisation
- Organisational culture
- Organisational learning
- Communication.

The goal of the report was to define a comprehensive list of factors which can influence safety. There are interdependencies and overlays amongst the factors as they are in the organisational environment. For each of the factors a definition is provided (OECD/NEA 1999b).

In 1999, the state-of-the-art report was supplemented by additional information contributed by countries and institutions which were not represented at the workshop in 1998. In the revised report, as recognised from experience and information exchange, it was stated that (OECD/NEA 1999c & 1999d):

- Unfortunately, there are almost no tools available for the self-assessment of organisations, and neither research institutes (with the main interest to continue research) nor consulting companies (for commercial reasons) show significant motivation to improve this situation.
- Cultural differences between the evaluator and the evaluated organisation shall not be underestimated. They heavily influence the urgently required possibility of an understanding of the organisation to be evaluated. Even the application of a method from another country requires high attention.
- The organisations in nuclear power plants are subject to change in the near future because of the need for optimisation due to external economic pressure. There is an urgent need for tools for self-assessment and change-management to help utilities to evaluate their future organisational changes in advance and to judge the effect of the change.

2.2.5. Safety culture versus safety climate

Safety culture can be viewed as the overarching policies and goals set by an organisation relating to the overall safety of their facility or environment. Safety climate is often used interchangeably and in conjunction with safety culture. While both can be used to describe the underlying safety attitude of an organisation, safety climate generally refers to the attitude that the people in the organisation have towards safety. It describes the prevailing influences on safety behaviours and attitudes at a particular time (Olive et al. 2006).

By organisation culture it is meant here as the shared values and beliefs of an organisation ─ commonly described as “the way we do things here”. This concept is widely understood, but what is less widely understood is the relationship between organisational culture and safety climate. Both are critically important. Where organisational culture comprises unstated assumptions that govern how we do things around here, climate is the prevailing influences on a particular area of functioning (such as safety) at a particular time. Thus, culture is something that is more deeply embedded and long term, which takes a longer time to change and influence organisational performance across many areas of functioning. Climate, on the other hand, changes faster and more immediately reflects the attention of leadership. Culture can be viewed as the background influence on the organisation, while climate is the foreground. Climate changes faster than culture. Organisational climate often changes very quickly after a significant incident, but the underlying organisational culture may not change sufficiently to prevent further incidents from occurring (Behavioural Science Technology 2004).

If the underlying culture is not sufficiently, and accordingly, altered to support the climate, further incidents are inevitable. The primary example of such a phenomenon can be found in the duality of the Challenger and Columbia disasters experienced by NASA. Following the Challenger explosion, the climate at NASA was strongly oriented towards improving safety performance. However, because the underlying culture did not adequately promote the importance of placing safety as a priority, the safety climate degenerated to such a dangerous degree that the Columbia disaster resulted (Olive et al. 2006).

There are three main components to safety culture; psychological, situational and behavioural, and there are a number of tools available, qualitative and quantitative, which can be used to measure them (Cooper 2000). Situational aspects of safety culture can be seen in the structure of the organisation e.g. policies, working procedures, management systems etc. Behavioural components can be measured through self-report measures, outcome measures and observations. The psychological component is most commonly examined by safety climate questionnaires which are devised to measure people’s norms, values, attitudes and perceptions of safety.

Safety climate measures have been widely researched and tend to be used as substitute measures of safety culture. Recent interest in the measurement of safety culture has resulted in a number of reviews of the area. These reviews demonstrate the wide range of assessment tools, typically self-report questionnaires from large scale surveys that have been developed. Such assessment tools are often customised to a particular industry, principally the energy industry but also manufacturing and health.

As Flin et al. (2000) point out the dimensions of climate measures vary considerably in terms of criteria, statistical analysis, size and composition of workers and industry. Thus, drawing comparisons between the measures is difficult not only because of the methodological differences outlined but also because of language and cultural variations. Consistency amongst safety climate measurements is difficult (Gadd & Collins 2002).

2.2.6. Characteristics of a good safety culture

One of the characteristics of a good safety culture is a definable commitment to the improvement of safety behaviours and attitudes at all organisational levels. A second characteristic of an organisation with excellent safety culture is free and open communication. Resilience is another feature of a good safety culture. An organisation with ideal safety culture should be able to easily process small incidents or errors within the system and then continue operating. By doing so, the organisation and the system will be ultimately stronger. The final characteristic of an organisation with excellent safety culture is a prevailing attitude of vigilance (Olive et al. 2006). Preparedness for and the prevention of accidents must be maintained with a constant unremitting watch (Kharbanda & Stallworthy 1988).

2.2.7. Assessment of safety culture

A situational approach to assess safety culture

Semmer and Regennass argue that many approaches to the study of safety culture focus on values and social norms and their underlying assumptions (Semmer & Regennass 1999). Most existing research tools and instruments are designed to collect data on norms and assumptions. However, social science research has long demonstrated that the correlation between general preferences and specific behaviour is rather modest. As the researchers explain, “Responses to general questions do not guarantee that the aspects salient in the measurement situation are the same ones that are salient in a real-life situation. Moreover, it has been shown that actors do not behave according to one single norm; they are rather confronted to different and often competing norms. Which norm will dominate cannot be determined from understanding the norms, but rather by careful consideration of situational aspects”.

The Situational Approach suggests that the emphasis should be put on collecting data on actual practices, real dilemmas and decisions (what is also called “theories in use”) rather than on social norms. Acknowledging that values and assumptions are expressed in situations, Semmer and Regennass propose

a situational approach, in which subjects are not directly questioned about values and norms, but are confronted with a dilemma that stems from conflicting social norms and various costs and benefits associated with different types of behaviour. The subjects are asked what they do in such a situation, what they think others would do what reactions they would expect their behaviour to elicit from others, and so forth.

A socio-technical model of safety culture: total safety management

Grote and Künzler (1997) are combining a theoretical framework of the socio-technical systems approach with an audit methodology. The researchers claim that mixing the two can be fruitful in order to assess safety culture but more importantly the organisation as a whole. It is Grote and Künzler's opinion that models of safety culture after the Chernobyl Accident suffer from a lack of integration into general models of organisation and of organisational culture. In addition, the connection between safety-related characteristics of a system and more general characteristics like job and organisational design and the use of technology, is missing. This gives the impression that safety can be looked upon and promoted as something detached from the make-up of the socio-technical system as a whole.

For Grote and Künzler (1997), the socio-technical approach describes work systems as having a technical and a social subsystem which together determine how well the primary task of a work system can be accomplished. In this perspective, maximum effectiveness can be achieved only if the two sub-systems are jointly optimised.

Both researchers argue that on at least two levels the socio-technical approach can be linked to safety:

- The definition of the primary task
- The degree of self-regulation of sub-units in the system.

From this follows:

- The definition of the primary task should include safety in order to foster, in analogy to the Total Quality Management approach, a Total Safety Management
- A high degree of self-regulation of work teams is beneficial to safety, because it fosters flexibility, initiative and ownership, which are all crucial qualities to adequately deal with problems or incidents.

Therefore, a model of safety culture should be incorporated into a more general model of organisational culture, emphasising complex interactions between an

organisation's material and immaterial reality. Secondly, characteristics of the work system not directly related to safety should be included, especially characteristics of job and organisational design influencing the degree of self-regulation on the shop floor.

Two main results emerge from field-work in four chemical plants and one transportation company:

- The integration of safety into day-to-day operations is easier in organisations whose primary task is defined in terms of quantity, quality and safety of production, as opposed to organisations whose primary task is only defined in terms of quantity and quality.
- There is evidence that safety system awareness, organisational and technical designs are positively correlated.

A sociological approach to study organisational reliability

Bourrier's (1994, 1996, and 1998) research is an attempt to contribute to the study of organisational reliability in high-risk industries through a sociological analysis, using organisation theory and anthropological methods. The goal is to identify crucial social nodes, supporting and fostering organisational reliability in a given organisation. Using the concept of "Strategic compromises" that have proved to be at the core of organisational reliability, the primary task of the research is to determine the conditions under which these compromises are emerging in order to assess their strengths and weaknesses, their costs and benefits. This will give access to a deeper understanding of dysfunctional patterns in organisations for early detection.

The research background is the following. Too often, organisational analyses are carried out only after a catastrophe has occurred. While very interesting, this perspective has serious limitations: it is always easier to explain and reconstruct events after they have taken place. It is more essential to understand the mechanisms of normal functioning, because having a correct perception of their normal operation can help to prevent future dysfunctions and possible errors. In this way, it should be possible to predict in what areas failures are more likely to occur. To do so, organisational reliability should be researched through the study of social interactions and professional relations.

Bourrier's claim is that organisational reliability is highly dependent upon the quality and nature of social relations, which are driven in turn by self-interest and, therefore, by power and strategies (which could introduce dissent, compartmentalisation, power struggles and goals displacement, poorly reliable features of most organisational life). Bourrier points out that organisational reliability issues should be investigated and seen as properties of the social

systems embedded in reliability-seeking organisations. The social construction of organisational reliability can best be analysed through a systemic analysis thus helping to focus on systemic effects.

2.3. Safety management

Safety management is the term used for the organisational measures applied to ensure that an acceptable level of safety is maintained throughout the life of an installation. Management is responsible for recognising the safety significance of both the design of the installation and the way in which it is operated and maintained, and to put in place suitable organisational processes to manage risk. This requires that the organisation is well structured with clear lines of authority and well defined responsibilities. In addition, the safety policy, requirements and procedures need to be well established, understood and observed by all (INSAG-13, 1999).

2.3.1. Concept of safety management

All these features of control and operation need to be considered systematically, and this leads to the general definition of *Safety Management System* as offered in INSAG-13 (1999):

"The safety management system comprises those arrangements made by the organisation for the management of safety in order to promote a strong safety culture and achieve good safety performance."

The Organisation and Management Review Method (Haber & Barriere 1998) allows the generation of a behavioural profile of the organisation through those processes and management functions related to the safety performance of nuclear facilities (OECD/NEA 2006). The Organisation and Management Review Method is used to measure five Safety Culture characteristics within a nuclear organisation. Those characteristic areas are as follows:

- Safety is a clearly recognised value
- Accountability for safety in the organisation is clear
- Safety is integrated into all activities in the organisation
- A safety leadership process exists in the organisation
- Safety culture is learning driven in the organisation

The method uses a functional model of the organisation. Five organisational components identify the key organisational and management processes that relate to safety, their primary functions, key coordinating mechanisms, and the way that information flows throughout the organisation. Organisational

behaviours within those components are measured both qualitatively and quantitatively.

The behaviours include attention paid to safety, coordination of work, decision-making, goal/priority-setting, resource allocation, time urgency, aggressive-defensive culture style (high perfectionist), roles and responsibilities, performance quality, management emphasis on safety, employee awareness of risk, external communication, formalisation, training, organisational knowledge, constructive style, cohesion, hazard, offsite consequences, on-site consequences, organisational culture, communication (interdepartmental and intradepartmental), commitment, job satisfaction, organisational learning, problem identification and resolution, performance evaluation, personnel selection, and passive-defensive style (low avoidance). The Organisation and Management Review Method is published under the Canadian Nuclear Safety Commission Research document, RSP-0060 (Haber & Barriere 1998).

This methodology was originally developed with the support of the U.S. Nuclear Regulatory Commission to assess the influence of organisation and the management of safety performance. In 2003, the existing safety culture at the Davis-Besse Nuclear Generating Station was evaluated against the characteristics identified to be important for the promotion of a positive safety culture in a nuclear facility (FirstEnergy Nuclear Operating Company (FENOC) 2003). The method is well-founded through extensive international research. However, the evaluation process is labour-intensive, with a long planning cycle and data analysis period. Because of the unique skills required to perform the evaluation, staff must be appropriately trained to use this method.

Guidelines of regulatory expectations (performance objectives and criteria) should be developed in the area of safety culture and safety management. Safety Management programmes should be developed by nuclear power plant organisations to meet those expectations and to perform their own assessments. The achievement of a learning organisation should be a goal (OECD/NEA 2006).

In some countries, the Total Quality Management system, EFQM (business excellence model developed by European Foundation for Quality Management) or Quality Management Systems compatible with the ISO-9000:2000 or IAEA Safety Series 50-C/SG-Q Quality Management (IAEA 1996, later replaced by IAEA 2006) are applied for safety management.

Total Quality Management (TQM) is a set of management practices throughout the organisation, geared to ensure the organisation consistently meets or exceeds customer requirements. TQM places a strong focus on process measurement and controls as means of continuous improvement.

The EFQM Excellence Model is a non-prescriptive framework based on nine criteria. Five of these are “Enablers” and four are “Results”. The “Enabler” criteria cover what an organisation does and how it does it. The “Results” criteria cover what an organisation achieves. “Results” are caused by “Enablers” and “Enablers” are improved using feedback (Learning, Creativity and Innovation) from “Results”.

Safety management refers to organisational measures that seek to identify, assess and control risks in order to guarantee nuclear, personnel and environmental safety. These risks include, among others, occupational accidents, accidental releases of radioactive substances and in the worst-case scenario, a meltdown of the reactor core.

The IAEA guidelines are very valuable as a starting point, but they show some limitations. First of all, they provide a top down structured approach to safety culture, focused on formal management tools such as feedback system, management commitment, and quality assurance and not on the point of view and experience of those who act in the organisation. Personnel should be given the possibility to reach and seize easily those actors and perception of the organisation (Mengolini & Debarberis 2010). The difficulty of measuring the safety culture concept is undeniable. However, there is a need, expressed by many authors, to establish a positive relationship between safety culture and safety performance (Sorensen 2002; Vinnem et al. 2005; Apostolakis & Bonaca 2004).

2.3.2. Safety management in the nuclear industry

Dr Zack Pate has stressed the following principle: “An organisation is strongly influenced by and is very responsive to perceived expectations from the top. And these perceived expectations can and often do have a profound impact on the behaviour of individuals in the organisation.”

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

The Three Mile Island accident occurred in March 1979 and highlighted the shortcomings in the relationships between the plant owner, the licensee, and

the project organisation. Several actions were undertaken in response to the accident. The corrective actions were mainly focused on human engineering aspects such as technological, procedural, training and man-machine interface aspects. The increase in requirements and regulations thereafter is well known, and shaped the approach taken by the nuclear industry to the introduction of the discipline of human factors for several years. However, subsequent analyses on the causes of the accident pointed out the influence of factors related to deeper underlying organisational aspects such as project management, plant management and resources. It was increasingly believed that these aspects could have a significant impact on plant safety because they set the context under which plants are designed and operated, and the way in which plant hardware is utilised, maintained and understood by plant operators.

It is instructive to note that, even organisational weaknesses were identified as significant in the investigation reports:

- As the evidence accumulated, it became clear that the fundamental problems are people-related problems and not equipment problems (Kemeny 1979)
- The responsibility of management at all levels should be integrated in a consistent way (Kemeny 1979)
- There are structural problems in the organisations, there are deficiencies in various processes and there is a lack of communication between key individuals and groups (Kemeny 1979)
- The principal deficiencies in commercial reactor safety today are not hardware problems; they are management problems (Rogovin 1980)
- The kinds of changes needed to cope with these problems and attitudes are institutional, organisational, and managerial (Rogovin 1980)
- Individuals managing and operating nuclear plants constitute a relevant safety system (Rogovin 1980).

The human and organisational factor focus is shifting gradually from the individual operator performance towards the performance of the organisation.

The Kemeny Commission – set up by President Jimmy Carter to investigate the March 1979 accident at the Three Mile Island nuclear power plant – had also recommended that:

- The (nuclear power) industry should establish a programme that specifies the appropriate safety standards, including those for management, quality assurance, and operating procedures and practices, and that conducts independent evaluations.
- There must be a systematic gathering, review, and analysis of operating experience at all nuclear power plants coupled with an industry-wide

international communications network to facilitate the speedy flow of this information to the affected parties.

In addressing those recommendations, the nuclear power industry in the US:

- Established the Institute of Nuclear Power Operations (INPO)
- Charged INPO with a mission that we continue to pursue today: To promote the highest levels of safety and reliability – to promote excellence – in the operation of commercial nuclear power plants (INPO website).

The World Association of Nuclear Operators (WANO) is an organisation created to improve safety at every nuclear power plant in the world. After the accident at the Chernobyl nuclear power plant in 1986, nuclear operators realised worldwide that the consequences had an effect on every nuclear power plant and international co-operation was needed to ensure that such an accident can never happen again. WANO was formed in May 1989 by nuclear operators worldwide uniting to exchange operating experience in a culture of openness, so that members can work together to achieve the highest possible standards of nuclear safety. The culture of openness allows each operator to benefit and learn from others' experiences, challenges and best practice, with the ultimate goal of improving nuclear plant safety, reliability and performance levels for the benefit of their customers throughout the world.

WANO's mission is:

"To maximise the safety and reliability of nuclear power plants worldwide by working together to assess, benchmark and improve performance through mutual support, exchange of information and emulation of best practices."

"With safety as the only goal, WANO helps operators communicate effectively and share information openly. Experience shows many accidents could have been prevented if lessons had been learned from previous incidents. Ultimately, this will raise the performance of all operators to that of the best."

A workshop on "Organisational Factors Identification and Assessment" was initiated by the Expanded Task Force on Human Factors. The objective of this workshop is to identify the organisational factors, their links to the individual and their influence on human performance, as well as the mechanisms important for organisational reliability (OECD NEA 1999a).

In 2002, OECD/NEA organised a workshop, which sought to present state-of-the-art information on organisational theory and to determine which approaches may be suitable in terms of application to nuclear installations. The workshop

also provided a wide forum for exchanging experiences of, and approaches to, the issue of safety management. Following the workshop, a survey was developed to collect information and experiences on systematic approaches to safety management used by licensees and regulators. The “State-of-the-art report on systematic approaches to safety management” sets out the principal outcomes of the workshop and the survey practices in Belgium, Canada, Finland, France, Japan, Spain, Sweden, Switzerland, the UK, and the US (OECD/NEA 2006).

The principal objectives of the report are (OECD/NEA 2006):

- To clarify the concept of safety management and its role and influence in nuclear facility operations, with respect to other concepts such as human factors, quality management and safety culture
- To identify approaches used by utilities and regulators from different countries, and to discuss specific tools and applications related to detection, prevention, monitoring, correction and mitigation of safety related issues
- To identify needs for further research and development.

The Special Experts’ Group on Human and Organisational Factors (SEGHOF) of the Committee on Safety of Nuclear Installations (CSNI) has examined the role and influence of safety management in nuclear plant operations. The state - of-the-art report provides a brief explanation of the relationship between safety management and safety culture, and reinforces the need to develop and sustain a robust safety management system as a part of the management system as a whole.

A questionnaire-based survey was prepared to investigate licensee methods and tools and regulatory expectations. The principal findings of the survey are summarised as follows (OECD/NEA 2006):

- There is a clear trend for regulatory bodies to develop regulatory requirements and guidelines on safety management
- There is a move towards developing integrated management systems in which safety, quality and business management are not perceived as separate activities to be managed in different ways
- A number of areas warranting further research and development in the area of safety management have been identified.

What should be developed or done? For what purpose is safety management needed? The principal proposals of the survey are summarised as follows (OECD/NEA 2006):

- Development of internationally accepted models (or standards) for safety management against which existing management systems could be assessed
- Development of tools to evaluate the performance of safety management (specific indicators and assessment methods)
- Knowledge on safety management is not restricted to the nuclear industry. Concepts and methods developed for and applied in other high-risk industries could be explored
- Guidelines of regulatory expectations (performance objectives and criteria) in the area of safety culture and safety management
- Safety Management programmes developed by each licensee to meet those expectations and to perform their own assessments
- A standard or other prescriptive document may not attain the desired results, i.e. the achievement of a learning organisation
- There is a need for methods, tools, which may be used for evaluating management of safety. It is difficult to measure what is a good management and what is not. There is a need for criteria. Some data may come from operational experience feedback
- To establish a common understanding of the concept
- To identify the relationships between safety management and traditional management systems
- To incorporate human and organisational factors in safety management systems
- To integrate safety management and safety culture
- To update safety management systems with modern scientific approaches
- In Knowledge Management systems to address the problem of knowledge losses due to early retirement or ageing workforce
- Moving towards a Learning Organisation is a must for any today's organisation.

During the NEA/SEGHOF workshop on safety management, which was held in 2002, a set of recommendations for future work was identified. They were structured in six main areas (OECD/NEA 2006):

- Operating experience
- Indicators and diagnosis
- Intervention and improvement tools
- In-depth research for specific issues
- Regulatory activities needs
- Other fields experience as related to nuclear safety.

The report also explores the development of current organisational theories and their application to nuclear plant safety management. It identified areas where future work should be considered (cf. INSAG-18, 2003).

2.4. Knowledge management

Ludwig Wittgenstein pointed out that “knowledge” is not easily defined in an exact manner. Wittgenstein further warns us that this lack of definition may lead us to believe that since we do not know what it means we have no right to use it. His reply would be that: “There is no exact usage of the word knowledge; but we can make up several such usages, which will more or less agree with the ways the word is actually used” (Wittgenstein 1958, p. 27).

2.4.1. What is knowledge?

In the theory of the knowledge-creating process, Nonaka and Takeuchi (1995) adopt the traditional definition of knowledge as “justified true belief”. However, the focus is on the “justified” rather than the “true” aspect of belief. In traditional Western epistemology (the theory of knowledge), “truthfulness” is the essential attribute of knowledge. It is the absolute, static and non-human view of knowledge. This view, however, fails to address the relative, dynamic and humanistic dimensions of knowledge (Nonaka & Takeuchi 1995).

Knowledge is dynamic, since it is created in social interactions amongst individuals and organisations. Knowledge is context-specific, as it depends on a particular time and space (Hayek 1945). Without being put into a context, it is just information, not knowledge. Knowledge is also humanistic, as it is essentially related to human action. Knowledge has the active and subjective nature represented by such terms as “commitment” and “belief” that is deeply rooted in individuals’ value systems. Information becomes knowledge when it is interpreted by individuals and given a context and anchored in the beliefs and commitments of individuals. Hence, knowledge is relational: such things as “truth”, “goodness” and “beauty” are in the eye of the beholder. In this study, we consider knowledge to be a dynamic human process of justifying personal belief toward the “truth” (Nonaka & Takeuchi 1995).

There are two types of knowledge: explicit knowledge and tacit knowledge. Explicit knowledge can be expressed in formal and systematic language and shared in the form of data, scientific formulae, specifications, manuals and such like. It can be processed, transmitted and stored relatively easily. In contrast, tacit knowledge is highly personal and hard to formalise. Subjective insights, intuitions and hunches fall into this category of knowledge. Tacit knowledge is deeply rooted in action, procedures, routines, commitment, ideals, values and emotions (Schön 1983). It is difficult to communicate tacit knowledge to others,

since it is an analogue process that requires a kind of “simultaneous processing”.

As Michael Polanyi (1967) wrote in The Tacit Dimension, we should start from the fact that “we can know more than we can tell”. He termed this pre-logical phase of knowing “tacit knowledge”. Tacit knowledge comprises a range of conceptual and sensory information and images that can be brought to bear in an attempt to make sense of something. Many bits of tacit knowledge can be brought together to help form a new model or theory. This inevitably led him to explore connoisseurship and the process of discovery (rather than with the validation or refutation of theories and models - in contrast with Popper, for example) (Smith 2003; cf. Polanyi 1969).

Western epistemology has traditionally viewed knowledge as explicit. However, to understand the true nature of knowledge and knowledge creation, we need to recognise that tacit and explicit knowledge are complementary, and that both types of knowledge are essential to knowledge creation. Explicit knowledge without tacit insight quickly loses its meaning. Knowledge is created through interactions between tacit and explicit knowledge, rather than from tacit or explicit knowledge alone.

Management scholars today consider knowledge and the capability to create and utilise knowledge to be the most important source of a firm’s sustainable competitive advantage (Drucker 1993). However, in spite of all the talk about knowledge-based management and in spite of the recognition of the need for a new knowledge-based theory there is little understanding of how organisations actually create and manage knowledge.

This is partly because we lack a general understanding of knowledge and the knowledge-creating process. The knowledge management that academics and business people talk about often means just information management. In the long tradition of Western management, the organisation has been viewed as an information processing machine that takes and processes information from the environment to solve a problem and adapts to the environment based on a given goal. This static and passive view of the organisation fails to capture the dynamic process of knowledge creation.

Instead of merely solving problems, organisations create and define problems, develop and apply new knowledge to solve the problems, and then further develop new knowledge through the action of problem solving. The organisation is not merely an information processing machine, but rather an entity that creates knowledge through action and interaction (Cyert and March 1963, Levinthal and Myatt 1994). It interacts with its environment, and reshapes the environment and even itself through the process of knowledge creation. Hence,

the most important aspect of understanding a firm's capability concerning knowledge is the dynamic capability to continuously create new knowledge out of existing firm-specific capabilities.

According to Nonaka et al. (2000), with this view of an organisation as an entity that creates knowledge continuously, we need to re-examine our theories of the firm, in terms of how it is organised and managed, how it interacts with its environment, and how its members interact with each other. The goal is to understand the dynamic process, in which an organisation creates, maintains and exploits knowledge. Knowledge is created in the spiral that goes through two seemingly antithetical concepts, such as order and chaos, micro and macro, part and whole, mind and body, tacit and explicit, self and other, deduction and induction, and creativity and control. Nonaka et al. (2000) argue that the key in leading the knowledge-creating process is dialectical thinking, which transcends and synthesises such contradictions.

By expounding, discussing and illustrating organisational knowledge the objective of Georg von Krogh and Johan Roos (1995) is to present an observation scheme to better understand organisational knowledge development on the individual and the social scale. This observation scheme is intended for the knowledge development.

The conceptual system distinguishes between individual knowledge and social knowledge, and describes the properties of both. It also makes two further attempts: first, to innovate a language that can describe the properties of knowledge, without resorting to conventional nomenclature; and, second, to innovate a language that can describe the messy, complex, and iterative processes that give rise to organisational knowledge (von Krogh, G. & Roos, J., 1995).

The word "epistemology" comes from the Greek words episteme (knowledge) and logos (theory). Epistemology has traditionally been conceived of as a branch of one of the grand divisions of philosophy, methodology, or ways we as human beings come to know the world. Epistemology is concerned with understanding the origin, nature and validity of knowledge: it seeks to provide knowledge about knowledge, and hence some refer to epistemology as theory of knowledge (von Krogh, G. & Roos, J., 1995).

Von Krogh's (von Krogh, G. & Roos, J., 1995) interpretation of organisational epistemology is, a collection of perspectives, theories and concepts related to the following set of issues:

- How and why individuals within organisations come to know
- How and why organisations, as social entities, come to know

- What counts for knowledge of the individual and the organisation
- What are the impediments to organisational knowledge development

2.4.2. Concept of knowledge management

Knowledge management is an integrated, systematic approach to identifying, managing and sharing an organisation's knowledge and enabling groups of people to create new knowledge collectively to help in achieving the organisation's objectives.

Knowledge may be applied for such purposes as: problem solving and learning; forming judgments and opinions; decision making, forecasting and strategic planning; generating feasible options for action and taking actions to achieve the desired results. Knowledge also protects intellectual assets from decay, augments intelligence and provides increased flexibility. Knowledge Management, Classic and Contemporary Works, provides an introduction to the field of knowledge management. Taking a learning-centric rather than information-centric approach, it emphasises the continuous acquisition and application of knowledge.

2.4.3. Nonaka's SECI model of knowledge creation

In the dominant Western philosophy, the individual is the principal agent who possesses and processes knowledge. Nonaka and Takeuchi show that the individual interacts with the organisation through knowledge. Knowledge creation takes place at three levels: individual, group, and organisational. Therefore, the discussion of organisational knowledge creation consists of two major components: the forms of knowledge interaction and the levels of knowledge creation. The two forms of interactions – between tacit knowledge and explicit knowledge and between the individual and the organisation – will then bring about four major processes of knowledge conversion, which all together constitute knowledge creation: (1) from tacit to explicit; (2) from explicit to explicit; (3) from explicit to tacit; and (4) from tacit to tacit. The distinctive approach of Western philosophy to knowledge has profoundly shaped the way organisational theorists treat knowledge. The Cartesian split between subject and object, the knower and the known, has given birth to a view of the organisation as a mechanism for "information processing" (Nonaka & Takeuchi 1995).

Some knowledge that is quite complex and initially tacit can be externalized and embedded in a company's products or services. The knowers use their expertise to develop a process or product that contains at least some of what they know. Any manufacturing process, whether automated or formalized in a set of procedures, is constructed from what was once the knowledge of

individuals. In theory, this embedded knowledge is independent of those who developed it and therefore has some organizational stability–an individual expert can disappear without bringing the process to a halt or reducing the company's stock of embedded knowledge. In practice, however, it is difficult to locate the dividing line between knowledge that is fully embedded in a process and the tacit, human knowledge that keeps the process going (Davenport & Prusak 1998, p.83).

Knowledge that is in part explicitly bound to the functions is relatively easy to transfer using documents and databases. Transferring tacit knowledge, on the other hand, requires extensive personal contact and interaction, allowing for the transfer of both tacit and explicit knowledge. As a general rule, the more rich and tacit knowledge is, the more technology should be used to enable people to share that knowledge directly (Davenport & Prusak 1998, pp.95-96).

An organisation creates knowledge through the interactions between explicit knowledge and tacit knowledge. The interaction between the two types of knowledge is called 'knowledge conversion'. Through the conversion process, tacit and explicit knowledge expands in both quality and quantity (Nonaka & Takeuchi 1995).

There are four modes of knowledge conversion. The four modes of knowledge conversion are S=socialisation (from tacit knowledge to tacit knowledge), E=externalisation (from tacit knowledge to explicit knowledge), C=combination (from explicit knowledge to explicit knowledge), and I=internalisation (from explicit knowledge to tacit knowledge) (Nonaka et al. 2001b, p. 16). The modes of knowledge conversion are presented in Figure 1.

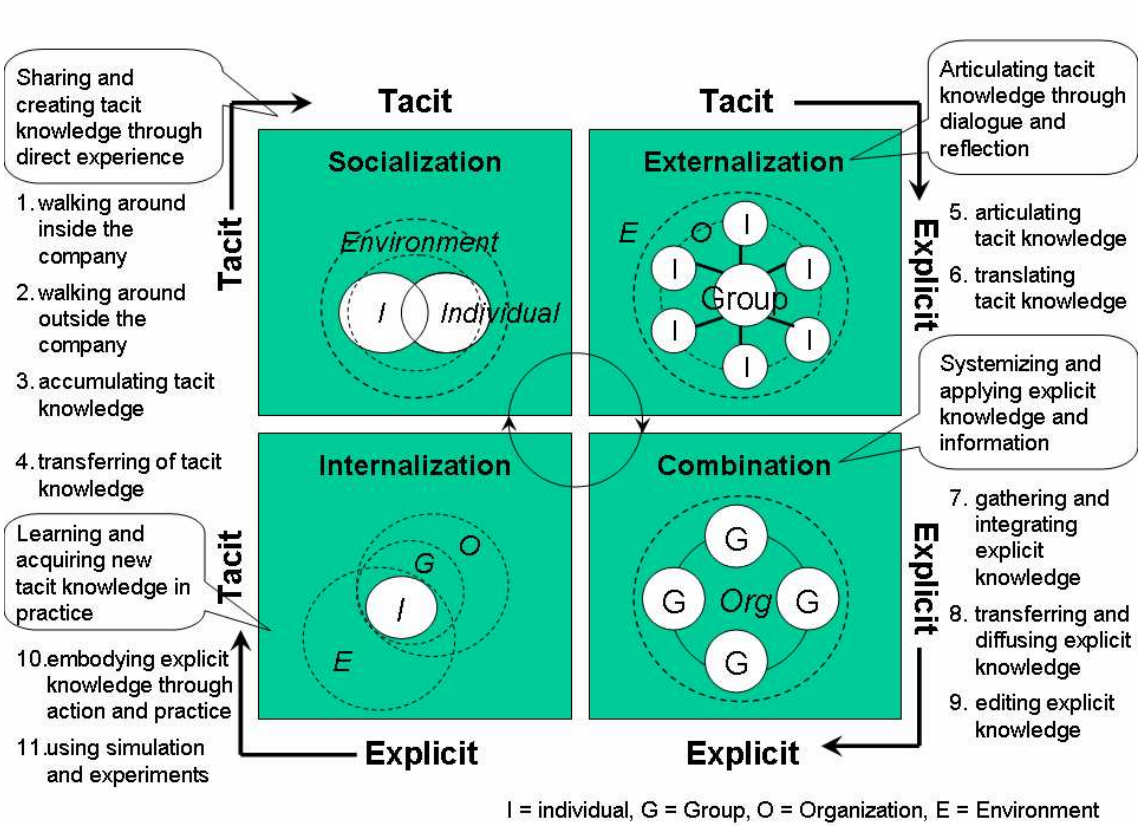

Figure 1. SECI model of knowledge creation (Nonaka & Toyama 2003, p. 5).

Socialisation is a process of converting new tacit knowledge through shared experiences. Since tacit knowledge is difficult to formalise, tacit knowledge can be acquired only through shared experience. Socialisation typically occurs in a traditional apprenticeship, where apprentices learn the tacit knowledge needed in their craft through hands-on experience, rather than from written manuals or textbooks. Socialisation may also occur in informal social meetings outside of the workplace. Socialisation also occurs beyond organisational boundaries. Firms often acquire and take advantage of the tacit knowledge embedded in customers or suppliers by interacting with them (Nonaka et al. 2000, pp. 9-12).

Externalisation is a process of articulating tacit knowledge into explicit knowledge. When tacit knowledge is made explicit, knowledge is crystallised, thus allowing it to be shared by others, and it becomes the basis of new knowledge. Concept creation in new product development is an example of this conversion process. Another example is a quality control circle, which allows employees to make improvements on the manufacturing process by articulating the tacit knowledge accumulated on the shop floor over years on the job. (Nonaka et al. 2000, pp. 9-12).

Combination is a process of converting explicit knowledge into more complex and systematic sets of explicit knowledge. Explicit knowledge is collected from inside or outside the organisation and then combined, edited or processed to form new knowledge. The new explicit knowledge is then disseminated among

the members of the organisation. Creative use of computerised communication networks and large-scale databases can facilitate this mode of knowledge conversion. When information is collected from throughout the organisation and put together in a context to make an analysis report, that report is new knowledge in the sense that it synthesises knowledge from many different sources in one context. The combination mode of knowledge conversion can also include the breakdown of concepts thus creating systemic, explicit knowledge (Nonaka et al. 2000, pp. 9-12).

Internalisation is a process of embodying explicit knowledge into tacit knowledge. Through internalisation, explicit knowledge created is shared throughout an organisation and converted into tacit knowledge by individuals. Internalisation is closely related to 'learning by doing'. For example, training programmes can help trainees to understand an organisation and themselves. By reading documents or manuals about their jobs and the organisation, and by reflecting upon them, trainees can internalise the explicit knowledge written in such documents to enrich their tacit knowledge base. When knowledge is internalised to become part of individuals' tacit knowledge bases in the form of shared mental models or technical know-how, it becomes a valuable asset. This tacit knowledge accumulated at the individual level can then set off a new spiral of knowledge creation when it is shared with others through socialisation (Nonaka et al. 2000, pp. 9-12).

2.4.4. Expertise and learning organisation

As Vaherva states, up to 80% of the new things learnt during one's working career are learnt outside of formal training or different courses. Even if formal training is well planned and executed, it cannot guarantee how much of the new information learnt during training transfers to preparedness that is taken into use in the work (Vaherva 1999, pp. 93-94). For this reason, organisations have started to emphasise continuous, individual learning alongside traditional, individually focused training programmes (Launis & Engeström 1999, p. 67).

However, it must be noted that informal learning cannot replace traditional learning based on formal training. It can only complement it. Today, formal training alone is not sufficient simply because it is usually based on very general, widely applicable training that focuses on thinking above acting (Vaherva 1999, p. 159).

In practice, however, both informal and formal training are required. Nowadays, the pace of working in many organisations is very hectic, and there is no time for separate formal training. Therefore, personnel seek different means of informal learning, such as conversations, seminars, visits, and conferences, in

order to meet any competence requirements that have been brought up (Vaherva 1999, p. 99).

An expert is a person who can solve problems in his or her field by analysing the field of problems, and form optimal solutions by synthesising and evaluating possible solutions. An expert knows the field so well that he or she has a structured overall idea of the field, its basic concepts, and processes as well as its main principles, their effects, and consequences. This requires learning-to-learn skills and higher order thinking skills, as expertise is not a permanent status. Expertise, or expert-level knowledge and skills, must be continuously maintained and refreshed. Important factors affecting the development of expertise include personal metacognitive and learning-to-learn skills as well as the content, variety, and challenge of work, and the social network. This kind of learning at work can be promoted with job rotation and by forming interactive multi-disciplinary teams and workgroups (Alamäki 2000a; Alamäki 2000 b).

Expert organisation is an organisational type whose main purpose is to continuously produce and maintain new information and special know-how for developing and maintaining systems or services. Ultimately, organisational learning depends on its experts' ability and desire to learn and share information together. Company management has an important part in creating and maintaining such a system. Organisations and practices cannot change if the individuals' thinking and the resulting behaviour remain the same. Practices are often guided by the organisational memory, culture, and current values. There are several examples of companies trying to change their functions with external factors, such as by providing more resources and time or creating better training plans and performing new tests. Experts and trainers may be involved in the change process. However, practices will not change if the employees only appear to be working according to the new system but their actions are still guided by the old thinking and operations models (Mäenpää 1995).

Two types that are essential in the analysis of the persistence and change of behaviour can be identified in how organisations, groups, and individuals behave. These two types are the espoused theory, or how people say they act, and the theory-in-use, or how people actually act. The espoused theory is easier to understand. It describes what people think and believe and how they say they act. It is often on a conscious level and can be easily changed by new ideas and information. However, it is difficult to be aware of the theory-in-use, and it is difficult to change (Mäenpää 1995).

For Senge (1990, p. 3), learning organisations are the kinds of organisations where people have the opportunity to continuous development in order to

achieve the results they want, where the birth of new thinking models is encouraged and where people continuously learn how they can learn together.

2.4.5. Core competency of groups and the organisation

As the tasks in an organisation become more complex, it is more difficult for individual employees to manage the field of know-how required for their duties. The actual or perceived environmental unpredictability, rapidly changing information, requirements of efficiency, and binding strategic solutions have increased. Today, an organisation cannot maintain its ability to change only by satisfying individuals' growth needs (Mäenpää 1997).

Organisational learning and learning organisation have become central frameworks and goals for organisational development (Argyris & Schön 1978; Senge 1990; Senge 1991; Mäenpää 1997). According to Senge (1990), a learning organisation can set its know-how targets above the minimum required level of knowledge and skills. He argues that, unlike an organisation following a survival strategy, a learning organisation can maintain a learning process that is able to create new know-how. In the process of organisational development, the new know-how is joined with the previous know-how. Without an in-depth understanding of an organisation's fields of know-how, development may easily become the obtaining of new, disconnected pieces of information.

The concept of core competency

The concept of core competency includes the following meanings, for example: an organisation's collective skills, complex social skills, the ability to communicate and convey know-how vertically and horizontally inside the organisation and between interest groups, and the ability to combine existing and potential skills innovatively for producing new, significant know-how about the organisation's processes or products. An organisation's core competency is formed through a complex learning event, which is very significant only for the organisation in question (Prahalad & Hamel 1990; Teece et al. 1990; Leonard-Barton 1992). Previously, a key question for business organisations was "What is the field of business that we are in? When analysing an organisation's competitive advantage dynamically, the question is: "What special know-how does our organisation have that could form a basis for our business?"

Mäenpää (1997) has analysed the way business organisations and researchers approach the concept of core competency. At least the following approaches are identifiable (Mäenpää 1997):

- Core competencies are mostly seen as static, latent properties – tacit knowledge and invisible assets; the focus is on the competency of individual employees
- Core competencies are seen as process know-how, core processes (core capabilities); the first step of the analysis is to define the core processes
- Core competencies combine the skills and processes in this order; core competency is mostly seen as collective know-how
- Core competencies in the context of a learning organisation. Core competency includes processes that progress at different speeds. The organisation and group interact as an open system with their environment.

Several approaches show a transition to finding and inspecting processes. First, the processes are defined and then the necessary know-how is located in the processes. In process know-how, managing the relationships between processes has developed into a kind of meta know-how (see e.g. Stalk et al. 1992). One advantage of process thinking is that it emphasises the dynamic nature of know-how. However, focusing on process thinking includes a risk of treating know-how as if it were something that could be processed on a production line. The traditional process thinking is controlled by a strict systems theory. It is also difficult to separate content from the process. Moreover, defining processes involves a risk of incorrect definition and prioritisation (Mäenpää 1997).

In general discussion, the concept of core competency has sometimes been used to describe the qualifications of individual employees. However, almost without exception, the current literature on organisational development defines core competency as collective know-how. The difference between core competency and group competency could be compared to the individual difference between an expert and a novice. Core competency is an organisation’s special competency related to advanced social skills that occurs on the group and organisational levels. Instead of “owning” information, core competency is the ability to share information. Even the same researchers use the concept to emphasise different sides of core competency; to describe an organisation’s specifically defined competencies, or its advanced social skills in general (Mäenpää 1997).

In the organisational learning process, Prahalad and Hamel (1990) define core competency as one learning skill of an organisation, which enables it to co-ordinate different production skills and combine different technological currents. They also list several features related to core competency (Mäenpää 1997):

- Core competency involves the skill to communicate and commit to work across organisational borders.
- Core competencies develop as they are used and their use is expanded.
- Core competency is cumulative, and it inspires new know-how and insights.
- Core competency is difficult for competitors to imitate.
- A medium-sized organisation can usually only have 2 to 5 fields of core competence.
- Core competency exists in an organisation just as the superior know-how that is set as the competency target.

Leonard-Barton (1992) describes the concept of core capabilities as four "intertwined" dimensions: 1) employees' knowledge and skills, 2) technological systems, 3) the process of producing, controlling, and guiding the information included in management systems, and 4) values and norms related to knowledge, skills, and the processes of controlling and producing information. Unlike many other models, the values and norms are included in her model of core competency. She mentions that values are usually separated in the management literature. However, she understands that they are relevant to the development of core competencies.

Two central fields of know-how that must be taken care of are:

- New know-how needed for meeting strategic goals
- Know-how required for the effective implementation of current operations.

Group competence

Meaningful information and knowledge transfer require the effective interaction of formal training, learning at work, and subconscious learning. Understanding group dynamics and social interaction is essential, as the information is quite often socially structured and formed. Therefore, know-how management includes the organising skills and system for sharing, classifying, and storing information, and methods related to know-how management. However, it is even more important to create a social and information technological system that enables obtaining and creating new information and know-how while performing duties (Mäenpää 1997).

The company production process is usually split into task groups according to different organisational bases. A group comprises a fixed competency resource, which is expected to deliver a certain performance. Although the results rarely show who has performed which part of the work, everyone's contribution is still essential in achieving the end result. When aiming to improve the contribution of a group, the best results are achieved if each member understands his or her

significance to the group. Each member's contribution is important even if different duties require different levels of skill. This is something that should be emphasised when aiming to improve a group's competency (Mäenpää 1997).

As all people are different, we have different capacities and attitudes towards learning. Some see continuous learning as a challenge, while small improvements every now and then are enough for others. It is likely that people have applied for the duties that match their capabilities. Each employee's contribution should be appreciated, and this appreciation should be clearly shown to the employee. When developing a group's competency, it would be good to clarify right from the outset that not everyone needs to be good at everything. It is enough that the members can together perform what is expected of the group, but the workload needs to be distributed fairly inside the group (Mäenpää 1997).

The people working in different phases of the production process are interconnected and dependent on others' work performances. Therefore, the different production phases should be working together as smoothly as possible. The duties of each production phase contribute to the end result, and no phase can perform poorly. However, in some organisations, the borders between groups stop information transfer. Managers face a challenge of preventing the formation of uncooperative groups. The challenge is especially difficult as sometimes team spirit is an inspiration that drives the group to outperform other groups but, when taken too far, this may cause employees to start withholding information in order to highlight the performance of their own group (Mäenpää 1997).

Team spirit can be utilised in engaging people and shaping attitudes. Previously, a strategy was considered a declaration issued from the top down. Understanding the values of the personnel is important in order to commit them to the company strategy. People act according to their values. People's values are formed in the environment they belong to and, therefore, identification with the group should be promoted. Values are also formed by actions, and they can be shaped through participation. Therefore, a strategy process is optimally a dialogue between the management and the employees. A too specific strategy can diminish employee creativity, and so groups must have some say in the formation of the strategy (Mäenpää 1997).

It is also unnecessary to impose on employees those values and strategies that they cannot identify with. The strategy process includes presenting upper-level visions to workgroups/teams with the discussion of the implications for and implementation in their work. Instead of taking a whole section of the company strategy at once, the visions could be broken down for the groups and discussed from each group's perspective. The critical and core competencies

are also discussed from each group's perspective in order to identify the competency needs and best working practices. Instead of individual competency, the focus should be placed on organisational competency. Developing competency is the slowest process in an organization (Mäenpää 1997).

2.4.6. Knowledge management in the nuclear industry

The nuclear industry is knowledge based, similar to other highly technical industries, and relies heavily on the accumulation of knowledge. Recent trends, such as workforce ageing and declining student enrolment numbers, and the risk of losing accumulated knowledge and experience, have drawn attention to the need for better management of nuclear knowledge.

The draft glossary of terms for knowledge management compiled by the IAEA was used as the basis for a discussion by the participants on issues and terminology related to knowledge management. A practical exercise was also conducted on the aspects of capturing tacit knowledge. The results of the discussion and the practical exercise are highlighted below (IAEA 2005):

- Tacit knowledge refers to the accumulated knowledge held by researchers, scientists, technologists, engineers, plant managers and operators who are working, or have worked, within the industry. Capturing tacit knowledge is one of the most important elements of the preservation of nuclear knowledge (cf. Nonaka 1995).
- There are knowledge management experts who are optimistic that technical solutions can eventually be found to overcome the difficulties in eliciting tacit knowledge and transforming it into explicit knowledge. Others are sceptical about the conversion of tacit knowledge to explicit knowledge as they believe that it is futile and that the endeavour should be abandoned altogether because it would never be possible to capture the rich common-sense knowledge that underlies all human reasoning. Hence, these researchers tend to focus on shaping corporate culture to encourage the sharing of knowledge (cf. Nonaka 1995).

As a field, knowledge management is relatively new. It is an amalgam of concepts borrowed from the artificial intelligence/knowledge based systems, software engineering, business process re-engineering, human resource management and organisational behaviour fields. Knowledge management has been the most visibly introduced to the nuclear industry as a response to the ageing nuclear industry workforce in IAEA member states, where the generation that designed, commissioned and initially operated these plats has begun to reach retirement age. Knowledge management tools for capture and transfer of

fundamental nuclear knowledge from the ageing workforce to its younger replacement have been emphasized (IAEA 2005).

A threat to sustaining nuclear competence, recognised for quite some time, has been the declining number of appropriately qualified young professionals entering the field. This trend has an adverse impact on preserving and further developing the accumulated nuclear knowledge and expertise. In nuclear power plant organisations the loss of institutional memory of nuclear knowledge could become the precursor of problems in nuclear safety. Therefore, the decline in the number of students of nuclear sciences and a growing number of universities giving up their nuclear education programmes have given rise to understandable concerns (IAEA 2005).

Many nuclear power plant experts around the world are retiring, taking with them a great deal of knowledge and corporate memory. The people retiring are those who can answer questions easily and have tacit knowledge that was not extracted from them previously. Loss of employees who hold knowledge that is critical either to operations or safety poses an internal threat to the safety and operation of nuclear power plants. The primary challenge of preserving knowledge is to find ways in which tacit knowledge might be captured or at least be transferred to successors (IAEA 2005).

Maintaining competences in the nuclear industry and nuclear regulatory authorities will be one of the most critical challenges in the near future. There have been very few orders for new nuclear power plants in the Western world in the past few decades. The ability of universities to attract top quality students to nuclear programmes, meet the future staffing requirements of the nuclear industry and conduct leading edge research in nuclear topics is becoming seriously compromised in industrialised countries. National studies undertaken by several member countries of the OECD/NEA have shown that in spite of several initiatives undertaken by them, more engineers and scientists with nuclear knowledge are required than are graduating. For example, in Germany, the number of students graduating in nuclear related subjects dropped to almost zero in 2001. Maintaining competence is a high priority issue. Continuous technical training, succession planning and effective implementation of a knowledge management strategy are of paramount importance in coping with the adverse impact of the increasing rate of retirement of nuclear workers (IAEA 2004).

In recent years, knowledge is increasingly being recognised as a primary source of wealth. The nuclear industry has been losing its attractiveness to young professionals over the last few decades, thereby causing an adverse impact on preserving and further developing the accumulated nuclear

knowledge and expertise over the last six decades. It could also negatively affect future potential to apply nuclear techniques and methods in important areas. A number of initiatives have been implemented in order to maintain competency, capture and preserve existing knowledge, advance nuclear technology, develop future nuclear workers and maintain a critical level of R&D capabilities (IAEA 2005).

Knowledge management (KM) is defined within the IAEA as an integrated, systematic approach to identifying, acquiring, transforming, developing, disseminating, using, sharing and preserving knowledge, relevant to achieving specified objectives. Knowledge management consists of three fundamental components: people, processes and technology. Knowledge management focuses on people and organisational culture in order to stimulate and nurture the sharing and use of knowledge; on processes or methods to find, create, capture and share knowledge; and on technology to store and make knowledge accessible and to allow people to work together without being together. People are the most important component, because managing knowledge depends upon people's willingness to share and reuse knowledge (IAEA 2005).

The Fraunhofer Reference Model for knowledge management has been recognised as one of the few holistic knowledge management frameworks for standardisation in Europe. The model is a three-layer schema that depicts the relationships between *value-adding business processes*, four *knowledge management core processes*, and six *design fields of knowledge management* (IAEA 2005).

Heisig (2002) presents several approaches towards Knowledge Management:

- Spiral of Knowledge Creation by Nonaka & Takeuchi 1995
- Three Pillars of Knowledge Management by Wiig 2000
- Four KM Pillars Conceptual Model by Stankosky 1999
- The Knowledge Life Cycle (KLC) Framework developed by KMCI, Firestone, McElroy 2002
- Levers for the Development of a Knowledge Enterprise, Booz, Allen & Hamilton 2001
- Framework of Intellectual Capital Management by IBM Corp. 2001
- Knowledge Management as Organisational Competence by Cranfield School of Management 2001
- Knowledge Management Media Reference Model by mcm-institute St. Gallen, Eppler et al. 2001
- Knowledge Management Framework by APQC/Arthur Andersen 1996

- Building blocks of Knowledge Management by Probst, Raub, Romhardt 1997
- Knowledge Enabling: The 5x5 Grid by von Krogh, Ichijo, Nonaka 2000
- Business Knowledge Management Framework by Bach, Vogler, Österle 1999
- Knowledge Management Process Framework by Bukowitz, Williams 1999
- Knowledge management event chain by Despres, Chauvel 1999
- Knowledge Value Chain by Weggemann 1999
- Different components of the structure of operations on knowledge by van der Spek, Spijkervet 1997
- Knowledge Management approach of CommonKADS by Schreiber, Akkermans et al. 2000
- Nine Success Factors (hypotheses) for Knowledge Projects by Davenport, Prusak 1998
- Central concepts of process oriented KM by Remus 2002
- Tasks of Knowledge Management by Allweyer 1998
- Basic model of KM by Amelingmeyer 1999
- Components of KM by VBM 2000
  (Association of Bavarian Metal and Electro Industry – KM Guideline for SMEs)
- The Fraunhofer IPK Reference Model for KM by Heisig 2000
- The Movement of Knowledge in the I-Space by Boisot 1998
- Knowledge Management Process Model by Kucza 2001
- Four perspectives which form Knowledge Management by Rivero 2002
- Know-Net Framework 2002
- Knowledge Ecology 2002
- Knowledge Production System Activities Global Knowledge Economics Council KM Framework
- The Design fields of the Knowledge Management Maturity Model (KMMM®)
- The Intellectual Capital of the Firm by Sullivan 1998
- EKMF KM Framework – Version 1.4 (2002).

The following definition of Knowledge management complements the earlier definition provided (IAEA 2006a):

"*Knowledge management includes all methods, instruments and tools that contribute to the promotion of an integrated core knowledge process — with the following four core activities as a minimum, to generate knowledge, to store knowledge, to distribute knowledge, and to apply knowledge — in all areas and*

levels of the organisation in order to enhance organisational performance by focusing on the value creating business processes."

Note the pervasive impact of KM across the entire organisation. Succinctly put, "*Knowledge management is the process through which organisations generate value from their intellectual and knowledge-based assets (IAEA 2006a)*."

2.4.7. Knowledge Management developments at the IAEA

The IAEA is developing a series of guidance documents on knowledge management, including knowledge preservation, knowledge loss risk assessment, and knowledge transfer in the nuclear sector. The IAEA knowledge management initiative has developed a dual objective: an external one oriented to the needs of member states to manage nuclear knowledge and competence, and an internal one focused on knowledge management inside the organisation. The external knowledge management objective relates to how the IAEA involves nuclear knowledge management in programmatic activities with member states (IAEA 2005).

The four discernible elements of external knowledge management activities, which have been identified by the member states, are (IAEA 2005):

- Enhancing nuclear education and training
- Preserving and maintaining nuclear knowledge
- Pooling and analysing nuclear knowledge
- Promoting policy and guidance for nuclear knowledge management

The objective of the IAEA in the medium term is to be the independent, credible and authoritative international source of nuclear data, nuclear information and knowledge, and to maintain an adequate potential to meet the needs for capacity building, analysis and technology transfer in support of the peaceful, economically beneficial and safe use of atomic energy. A strategic framework for developing nuclear knowledge management involves six areas for the development of projects and activities (IAEA 2005):

- New partnerships for the advancement of nuclear knowledge
- Networks for education, training and knowledge transfer in nuclear science and technology
- Support in preserving, maintaining and widening the knowledge base
- Developing a coherent set of methodologies, guides and services for nuclear knowledge management
- Introducing knowledge management as a tool to strengthen safety and security

- Knowledge packages and knowledge organisation systems in areas of interest to the IAEA member states.

The IAEA internal knowledge management objective for the medium term is the development of a systematic and integrated approach for identifying, managing and sharing the organisation's knowledge, and creating new knowledge to enable maintaining a high level of competence in the areas of interest to member states. Fulfilling the knowledge management objective will make the collective knowledge and experience of the organisation available and accessible to individual staff members, who are expected to use it wisely and to help replenish the knowledge stock by sharing their individual knowledge and experience. Such an ongoing cycle will encourage learning at work, will stimulate collaboration, and will empower members of staff to continually enhance their performance. The successful and efficient operation of any nuclear power plant is highly dependent on effective knowledge management processes (IAEA 2005; cf. Paajanen 2006; cf. Viitala 2005).

A clear distinction between explicit knowledge and tacit knowledge is the fact that explicit knowledge is easily duplicated and distributed while tacit knowledge is not. One of the potential benefits of knowledge management is the elicitation of tacit knowledge and its conversion to explicit knowledge. A general conclusion is that elicitation is difficult and results in incomplete (explicit) knowledge. It is difficult because people find it hard to fully describe what they know and it is incomplete because it always assumes background knowledge with the reader. The danger then is that the tacit knowledge converted to explicit knowledge might imply a level of comprehensiveness that it does not have. These difficulties have divided knowledge management experts into two camps (IAEA 2005).

The first camp views failures as largely technical. These experts are commonly technological optimists who believe that solutions will be found for the elicitation of knowledge as technology improves. They tend to focus on issues such as knowledge bases (IAEA 2005).

In the second camp are the technological sceptics. They believe that elicitation of tacit knowledge is futile and that the endeavour should be abandoned altogether because it would never be possible to uncover and capture the rich common sense knowledge that underlies all of human reasoning. Hence, these researchers tend to focus on corporate culture and its effects on the sharing of knowledge (IAEA 2005).

The criteria and guidelines for an assessment of knowledge management functions in nuclear power plant operating organisations are given in the following. The particular areas of interest include (IAEA 2005):

- Knowledge management policies and strategies
- Knowledge capture/transfer methods and techniques
- Training and qualifications
- Communication methods and techniques
- Human resource management
- Methods for effectively learning from operating experience
- Work control methods to facilitate knowledge management
- Human performance improvement
- Implementing procedures and documentation
- Information technology solutions supporting knowledge management.

By the early 1990s, it was clear that there were two distinct branches of Knowledge Management.

First-generation Knowledge Management involves the capture of information and experience so that it is easily accessible in a corporate environment. Managing this capture allows the system to grow into a powerful information asset. This first generation had its roots in the use of information technology. In this view, Knowledge Management is an issue of information storage and retrieval. It uses ideas derived from management theory. Typically, first-generation Knowledge Management involved developing sophisticated data analysis and retrieval systems with little thought as to how the information they contained would be developed or used. This led organisations to invest heavily in technological fixes that had either little impact or a negative impact on the way in which knowledge was used (IAEA 2006a).

Faced with the theoretical and practical difficulties of first generation techniques to live up to their promise, theorists began to look more closely at the ways in which knowledge is created and shared. Along with this realisation came a change in metaphor. Organisations came to be seen as capable, and so a link grew between learning theory and management (IAEA 2006a).

Second-generation Knowledge Management gives priority to the way in which people construct and use knowledge. It is closely related to organisational learning. The goal of Knowledge Management in its second generation is to improve an organisation’s effectiveness by leveraging three learning processes in smart and lasting ways (IAEA 2006a):

- Learning from successes and failures at the individual, team and organisational levels
- Learning from peers and colleagues in the organisation
- Learning from the outside: suppliers, customers, competitors, and non-nuclear enterprises.

Knowledge Management should empower the plant staff to integrate these learning processes into their work practices and habits. However, learning should take place in a focused, relevant way because learning itself is not the goal, but, rather, is a tool to improve the organisation's performance and capabilities (IAEA 2006a; cf. Nonaka et al. 2008).

2.4.8. Nordic perspective

An objective of "Nordic Nuclear Safety Research Workshop on Knowledge Management in Nordic Nuclear Power Plants" was to explore if and how knowledge retention activities could be coordinated between the various Nordic utilities. The main conclusions of the workshop can be summed up as follows: Establishing good knowledge management routines is recognised by many utilities today. However, there seems to be no real consensus on what should be focused on in the present situation. Maybe the most pressing problem is to avoid undesirable consequences of the massive retirement soon to follow. Still, there is no consensus on what those consequences might be, and what should be done to avoid them. There is also no clear signal from the safety authorities on how to approach the problem. Without clear indications from the safety authorities it is doubtful that the utilities will prioritise knowledge management to the degree that will be needed to deal systematically with the problem. It is the impression of the author that there is still some way to go before the Nordic nuclear power plants industry has decided on priorities and solution strategies for the knowledge management problems of the future (Nilsen 2005).

During the first few years of Knowledge Management, the main focus was placed on the role of technology. Changes to the organisation were not considered effective means to improve Knowledge Management. This view prevailed almost 10 years from the beginning of the 1990s to the new millennium. The predominant philosophy during this first period was the assumption that knowledge problems were caused by 'not-enough-of-explicit-knowledge' (Articulating and integrating innovation in business, IBM Global Services website). Consequently the challenge was to extract, codify, organise, index, and retrieve knowledge, from data, from people, from documents etc. Technology/software was available to support those tasks to a certain degree, and appeared as an easy way toward a working solution (Nilsen 2005).

After the first wave of Knowledge Management enthusiasm, reports on failures started to seep in, and the suspicions that Knowledge Management was another consultant's fad started to spread. At the same time, some people started to look for an explanation as to why so many Knowledge Management initiatives failed. As part of this process, new viewpoints on knowledge emerged (Nilsen 2005):

- Knowledge is not really the asset, but the people owning the knowledge and being able to exploit it are the asset.
- Knowledge is not only explicit, but also implicit and tacit, actually it could happen that the most valuable knowledge is tacit and so people started to suggest that an important part of knowledge could never be codified.
- Knowledge is extremely dynamic, technology often ended in creating repositories difficult to update.
- Instead of managing knowledge it is necessary to look at the knowledge process.

This led to a big change in perspectives, and today some theoreticians talk about a first generation Knowledge Management and the second generation. The shift of focus to the human and organisation does not mean that technology has become irrelevant, or that the first technological phase was a big mistake. Experiences collected during the first Knowledge Management generation era are still useful since they enabled a more focused exploitation of the technology during the second generation era, which is the era that we are currently experiencing (Nilsen 2005).

2.5. Summarising this chapter

Organisational culture's definitional problems mirror longstanding arguments in anthropology, archaeology, and cultural anthropology about the general concept of culture. There is continuing debate between anthropologically oriented and materially oriented archaeologists over what culture is. The situation is perhaps even less clear relative to organisational culture.

There are very few areas of general consensus about organisational culture. They include the five assumptions stated earlier in this chapter:

- Organisational cultures exist
- Each organisational culture is relatively unique
- Organisational culture is a socially constructed concept
- Organisational culture provides organisation members with a way of understanding and making sense of events and symbols

- Organisational culture is a powerful lever for guiding organisational behaviour. It functions as “organisational control mechanisms, informally approving or prohibiting some patterns of behaviour”.

Beyond these five basic points agreement is very limited, and the points say nothing about what organisational culture is. Consensus is restricted to its existence, relative uniqueness, and a few functions that it performs.

The International Nuclear Safety Advisory Group (INSAG) introduced the concept of safety culture in its report (INSAG-4, 1991). It is used to describe the corporate atmosphere or culture in which safety is understood to be, and is accepted as, the number one priority. In high-risk industries safety should be the dominating characteristic of corporate culture. Safety culture is a sub-component of corporate culture, which alludes to individual, job, and organisational features that affect and influence health and safety. Nuclear safety culture is a sub-component of safety culture.

There are three main components to safety culture; psychological, situational and behavioural, and there are a number of tools available, qualitative and quantitative, which can be used to measure them. Grote and Künzler’s claim that models of safety culture suffer from a lack of integration into general models of organisation and of organisational culture. In addition the connection between safety-related characteristics of a system and more general characteristics like job and organisational design and the use of technology, is missing. The definition of the primary work tasks should include safety, to foster in analogy to the Total Quality Management approach a Total Safety Management. This idea will be further modified and developed in this thesis.

It can be concluded that theories related to nuclear safety culture give little guidance on how to apply this concept to enhance safety of nuclear power plant operation.

Knowledge management is a process used to create, acquire, store, share and apply knowledge. Knowledge management is an integrated, systematic approach to identifying, managing and sharing an organisation’s knowledge and enabling groups of people to create new knowledge collectively to help in achieving the organisation’s objectives. In spite of all the talk about knowledge-based management and in spite of the recognition of the need for a new knowledge-based theory there is little understanding of how organisations actually create and manage knowledge.

Nonaka and Takeuchi show that the individual interacts with the organisation through knowledge. Knowledge creation takes place at three levels: individual, group, and organisational. Therefore, the discussion of organisational

knowledge creation consists of two major components: the forms of knowledge interaction and the levels of knowledge creation. The two forms of interactions – between tacit knowledge and explicit knowledge and between the individual and the organisation – will then bring about four major processes of knowledge conversion, which all together constitute knowledge creation: (1) from tacit to explicit; (2) from explicit to explicit; (3) from explicit to tacit; and (4) from tacit to tacit (SECI model of knowledge creation).

As David Stamps states: “Companies need to quit thinking in terms of training and start thinking about knowledge creation and knowledge transfer as distinct and important business processes.” This is outstandingly important in the nuclear power plant organisations.

An analogy that should be followed is the “Systematic Approach to Training” that is used for training activities; as a result of the development, the nuclear power plant would have a documented “Systematic Approach to Safety”. This documentation would describe how safety is related to practical work. This would turn safety culture into a concrete tool. Documented safety thinking provides the organisation with a common starting point for future development.

3. RESEARCH RESULTS

3.1. Studies on knowledge management

“The new paradigm is that the basic economic resource is no longer capital, nor natural resources, nor labour. It is and will be knowledge” (Drucker 1993). The use of nuclear technology relies on the accumulation of knowledge and is characterised by long time scales and technical excellence.

The following studies deal with knowledge management problems and are based on master’s theses by Liikamaa (2000), Isotalo (2002), Alatolonen (2000), and Paajanen (2003), in addition to specific studies by Alamäki and Mäenpää (2002) and Koskinen (2001) related to transfer of tacit knowledge in the maintenance organisation and transfer of tacit knowledge between the workers of the old generation and young generation.

3.1.1. Human resource management

Issues related to human resource management are generally considered the important. Essential questions are:

- How to attract new employees?
- How to retain competent workers?

For attracting new employees, the nuclear power industry should better utilise the fact that it is, after all, a rather secure employer. However, people have different expectations: career, money, working in power generation rather than at a decommissioning plant, etc. A good salary is maybe too easy a solution. In general, utilities should be able to market the industry more effectively. A steady intake of new recruits helps to avoid many problems (Alamäki & Mäenpää 2002).

A further question arises on how knowledge should be transferred to the younger generation. It is very difficult because formal training can never replace experience, which is essential. Knowledge transfer must be encouraged. The real challenge is how essential knowledge can be transferred without transferring all the outdated practices and thinking. National governments should ensure that adequate education and training is made available in the nuclear industry, but this is not always the reality (Alamäki & Mäenpää 2002).

Nuclear power plants in Western Europe and North America are facing major problems due to the retirement of many employees. This is especially significant

considering that, as a working environment, a nuclear power plant requires special knowledge that cannot be obtained elsewhere. In the course of their long careers, the retiring personnel have developed a very high level of expertise and understanding of the plant. The personnel seem to be worried about who can continue their life's work and take care of the plant after them, expressing responsibility. Moreover, they are on average highly committed and demonstrate a strong work ethic (Alamäki & Mäenpää 2002).

Almost without exception, it takes 2–3 years to train and familiarise new employees until they can start to take responsibility independently. It is essential for safety and the duties of operation and maintenance that the employees understand the plant's operation as a whole and are familiar with their own duties as well. Performing the duties independently in a safe and efficient manner is demanding in most positions. There is no room for error, so expertise must be thoroughly ensured. For new employees, this job requires patience and care – especially since actual disturbances or maintenance-related repair tasks occur rarely. Therefore, learning the duties and working methods requires managers to have patience towards new employees, and the employees to have the right attitude and personality. Experienced employees, many of whom have been working at the plant since its early days, have in the course of their work become highly trained specialists. They are experts in their field. It is typical of these experts that they themselves are not even aware of how deep their knowledge and expertise really is. One reason for this is that these experienced professionals have obtained their practical know-how through tacit knowledge, which is sometimes difficult to articulate into words (Alamäki & Mäenpää 2002).

Because of economic pressures, often when an employee retires, others share the work. Currently, experienced long-time employees are able to do the work of two people due to their extensive knowledge and good understanding about the operation of the plan. They have developed a so-called extended working memory, which enables them to keep in mind and process more separate matters than usual, and they have an improved ability to perceive things. In the future, risks emerge when the long-term employees are replaced with less experienced employees who are not capable of handling two tasks at once. Professionals produce results always on time with good quality. The educational framework that young people have experienced shows also some dissimilarity with the educational framework existing thirty years ago (Alamäki & Mäenpää 2002).

In order to ensure that the special knowledge in a nuclear power plant organisation is transferred forward, the organisation will always need younger people to whom the knowledge and skills, which are obtained through experience, can be transferred. The recruitment of new personnel and

knowledge transfer should be started already a few years before the personnel retire. In knowledge transfer, it is relevant to understand that most of the practical knowledge that an organisation has is undocumented. One example is the observation that if NASA wanted to make a quick trip to the Moon right now, they would have to hire many of the experts who were employed over 30 years ago to plan and carry out the lunar mission. It is difficult to document the complex and detailed knowledge and understanding of the system as a whole that are obtained through experience. Human thinking and knowledge is such an intricate process that all attempts to store and document it will omit relevant information. Especially if performing something that requires a team or a large organisation, all the related dynamics, non-verbal processes, and streams of information are not yet known (Alamäki & Mäenpää 2002).

The following problems may arise in the transfer of knowledge and expertise (Koskinen 2001):

- There is no clear definition of less experienced people to whom knowledge should be transferred
- The company does not understand that, for instance, transferring the understanding about a plant to new personnel takes several years
- Even good thesis students are only offered a six-month contract, which is why young people do not remain with the company
- Documentation is partially outdated and cannot be transferred as is
- Individual persons have been responsible for different fields of know-how
- Separate closed cliques have been formed inside the company
- The direction of learning goals is not always clear
- Senior employees do not always understand that many things they consider self-evident are clear obstacles for learning to young employees.

Usually senior employees are motivated to work. Reasons that reduce the motivation for young employees include (Koskinen 2001):

- The company has old-fashioned working methods
- They cannot see the next step that they could try to reach in their career
- The duties are too familiar to them and not challenging enough
- The relationships between people are weak
- Personnel management is weak
- Underlying problems are not acknowledged.

For the most part, senior employees feel that at least the company management appreciates their expertise. Younger employees do not feel the appreciation very clearly. The company should avoid forming units that only

include long-term employees and very young persons. This is because people of around the same age usually share similar values and attitudes, so they tend to interact more with one another and avoid interacting with people of a different age (Koskinen 2001).

3.1.2. Maintaining competences in the nuclear industry

New employees should be recruited a few years before they have to take independent responsibility for their duties. According to the interview results, it takes 2–3 years for new employees to learn the new duties well enough that they can take responsibility independently. This is quite a credible statement in the light of scientific studies. For all experts, work itself is a much more important way of learning than any course or training programme. Naturally, education is important, but its role should be seen as one teaching theoretical basics, which are elaborated upon and developed through practical work (Alamäki & Mäenpää 2002; Koskinen 2001).

The planning of training requires the reinforcement of pedagogic expertise, as the experts in a technical field are not teachers or educators – nor should they be, if they are supported by experts in that field. It should be mentioned here that teaching and training are not considered knowledge transfer, as the taught or trained information is not transferred as is into the minds of the learners to become know-how. Knowledge is not a concrete object or matter; it is an individual's own construction about something. Learners who can remember and list information are not necessarily ready to apply and use that information in an actual context if they have not yet understood and observed its structure and content themselves. The purpose of pedagogic expertise is to help convey and transfer technical substance knowledge to learners using the right methods and phasing so that the learners can prepare for action.

Knowledge and know-how transfer should utilise the master and apprentice model, which combines several proven training and pedagogy-related elements. This model transfers both so-called tacit knowledge obtained through experience and more codified knowledge that can be expressed more easily.

A true master can simplify things and convey them in a clear and concise way. He or she can show the learner where to find information, explain things in an understandable way, correct misconceptions, and evaluate the learning process and the learner's abilities to learn.

The special in-depth know-how needed at a nuclear power plant cannot be taught fully by an outsider. The nuclear power plant technology and the related safety culture are something that requires knowledge and understanding of the field for teachers, even if they are experts in their own field. Employees need

freedom for retraining and self-development in their special field. Therefore, training methods should discuss developing learning-to-learn skills and the principles of lifetime learning.

The work itself and its contents are the most significant thing for the development of expertise. Learning at work is the most important method in expert development. It can and should be supported with theoretical training courses and online training resources. Becoming an expert in a field does not happen in a few months. Even in a diverse working environment it takes many years. Understanding and analysing things is not enough; an expert must be able to independently solve even surprising problems that he or she encounters and to assess their impact and consequences (Alamäki & Mäenpää 2002).

Working method and process knowledge is required in addition to the necessary basic competency, for instance, on the nuclear power plant technology. Working methods include knowledge that is partially instructed, but mostly methods, learnt through experience, that are not reasonable to convey by instructions. The basic training can be utilised effectively only after these competencies (Vähämäki 2008).

Core competencies are a company's working methods and procedures that ensure that the approved strategic targets and visions can be realised. Core competencies can also include the following:

- Procedures that ensure the expertise of the interest groups on which the operation is dependent in the future
  - ✓ contractors
  - ✓ research institutes
  - ✓ universities
  - ✓ technical support organisations
- Ensuring personnel resources
  - ✓ resource availability at educational institutions of different levels
  - ✓ training personnel to become highly qualified specialists in their duties
- Good (productive) management of community relations
- Inspiring and engaging personnel (learning organisation)
  - ✓ improving information transfer
  - ✓ improving human resources management

3.1.3. Transfer of formal and tacit knowledge

Isotalo (2002) has studied the experiences of new employees on their expertise, learning in the organisation, and information transfer and sharing inside the organisation. The empirical material of the study was collected via survey forms.

The study focused on persons who had entered permanent employment at a nuclear power company after 1998. The focus group comprised 34 persons. This survey study used a quantitative method to analyse the results (cf. Tannenbaum 1997).

The majority of the participants in the survey seem to have also used other methods of informal learning. Most of the respondents (65%) felt that official training was not the best way to receive induction. The reasons for this cannot be found in the results of this study; instead, we need to examine the developments in the induction training during earlier years. Initially, the commissioning of the nuclear power plant, fine adjustment of control systems, and the elimination of operational disturbances consumed a significant amount of resources. In addition, training was not the responsibility of an external organisation unit; instead, it had been delegated to the organisation units. Therefore, induction training has been mostly limited to compulsory entrance training, which is a requirement for the access card. The rest has been the responsibility of the supervisor and colleagues. The implementation of the training may have often been delayed due to other work pressures, and it has not been as systematic as it is now.

During the years of recession in the early 1990s, very few new employees were hired. During this time, however, the contractor training programme and its related documentation were renewed in Finnish, English, and German. The purpose was to familiarise the external outage personnel with the power company's procedures, especially to ensure safety. This documentation has been later supplemented to include a general technical description of the plant and the general design basis of its safety systems. The sections concerning safety culture, occupational safety, human error prevention, and the reporting of defects have been added. This material has been developed into more extensive induction documentation for in-house personnel.

The reason why the actual induction training has only later on been developed is partially explained by the fact that the number of new employees has only started to increase in recent years. Therefore, only a small number of the respondents (those who started in 2002) have been able to participate in actual induction training. The lack of systematic induction training is also evidenced by the fact that, when the participants were asked whether "trial and error" is more important for work initiation than official training, the variation in the responses was very high. However, most of the respondents felt that "trial and error" affected their work induction more than official training.

For on the job learning, important factors also include reflecting on one's working methods and learning from mistakes, following the work of others, and learning from informal conversations with colleagues, in addition to participating

in formal training at the worksite. Utilising informal learning at the worksite is important, when the aim is to develop the working organisation and to develop the skills related to the work of individual employees (Aittola 1998, pp.71-72).

Following the work of others also came up in this study. Over one fourth (26%) of the respondents considered that following the work of other people is an important factor for their personal learning. 58% of the respondents considered that following other people working was of some importance in their induction. When reviewing the respondent's understanding of the provided training, the respondents considered the laws and regulations concerning the operation of a nuclear power plant and working at one. Table 1 below shows the percentage of the respondents who considered that training in the area was sufficient. When looking at the table, it must be borne in mind that this is by no means a complete list of the content areas of the provided training. The study has mainly been performed to survey the opinions of new employees concerning a few, broadly defined areas (Isotalo 2002).

Table 1. Sufficiency of training concerning a few, broadly defined areas (Isotalo 2002).

I find that training for a new employee is sufficient in the following areas:	***Strongly agree***	***No clear opinion***	***Strongly disagree***
Technical competences required for the work (technical skills required for the work)	29%	62%	9%
Cognitive competence	35%	62%	6%
Maintaining working ability	26%	62%	12%
Team/group work skills	9%	65%	24%
Self-development	15%	67%	18%
Increasing professional skill	29%	50%	21%
Adopting working methods	12%	71%	18%
Laws and regulations that apply to work in a nuclear power plant environment	62%	24%	15%

Even this highly superficial analysis shows that, ranked by percentage, all the “humanist” topics take the bottom places. The respondents find that the company emphasises technical knowledge and cognitive competence rather well, but topics related to applying the know-how, such as group work skills, have been left in their shade. A technically inclined environment explains this in part, but it is by no means a justification. New employees feel that developing working life related skills is as important as the actual technical, cognitive, and professional issues. In the future, training should also emphasise using the skills acquired by formal learning in the organisation. Group work skills, for example, are essential for informal learning. Without the necessary social skills, informal learning is practically impossible. The need for social skills is further emphasised when we study the results of the study regarding the relationship between formal learning (official channels) and informal learning (unofficial channels). According to the participants of the study, only 33% of their work-related learning has taken place through formal learning. This in turn means that 67% of learning has taken place by means of informal learning. The table has been combined based on the dichotomy, formal and informal learning, established by the respondents. In the form, the focus group was asked to divide 100% according to how much of the learning has taken place through the above channels. The result clearly shows that, as stated above, the company had no induction programme before 2002 (Isotalo 2002).

The fact that respondents gave such large importance to unofficial channels, or tacit knowledge, also gives cause to note the coming generation change. If nearly 70% of all learning takes place through informal channels, how can the company survive the change of the generation without losing an enormous amount of information? The company has already awakened to this reality, however. The old idea of master and apprentice learning has been reintroduced. In the autumn of 2002, the company started a mentoring pilot project to find a means of transferring tacit knowledge. The project aims to develop a method for offering each new employee an opportunity to have their own mentor relationship (Kannisto 2002).

The focus group of the study was a group of 34 people. This can be considered a comprehensive sample, since it included – with the exception of two people – all the new employees who started permanent employment with the company in the past few years. However, efforts have been made to avoid excessive generalisation, since the new employees only represent 7% of the company’s entire personnel. However, since the study includes all of the new employees, the research information provides clear clues as to how the new employees have experienced induction training and other training. These results provide information on how personnel training for new employees should be developed (Isotalo 2002).

3.1.4. Transfer of knowledge in project work

The aim of the master's thesis by Liikamaa (2000) was to develop a method to activate the transferring of companies' important tacit knowledge between the project manager and the staff in his/her working environment. The study was based on recognising the invisible intellectual capital. The aim was to find factors that influence the effective transfer of tacit knowledge. The study also included an empirical part, wherein the knowledge transferred to the project managers was categorised and the amount of tacit knowledge was determined. In addition, the commitment, experience, organisation culture, and interaction between the project manager and the people in his/her working environment were studied. A total of nine project managers were selected for the study; their experience in project management varied between two and 26 years. The average experience in project management was 14 years. The study included smaller and larger projects, as well as projects from different fields of expertise.

There are many cultural factors that inhibit knowledge transfer. Table 2 presents the most common friction and ways of overcoming them.

Table 2. Obstacles for knowledge transfer and the means to remove obstacles (Davenport & Prusak 1998, p.97)

Friction	**Possible solution**
Lack of trust.	Build relationships and trust through face-to-face meetings
Different cultures and vocabularies	Create common ground through education, discussion, team formation, job rotation
Lack of time and meeting places	Establish times and places for knowledge transfers: fairs, discussion rooms, conference reports
Status and rewards go to knowledge owners	Evaluate performance and provide incentives based on sharing knowledge
Lack of absorptive capacity in recipients	Educate employees for flexibility; provide time for learning, encourage openness
The belief that knowledge is a privilege of a certain group, "not from here."	Encourage nonhierarchical approach to knowledge; quality of ideas more important than status of source
Intolerance for mistakes or need for help	Accept and reward creative errors and collaboration; no loss of status from not knowing everything

Davenport and Prusak (1998, pp.101-102) specify that knowledge transfer consists of two functions:

- Transmission; sending or presenting knowledge to a potential recipient
- Absorption by that person or group.

If the knowledge is not received, it has not been transferred. The purpose of knowledge transfer is to improve the organisation's ability to function and to increase its value. The speed of transfer and the content of the knowledge are significant factors in terms of knowledge transfer. Only knowledge transfer that affects behaviour or the creation of new ideas is meaningful. The reasons as to why the received knowledge is not used may include the following (Davenport & Prusak 1998, pp.101-102):

- Lack of confidence in the meaningfulness of the knowledge
- Pride prevents receiving the knowledge
- Knowledge that differs from one's own viewpoint is not wanted
- Lack of time
- Lack of opportunities
- Fear of risk-taking.

Communication is important for knowledge transfer, but we must also know where the necessary knowledge is located inside the company, and who can help solve the problem (von Krogh et al. 1996, p. 42). Effective communication and knowledge exchange are dependent on the formation of suitable conditions, structures, and routines. Information and knowledge can easily be distributed into the organisation and within the organisation, if a suitable information infrastructure has been established. According to von Krogh et al. (1996, p.60-66), the transfer of tacit knowledge between one or more persons is affected by four factors: openness, channel of interaction, trust, and experience.

The project managers were asked whether the workplace culture supports interaction with other employees. The opinions were divided both ways. It must be noted here that nearly half of the interviewees felt that the organisation culture at the worksite did not support interaction. This is an important feature for the transfer of tacit knowledge. If the employees cannot discuss things freely at the workplace, it may prevent the transfer of tacit knowledge. However, the social activeness of a person may also affect the results of the interview (Liikamaa 2000).

The project managers were also asked about the amount of collaboration at the workplace. It was somewhat surprising that up to one third of them thought that

not everyone was working towards a common goal. Creating team spirit and finding common goals is important for work success. When such a problem is observed, it must be solved as quickly as possible, as it presents a clear obstacle for the transfer of tacit knowledge (Liikamaa 2000).

To summarise, it can be stated that although the atmosphere at the workplace is considered to be relatively open, it did not support open discussion and interaction during working hours. Meetings that discuss project issues have time limits, and they do not necessarily offer the best possible conditions for the transfer of tacit knowledge. Therefore, the atmosphere at the workplace should be open, and everyone should be aware of the common goals. Communication outside the meetings assists in knowledge transfer if people working on the same problem can also meet under informal circumstances (Liikamaa 2000).

Activities at the nuclear power company are controlled and are precisely based on explicit knowledge. The tasks are clearly defined, and the uncompromising application of commands and orders guarantees high-quality operation. The normal operation of a power plant takes place in a highly technical environment. Project activities, on the other hand, are largely based on personnel competence that is transferred to the organisation through social interaction. This necessitates the horizontal transfer of information. It may be stated that projects take place in a business environment that represents both the mechanical and organic context. The effective transfer of tacit knowledge could be supported by the development of organisational culture and improvement of personnel's communication, interaction, and commitment as follows (Liikamaa 2000):

- More get-togethers should be arranged because informal interaction assists the activities during the project. These get-togethers should be aimed at strengthening the social interaction between persons from different groups.

- It must be ensured that each employee is carrying out work that they feel is purposeful and motivating. Internal "training" for project managers would help in transferring tacit knowledge between project managers. The theme could be reviewing and analysing technical, commercial, and project management related problems.

- It is important to make the employees aware of the common goals. Nearly half of the project managers found it difficult to create common goals. There are many reasons for this, and it absolutely requires management's improvement actions.

- Based on the interviews, it may be stated that the working community was considered to be open, but the workplace culture was not seen to support worker interaction. An example of this is the line organisation supervisor group; they estimated the transferred tacit knowledge to be on average 57% of the total amount of knowledge. It may be stated that, although the project managers have received a large amount of knowledge from the line organisation's supervisor, it is not completely meeting the goals.

- Although the atmosphere is considered to be open, the study shows that a feeling of collaboration is missing. There may be many reasons for this, including poor work motivation and a lack of common goals.

- A project manager is responsible for many different types of things and deals with many different people. As work experience increases, a routine develops. The positive consequences of this are the increase in the amount of knowledge, and the use of tacit knowledge from the environment. The project managers should also aim to increase their own expertise, task by task.

- Assisting persons, even in issues that may be of small significance, in co-operation environments and between co-workers alike, is highly recommended.

- The project managers' co-operating groups must take into account the project manager's starting points for managing the project. Based on the interviews, the amount of work experience in project management tasks affected the expectations that the project managers had in terms of the transfer of tacit knowledge. Less experienced project managers expected widespread experiential knowledge, with backgrounds and justifications. Experienced project managers expected a dialogue between experts and comparing experience, resulting in the transfer of tacit knowledge.

The study did not address the typical features of an operating organisation and a project organisation; these features are formed according to the goals set for the organisation. By virtue of its normal activities, an operating organisation is not very dynamic. Its standard tasks have no major schedule pressure, and cost supervision is not essential. Therefore, an operating organisation does not usually meet the requirements for more versatile project activities.

3.2. Competencies of the control room operators

The objective of this research is to develop a management tool that enables the better monitoring of shift personnel's responsibility and commitment to work. The tool supports individual development by focusing on the competencies required for successful performance in the task, and by identifying the individual's current state and personal goals. By understanding these personal qualities, shift personnel development and training can be better targeted according to the desired and actual needs (Nurminen 2003).

3.2.1. Basic requirements for operators

The Finnish Centre for Radiation and Nuclear Safety (STUK) issues detailed regulations concerning the safety of nuclear power plants. Regulatory Guide on Qualification of control room operators for nuclear power plants YVL 1.6 defines the requirements related to recruitment and general competence of operators as follows:

"The licensee shall have systematic procedures for the recruitment of those to be trained as operators. The procedures shall contain the objectives of the choice of persons, the selection criteria and the personal assessment methods based on the first two. The selection criteria shall include requirements for education, previous work experience, health and other suitability.

An operator shall have a polytechnic degree or other technical degree suitable for his duties. A shift supervisor shall have a minimum work experience of five years in tasks that support his intended duties, with at least three years in the nuclear sector. Furthermore, a shift supervisor shall work as a control room operator for a minimum of six months, with at least three months as a reactor operator. Other operators shall have a minimum work experience of three years in duties that support the task of a control room operator, with at least one year in the nuclear sector.

The health and other suitability of those selected as operators should enable them to work as superiors or members of their shift teams under normal operational conditions and during transients and accidents. This requires good communicative and co-operative skills, tolerance to pressure as well as normal sight and hearing. Operators shall be reliable, and they shall not be inclined to abuse intoxicants.

The doctor who makes a physical examination shall be aware of the examined person's duties in the nuclear power plant and of the suitability requirements related to these duties. In addition to the pre-employment examination, the licensee is obliged to arrange a regular and appropriate physical examination

for the persons in question. An aptitude assessment by a psychologist is recommended when selecting persons as operators and to other positions directly related to plant operations significant for safety. To ensure reliable personal assessment, sufficient expertise shall be available to the licensee in selecting and interpreting the assessment methods and in monitoring them in the long term. The reliability of shift supervisors and operators shall be regularly monitored by available means."

3.2.2. Competency requirements

Competency is described as a characteristic quality of an individual who has a causal relationship with an excellent or efficient performance at work or in a certain situation. Individuals' competencies are necessary, but not enough for an efficient work performance. The inadequacy of competencies is shown in how a review of the efficiency of an individual's performance must also take into account the factors affecting the performance, environment and situation, the requirements of the work, and the ethical and developmental factors. This way, competency can be defined in relation to achieving the set goals in a specific working environment using acceptable and appropriate methods, while providing positive results (Boyatzis 1982, pp. 10–16; Ford 1992, pp. 67, 247; Spencer & Spencer 1993, pp. 9–11).

Intention is an essential part of competency. It is a force resulting from motives or characteristics, which leads to action and the action's consequence. If there is no intention related to behaviour, it is not considered a competency.

The shift personnel are responsible for operating and monitoring the plant as required by good operation and practice, in accordance with the Technical Specifications, administrative procedures, operating manuals, and operating requirements. Each shift includes a shift supervisor, reactor operator, turbine operator, area work supervisor, and two or three field operators. The shift must meet the Technical Specifications' requirements on minimum staffing. The reactor operator, turbine operator, and area work supervisor must know each other's duties well in theory and in practice, so that they can perform the duties of a substitute, if necessary. Ideally, a shift can work as a team in which each person knows and performs their duties without a separate request.

The shift personnel must have a good feel of the plant. The shift supervisor, reactor operator, and turbine operator must maintain their technical system knowledge and make sure that they understand what happens in the plant when operating procedures are performed. The shift supervisor must be aware of how the shift personnel move around the plant. The shift must work on its own initiative and perform its duties effectively and on time. Common sense must be used actively and responsibly, and the next shift cannot be left in trouble.

Information transfer must be transparent and smooth not only within the shift and between different shifts but also between the shifts and operation management and other personnel.

Skilled and qualified personnel are a very important resource for all companies, and appropriate training is required to create and maintain this resource. For many reasons, training is more significant in nuclear power plants than in the Finnish industry in general. A nuclear power plant is an expensive investment whose operation depends on skilled personnel. From the safety perspective, operations in the nuclear power industry require especially skilled personnel.

All shift supervisors and operators undergo simulator training at least ten days per year. In simulator training, the shift personnel can also train for rare operation situations and prepare for different accident conditions. However, simulator training does not only focus on disturbances. It is rare for specific unusual disturbances to repeat in the operation of the plant. Thus, one goal of simulator training is to teach the operators to act reasonably in all situations that they encounter. Training for different disturbances helps the operators to understand the behaviour of the plant even better. The simulator is an essential tool in the basic training of new shift personnel because it allows training the operation and monitoring of the plant without disturbing normal operation.

3.2.3. Operation of the plant during disturbances

Evaluating shift performance during disturbances is a central area of training. The plant specific full-scope simulator provides excellent opportunities for this. When operating personnel and trainers work together, the training programmes become more meaningful. Usually, the shifts have one day reserved for simulator training that they consider necessary.

Regulatory Guide on Qualification of control room operators for nuclear power plants YVL 1.6 defines the requirements related to the demonstration of professional skill at a training simulator as follows:

“The demonstration of professional skill is to ensure that the trainee control room operator has the necessary expertise as well as working methods that take nuclear and radiation safety aspects into account. The operator is also required to have the skills and co-operation capability necessary to function as a member of his team so that the shift team can manage normal operational conditions of the nuclear power plant and perform the actions necessary during transients and accidents.

The demonstration of professional skill shall be given at a training simulator. Two types of operational conditions are run:

- Situations requiring interpretation of the Operational Limits and Conditions during which the trainee/operator, by means of plant alarm system signals and other data, assesses the plant state and deviations from normal operational conditions as well as determines and carries out the necessary actions
- Situations relating to the transient and emergency procedures during which the trainee/operator identifies the disturbance, performs first actions required by the procedures, detects an abnormally functioning component, corrects the situation and determines the necessary further actions.

The demonstration of professional skill shall be arranged for the trainee control room operator before the oral examination and thereafter at least every second calendar year. Furthermore, a demonstration of professional skill shall always be arranged after extensive modifications that affect control room work."

During several years, a methodology has been developed to be able to demonstrate professional skill of the shift crew in a reliable way. The researcher as an operation manager has participated in this development work. The scientific basis of this methodology has been described in several publications (Hukki & Norros 1994.; Norros & Hukki 1995; Norros and Hukki 1996; Norros & Hukki 1997; Hukki & Norros 1998; Norros & Nuutinen 1999).

The methodology is shortly described in the following. The tools, which are forms, diagrams and tables, serve several functions in simulator training. They provide general frameworks for the description of a specific task situation, give general criteria for the observation and evaluation of the crew's activity, afford informative ways of giving feedback to the operators and serve as a means of documentation.

During the preparation phase, after the task situation has been chosen by the trainers they, in addition to the normal design of the simulator programme, conceptualise the task situation of the simulated scenario from the decision-making point of view. The main task of the crew in the disturbance situations is to stabilise the process. At first, with the help of the description of the general process control task demands the trainers define what are the concrete task demands in that situation. After that, they describe the availability and informativeness of the process information and the availability and usability of the alternate operating methods in relation to the concretised demands. At last, they define the situational cognitive task demands by concretising the general cognitive criteria provided by the method.

During the simulator run, the crew's activity is videotaped and trainers observe the verbalisations and operating actions of the crew. If the operators' verbalisations or actions do not reveal their diagnostic and operational bases of interference, the trainers try to find them by asking for them immediately after the run, before debriefing session.

During and immediately after the run, the trainers evaluate the adequacy of the crew's task performance and the characteristics of the operator's habits of action with the help of the concretised criteria. On the basis of the evaluation, summary profiles of the crew's habits of action are created. These profiles express to what extent the concrete criteria are fulfilled. The evaluations of the trainers are preliminary and may change as a result of discussion in the debriefing phase.

In the debriefing session, the trainers show the trainees the relevant periods of their task performance with the help of the videotape. They also introduce their preliminary evaluations of the adequacy of the crew's task performance and of the characteristics of the operator's habits of action. It is important that these are considered both from the trainers' and trainees' point of view.

The following items are evaluated for the shift's disturbance management:

- Identifying the situation (identifying faults, determining trigger conditions and establishing an understanding of the disturbance, and contacting the outside of the control room)
- Operative actions (accuracy and timing of operation activities, use of procedures and following the reactor pressure and water level, maintaining mass and energy balances, and trend analysis)
- General evaluation.

The assessment of the shift supervisor's operating strategy is based on the following factors:

- Analysis of the disturbance (search for information, attempt to determine the significance of the events in terms of process dynamics, changing diagnostic assumptions according to the situation, and ensuring the interpretation using additional information)
- Evaluating possibilities for operative actions and implementing them (critical assessment of the method's limits, prioritising the method considered the most functional for the situation, making situation checks, organising time usage according to the situation, and using external help for decision-making)
- Coordinating co-operation (following other people's activities, utilising input from others, organising shift operation, preparing for changes in the

situation, organising co-operation based on the shift members' experience)
- Noting the uncertainty and instability of the situation (using redundant information sources and preparing for changes in the situation)
- Critical assessment of own activities (using additional information to ensure the correct interpretation, critical assessment of task priority, and reacting to obstacles preventing activity)
- Communication (informing, bringing out justification clearly and in a concrete manner, aiming for interaction, communicating outside the control room, active participation in common interpretation, acting with others in a coordinated manner, informing regarding essential observations and activities, and discussing matters, unclear issues, and problems related to own activities in concrete terms).

The objective is to develop for operators a model way of action in normal and disturbance conditions. This could then be used in training and included in plant operating procedures.

3.2.4. Selecting operating personnel

In addition to the basic requirements, the operating personnel's selection procedure includes an applicant interview that is used as a basis for sending suitable applicants for psychological testing. One part of the testing results describes personality factors, of which there are five categories, and aptitude, including linguistic capability, logical thinking, ability to develop ideas, and spatial perception. Based on these, a feature profile for a good operator has been defined. In addition, a total of seven key personality criteria have been defined. The following are examples of them:

- Always acts according to the rules, as it is difficult for a single individual to understand the entire workings of a nuclear power plant
- Is calm and has a long-term focus, as the work contains repetition with little variation, and the situations require calm consideration
- Does not long for varying human contact, since the work shifts are rather permanent
- Balanced and mature personality, as predictability in all fields of activity is important, etc.

Course success is evaluated in the fields of technology, group work, and human activities. Technology includes know-how (theory, plant operation, and plant dynamics), normal operation (preparation, performance, supervision, and use of procedures), and disturbance management (identification, analysis, interpretation, decision-making, implementation, supervision, and use of procedures). Group work includes co-operation (division of tasks, arrangements, management, and supervision) and communication (asking for

opinion, reaching a common understanding, reporting, and instructions). Human activities are evaluated in terms of behaviour, motivation, observation, and workload.

The shift supervisor's activities are especially evaluated in the following areas:

- Ability and methods used to process information (how information is collected, how the information to be collected is selected, how much and what types of information are needed, how information is analysed, how it is synthesised, and what the used risk levels are)
- Decision-making (how many different options are processed and how, what types of options are most likely selected, how critically thinking is reviewed, how much self-confidence the person has, how holistic the general picture of the situation is, and which factors affect the decision)
- Communication (amount and level of communication)
- Utilising surrounding resources (how much trust is placed in others, how much responsibility is delegated, how external knowledge is related to knowledge from own logistic reasoning, and what types of support is needed).

When evaluating a disturbance, attention is paid to diagnosing the disturbance, selecting the method for eliminating the disturbance, communication, and coordinating common activities. A training event defined the nine commands of shift work leadership as follows:

- Lead by example
- Develop the shift's co-operation
- Provide feedback
- Encourage individual self-improvement
- Do not leave issues hanging
- Show interest
- Listen
- Show what is important
- Only require from others what you also require from yourself.

Zack T. Pate (1995), President and CEO of Institute of Nuclear Power Operations (INPO) stated that: "When a control room operator places his hand on the IN-HOLD-OUT switch and moves it to the OUT position, withdrawing control rods, he has more *potential* power in his hand than:

- The captain opening the throttles of a 747 for takeoff
- The NASA engineer who ignites the booster rockets in a space shuttle for launch"

In the normal quiet and relaxed control room environment it is difficult to really understand how huge energy volumes operators control in the reactor pressure

vessel. The cockpit of a 747 is a more realistic environment than the control room if we think about sense of danger.

3.2.5. A concept of man

The operation and structure of the human brain is often compared to a computer. Researchers of artificial intelligence have tried to create computer programs whose operating principles resemble the human brain as closely as possible. Humans experience phenomena in their consciousness through the brain, but consciousness is often ignored in brain study. Consciousness is an important part of the holistic conception of man. Neurobiologists, cognition researchers, and psychologists who compare the operation of the human brain and consciousness to theatre seem to have a more realistic idea of the human brain than many previously presented views (Pihlanto 1997; Pihlanto 2002). One of such researchers is Baars, who has compiled research results from several disciplines into what he calls the “theatre metaphor” (Baars 1997).

According to the holistic concept of man, the three ontological basic modes of human existence are (Rauhala 1989):

- Consciousness (psychic-mental existence)
- Corporeality (existence as an organic event)
- Situationality (existence as relationships to reality).

For Rauhala, the human is realised in these three basic modes of existence. The holistic concept of man provides an integrated view of individuals as complex physical entities, and inseparably locates them in their individual situation (Rauhala 1989, p. 27). The holistic concept of man constitutes a common theoretical platform for all Co-Evolute applications (cf. Nurminen 2003).

Baars is specialised in studying the operation of the brain. He is especially interested in what truly happens in the brain when a person thinks, sees, or remembers. According to Baars’ understanding, consciousness is a key factor in explaining the brain’s ability to interpret, learn, communicate and work (Baars 1997, viii). The basic idea of this so-called theatre model is that an individual’s conscious experience is limited by the capacity of his or her consciousness. The audience in the theatre model can be divided into four groups, which are the motivation system, memory system, interpretation system, and automatic systems (Baars 1997, pp. 41–47). The theatre metaphor provides an opportunity to complement the holistic concept of man. The theatre metaphor is based on the latest findings in brain research, and the results can be applied in the framework of the holistic concept of man as developed by Rauhala (Vanharanta & Pihlanto 2001, pp. 15–16; Vanharanta et al. 2001, pp. 14–15).

This allows for building an understanding about human actions, including conscious and subconscious processes (cf. Nurminen 2003).

Vanharanta et al. claim that the theatre metaphor has quite a limited area of focus, which strongly emphasises the role of subconscious processes as a consequence of the brain-oriented nature of the metaphor. Indeed, the processes of the brain are subconscious, but the processes of the mind are mainly conscious and, therefore, voluntary. For Vanharanta et al. (2001, pp. 14–15), the theatre metaphor is limited in that it is a closed system which leaves out the effect of situationality.

3.2.6. Self – Assessment

Self-assessment can be considered an effective method in projects aiming at self-development, managing personal growth, clarifying roles, and commitment to targets. However, using self-assessment for evaluating one's personal work performance reduces the reliability of the results (Stone 1998, pp. 272–273). One of the essential problems with self-assessment is the human tendency to overrate their personal performance in comparison with their peer group (Dessler 2001, p. 167). Therefore, the self-assessment of one's personal performance provides somewhat biased and skewed results. In spite of the aforementioned disadvantages, self-assessment is used fairly often for evaluating personal work performance (Schuler & Huber 1990, p. 197; cf. Nurminen 2003).

Beardwell & Holden (1995, pp. 243–244) argue that one central problem with assessment is our limited ability to make accurate observations about ourselves and others. Our assessment of ourselves and others is strongly founded on the factors affecting the assessment situation and our personal subjective views, but there is no question about whether people are capable of self-assessment. The question is more about whether people are willing to assess themselves and whether the assessment has a factual basis. Self-assessment provides better results when an individual compares the relationship between different qualities instead of comparing personal performance to other people (Torrington & Hall 1991, pp. 484–485). Correct interpretation of the results is critical for the assessment process to succeed (cf. Nurminen 2003).

The results of the self-assessment process can be utilised for different purposes. Self-assessment can be used for motivating individuals, identifying areas for development, evaluating individual potential, evaluating individual performance, clarifying career development, expressing the expectations for individuals, as a basis for rewarding and hiring, and for obtaining feedback. Self-assessment can also be used for setting work-related goals, as a source of information for personnel-related functions, and for evaluating the efficiency of

the selection process. Mutual trust and respect are necessary for achieving the transparency that the assessment process requires (Torrington & Hall 1991, p. 495).

3.2.7. The self-assessment system, Deltoid

The self-assessment system built based on the master's thesis by Nurminen (2003), is called Deltoid. The competency model is a task type-based generic competency model, whose competencies have been selected based on task descriptions and literature. The general competency model for shift personnel is based on the human-oriented view presented by Goleman (1998). Goleman's classification is completed with the cognitive functions model presented by Spencer & Spencer (1993). The formed competency classification is individual-oriented and based on the frameworks of earlier studies. The classification combines competencies related to emotional intelligence and cognitive functions (Nurminen 2003).

In the classification the competencies are roughly divided according to whether they are related to an individual or other people. The main classes (personal and social competencies) are further divided based on whether they are related to an individual's feelings and identification, or the regulation of one's own actions. The class comprising the regulation of an individual's own actions is further divided into self-management, cognitive functions, and motivation (Nurminen 2003).

The behaviour models that represent an individual's conscious experience have underlying subconscious factors that interact with conscious experiences. The correlations between conscious experiences and subconscious factors are construed based on the description of the theatre model operation presented by Baars (1997). The connections between conscious experience and subconscious factors are by nature blurry to some extent. The subconscious factors are divided into 26 factors according to the Circles of Mind™ model as construed by Vanharanta. These factors form four systems, which are the motivation system, memory system, interpretation system, and automatic systems (Nurminen 2003).

The motivation system includes the functions regulating individual behaviour and emotional reactions. Functionally, the motivation system mostly resembles the limbic system, which controls an individual's emotional behaviour. The memory system includes the explicit information that is mostly related to declarative memory and stored based on conscious lifetime learning. The interpretation system interprets the content of the consciousness under the spotlight by comparing it with the individual's earlier experiences (Nurminen 2003).

The automatic systems comprise the implicit information and skills that are mostly related to procedural memory. Procedural memory does not function based on conscious information retrieval but more on the brain's attempt to find, through trial and error, the optimal memory structure for a certain stimulus. In time, the optimal memory structure is developed and found more quickly and automatically. In this kind of memory-based action, the individual might not even remember his or her past experiences and use the previously learnt models of operation subconsciously (Nurminen 2003).

Deltoid works based on the estimated occurrence frequency of 120 behavioural or operating models essential for the shift personnel duties. The behaviour models are described in Deltoid as conscious experiences in accordance with the theatre metaphor. Each competency consists of four behaviour models, which are presented through questions or, better, statements. The descriptions of conscious experiences (behavioural models) used in the assessment of individual competencies, competency classes, and subconscious factors are based on linguistic terms. Therefore, Deltoid uses a fuzzy logic controller for modelling the ambiguity of human assessment, complex interdependencies of the model, and nature of the abstractness related to the concepts (Nurminen 2003).

The fuzzy logic controller typically includes fuzzification, fuzzy rules, fuzzy inference, and defuzzification. In fuzzification, the values entered by a person are translated into fuzzy sets of linguistic terms. Fuzzy inference uses the fuzzy rules to process the input of linguistic variables and determine a response for the input. In defuzzification, this response is clarified into a value in the desired definition set (Kruse et al. 1994, pp. 163–164; Kantola 2005; Kantola et al. 2005).

3.2.8. First results

Building the self-assessment model (Deltoid) combined the goal-oriented and innovative processing of the problem, and the empirical and practically proven functional testing of the solution. In the empirical part of the study, 82 shift personnel of the nuclear power plant units 1 and 2 tested the Deltoid application and completed self-assessment. The creative tension of the shift personnel emerged based on the self-assessments (Nurminen 2003).

The creative tension of the shift personnel is analysed in three sections. The field operators' assessment of the current and target situations, and the creative tension resulting from their difference are presented first, then, the operators' and shift supervisors' assessment. The assessments of the current and target situations and the creative tension are illustrated graphically. The assessments and the creative tension are shown in the same graphics. The longer a bar is, the higher its value (Nurminen 2003, cf. the first research paper).

Field operators

The results present the field operators' assessments of the current and target situations and the creative tension by competency. The field operators consider conscientiousness and taking responsibility for their work as very important. As the creative tension of the sense of responsibility is quite low and the target situation is very high, it can be deduced that the field operators are very responsible. They also consider self-discipline, looking for information, problem solving, and stress tolerance as quite important competencies (Nurminen 2003).

The highest creative tension is seen with field operators' competencies related to cognitive functions. Especially the command and use of foreign languages and obtaining, maintaining, and sharing professional and technical information have room for improvement. Based on the field operators' assessments, language skills are nowhere near as important in their work as professional and technical know-how. According to the field operators' assessments, their work does not require special performance-orientation. Instead, commitment, or the ability to adopt the goals of the group or organisation, and staying on schedule despite obstacles and setbacks are considered important in the field operators' work. Field operators' assessments set a target level higher than the current situation for each competency, which is seen as creative tension as presented in Figure 2 (Nurminen 2003).

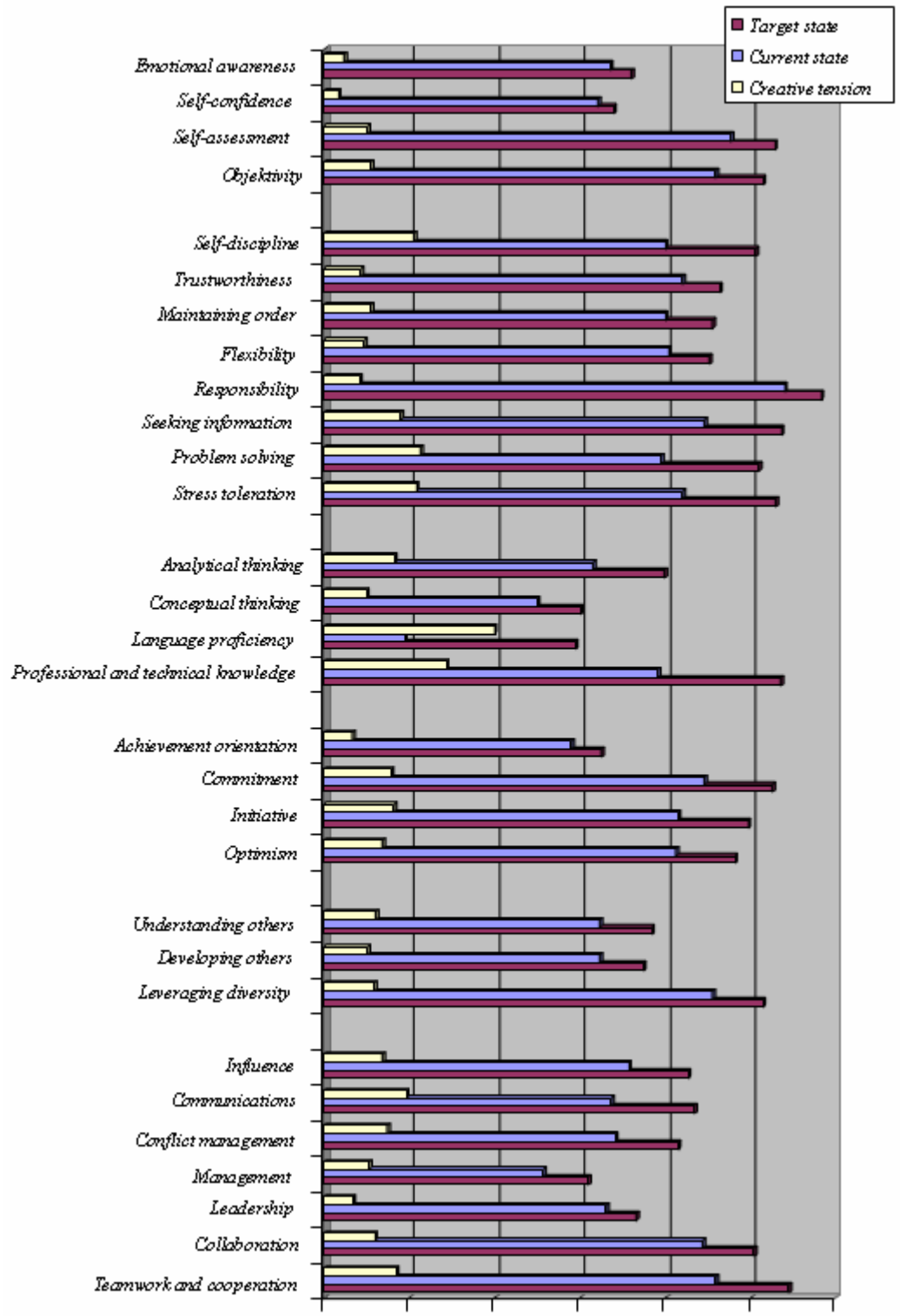

Figure 2. Field operators' perception of their own competence level currently, in the future and creative tension (Nurminen 2003)

Operators

Review of the operators' assessments of the current and target situations and the creative tension by competency shows that, like the field operators, the operators set the target higher than the current situation for each competency, which is seen as creative tension as presented in Figure 3. This results in a fairly even creative tension. Based on the assessment of the four competencies related to self-knowledge, confidence and the awareness of one's own emotions are not as relevant to their duties as self-assessment and objectivity. However, the creative tension is quite high for the awareness of one's emotions and objectivity. The next eight competencies are related to self-management. The operators consider conscientiousness and taking responsibility for their work as very important. As the creative tension of the sense of responsibility is quite low and the target situation is very high, it can be deduced that the operators also assess themselves as very responsible. Self-management as a whole is a very important part of the operators' work. This is seen in the higher target level of the self-management class in comparison with the other classes (Nurminen 2003).

The highest creative tension is seen with operators' competencies related to cognitive functions. Especially the language skills and obtaining, maintaining, and sharing professional and technical information have room for improvement. The creative tension is also quite high in analytical thinking, i.e. the individual's ability to divide problems into parts. However, it must be noted that the target level is lower in the cognitive functions competency class than in the other classes. The operators' current level of professional and technical know-how is much higher than that of the other competencies of the class. However, they set the target level even much higher than the current situation, so there is need for improvement. The high creative tension in language skills might be explained in part by the fact that operator recruitment has not always had language requirements. According to the operators' assessments, their work does not require special performance-orientation. Instead, commitment, or the ability to adopt the goals of the group or the organisation, and staying on schedule despite obstacles and setbacks are considered as important in the operators' work. Creative tension is also quite high with initiative and optimism (Nurminen 2003).

According to the operators' assessments, one special area for improvement is communication including receiving and sending messages. Influencing, or the individual's ability to persuade or affect others in order to promote their goals, as well as co-operation and teamwork skills are emphasised in their duties. The operators do not consider managing matters or people as especially important parts of their duties. The social competency class indicates a quite similar and fairly high level of creative tension (Nurminen 2003).

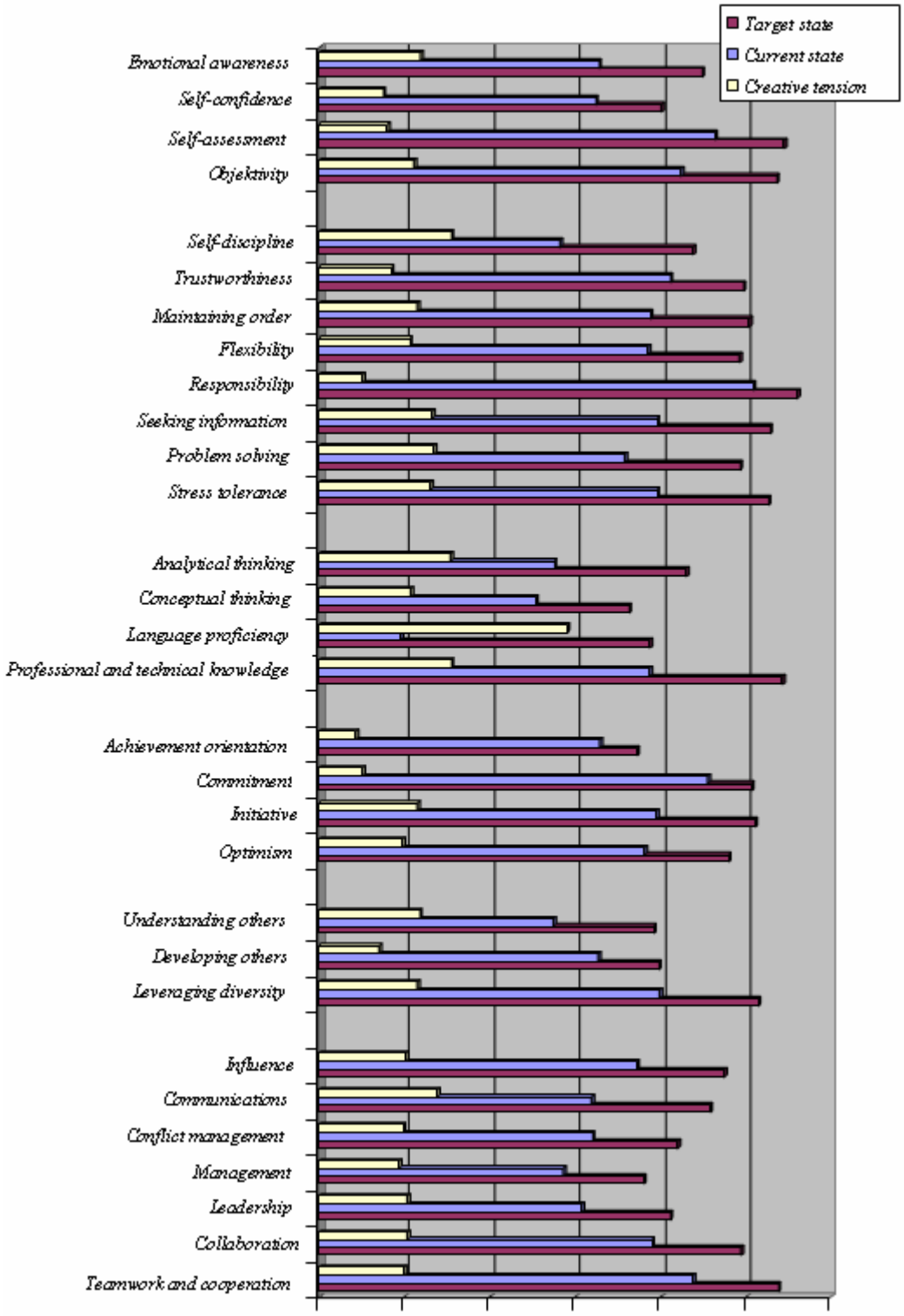

Figure 3. Operators' perception of their own competence level currently, in the future and creative tension (Nurminen 2003)

Shift supervisors

Like the operators and field operators, the shift supervisors' assessments set a target level higher than the current situation for each competency, which is seen as creative tension as presented in Figure 4.

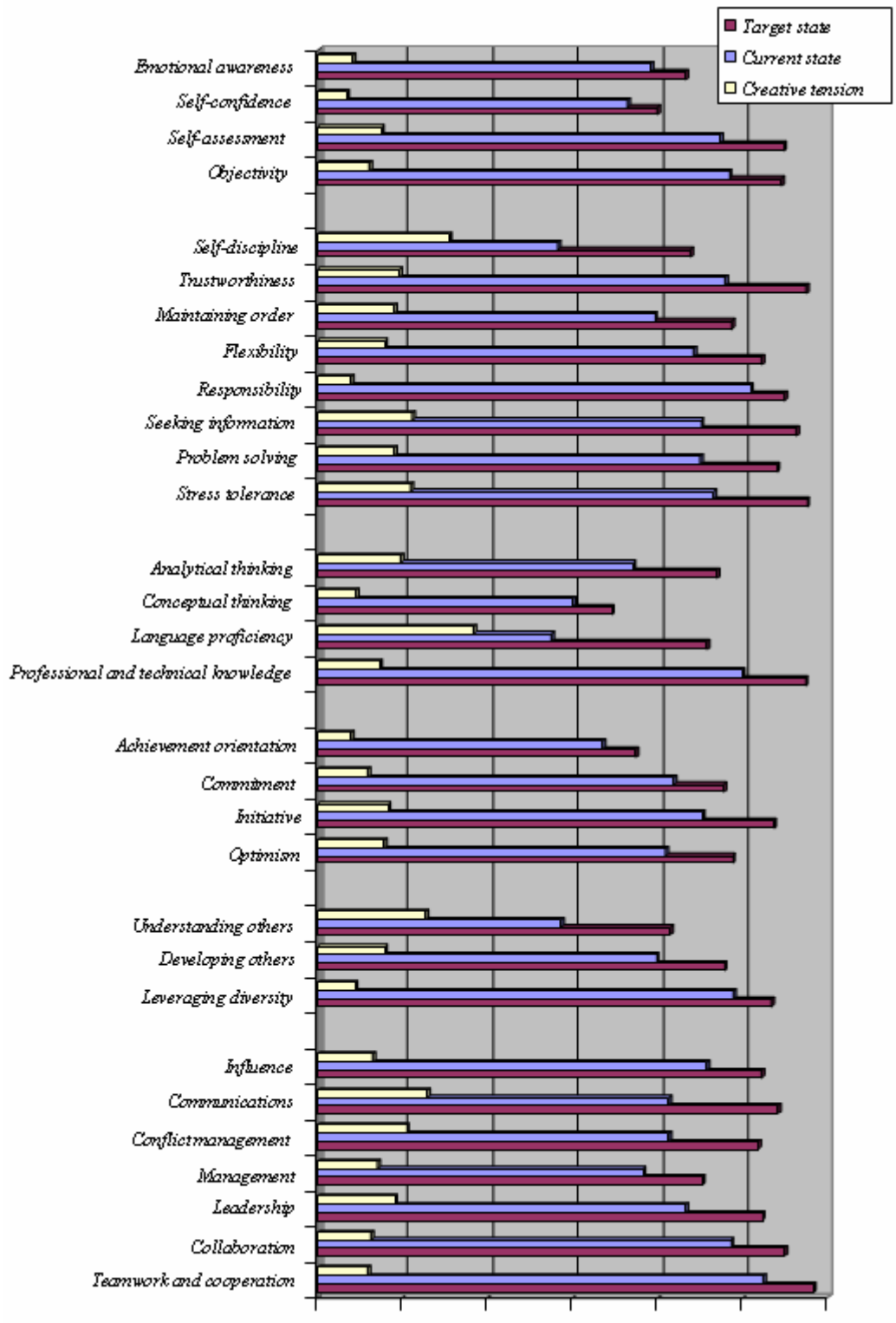

Figure 4. Shift supervisors' perception of their own competence level currently, in the future and creative tension (Nurminen 2003)

Based on the assessment of the four competencies related to self-knowledge, their work emphasises self-assessment and objectivity. This can be deduced from the high target levels of the competencies. The current level of these competencies is also quite high in the assessments. However, the shift supervisors still consider that the areas have room for improvement. Confidence and awareness of one's own emotions are not as relevant to their duties as self-assessment and objectivity (Nurminen 2003).

The next eight competencies are related to self-management. In this class, creative tension is the highest for self-discipline. This means that the shift supervisors want to develop their ability to control their emotions and actions. However, they do not consider self-discipline to be very important for their duties. The shift supervisors consider conscientiousness and taking responsibility for their work very important. Indeed, shift supervisors are responsible, which is indicated by the very high current level of the competency. Other, especially important, competencies in the shift supervisors' assessments include reliability, looking for information, problem solving, and stress tolerance. Even the current level of these competencies is quite high in the assessments. However, there is room for improvement, as indicated by the creative tension (Nurminen 2003).

For cognitive functions, most room for improvement is in language skills. According to the shift supervisors, obtaining, maintaining, and sharing professional and technical knowledge is very important in their work. Their current level in the shift field is already quite high. The shift supervisor's creative tension is quite high with analytical thinking, but not with conceptual thinking. The shift supervisors show initiative, which must be important for obtaining and maintaining information, for instance. The other motivation-related competencies also show a clear creative tension even though the assessment of the current and target situations shows that they are less important for the duties of field supervisors (Nurminen 2003).

According to the field supervisors' assessments, understanding others is a special area for improvement for them. They do not consider understanding others as important in their work as training others and utilising diversity. The latter competencies also show some creative tension but not as much as understanding others. Influencing, communication (both receiving and sending messages), and conflict management are important in the work of shift supervisors. They especially want to improve communication and conflict management. This can be deduced from the high level of creative tension in these competencies. The shift supervisors feel that managing matters and

people is essential for their work. Leading people is especially important, and it is an area that the shift supervisors want to improve. Co-operation and teamwork skills are very important competencies in their duties. The current level of these two competencies is very high for the shift supervisors, but they want to improve their ability to work with others even further (Nurminen 2003).

The highest creative tension is seen with the shift supervisors' competencies related to self-management and cognitive functions. However, the current and target levels of the self-management class are considerably higher than the cognitive functions. The current and target levels of the social skills class are also very high. Based on the above findings, self-management and social skills are emphasised with shift supervisors. The shift supervisors showed creative tension with all subconscious factors. The current and target level assessments and creative tension vary clearly between different factors. In memory systems, the creative tension is clear and even with all factors. For facts, the current and target levels are especially high. Facts and the reliance on them are emphasised in the duties of shift supervisors. In interpretation systems, the creative tension is very even and high apart from spatial perceptive skills. Respectively, the target levels are also high for each factor, especially for syntactic analysis and social interpretation. The importance of interpretation systems is emphasised in close teamwork (Nurminen 2003).

The shift supervisors set higher target levels than operators for competencies related to self-management, empathy, and social skills. The difference in the current levels is especially high with competencies related to cognitive and social skills, for which the shift supervisors set significantly higher levels than the operators. Based on the assessments by the shift personnel, it can be observed that the shift supervisors set a higher current level than the operators in all the competence classes. However, the operators set higher targets for improvement in different areas. This can be deduced from the operators' higher creative tension compared to the shift supervisors.

Based on the results, it can be said that the competency-based self-assessment system developed in this study (Deltoid) is suitable for identifying individuals' current situation and personal targets.

The shift personnel clearly showed creative tension, which means that the shift personnel have the desire and energy to develop themselves and their working methods. In the future, more attention should be paid to shift personnel training and on directing the training appropriately. Although professional and technical know-how is essential in the work of shift personnel, it also emphasises managing and developing other personal and social competencies, as shown by the creative tension in the results of this study. The training and development of shift personnel should be open towards different training events and methods

in order to enable development and learning in different and diverse areas. This can ensure that the company will have professionally skilled and motivated personnel with the ability to work together and the desire to learn and develop even more in the future.

The empirical results of the thesis have been used in later studies related to competence simulation, which helps in making the training paths rational in relation to the available resources during training cycles. The collection of unique creative tensions according to the occupational competences can be simulated in order to form similar groups, which have the size and required competence level supporting a company's strategy.

Therefore, competence simulation supports achieving the vision of the company with rational and structured steps by investing in the target training of employees. Target training makes the training efforts more efficient since resources are put at the right places at the right time. Simulation, therefore, helps to plan and build the target training to fit organisational strategy, resources, and current situation in a co-evolutionary way, cf. the second, third and ninth research paper (Nurminen 2003).

3.2.9. Further developments

The developed self-assessment system was utilised for the needs of managing the development of nuclear power plant shift personnel. The objective was to test the self-assessment system in a company environment, and to find the potentially emerging creative tension within the shift personnel. The shift personnel whose competences were analysed using the Deltoid method had a rather high level of experience. When comparing their qualifications at recruiting time and then the time of evaluation, their competence has been affected by approx. 25 years of work experience and different training events. Since there have been very few career changes, the effects of training have been cumulative for the entire work period.

Compared to other countries, Finland and Sweden have historically had a low number of shift personnel. In addition, the basic education level has not been as high as in Russia, for example, where the shift supervisor has an academic degree. The differences can be justified by looking at differences in plant design and the organising of activities. A boiling water reactor is rather straightforward in terms of dynamic behaviour. As long as the protection automation is fully functional, disturbances can be solved well. EPR, with its new digital I&C, will be more challenging. However, as there are now fewer nuclear technology engineers in the organisation than in the late 1970s, the thought that the same concept as before can be used from these very different starting points is worrying. The organising of operating activities should be analysed taking

account the new starting points. Instead of personnel numbers, the focus should be placed on having sufficient competences.

All activities affecting the operation of a nuclear power plant and the availability of equipment must follow systematic methods to ensure that the plant operators are constantly aware of the status of the plant and its equipment. These methods have been documented in the extensive set of instructions. The importance of following instructions has been emphasised, especially as regards the procedures used in the control room. The technical, system-specific instructions should be as error-free as possible and be up to date in terms of plant modifications. The more generic instructions, which are plant-specific, are related to changes in the operating state and disturbance management. Instructions concerning disturbance and accident management should especially be developed constantly, since such instructions cannot be completely validated or verified. Nevertheless, theoretically reviewing the instructions provides good training for disturbances. To achieve technically correct instructions, the best-performing shifts may be used for their development. The instructions may, however, become too straightforward. Therefore, the procedures must be checked for understandability; each shift must apply the procedure correctly.

In a nuclear power plant, the composition of shifts may remain similar for extended periods of time. This usually leads to the working methods and division of tasks becoming shift-specific. The operations management should try to prevent such developments by aiming for a good, standardised performance that is supported by a continuously developed set of instructions. A different kind of example is available from air traffic, where crew members change from one flight to another. Flight safety is highly dependent on the instructions that everyone is expected to strictly follow. At a nuclear power plant, however, the shifts have the same composition for a long time. This leads to slightly different working methods between the shifts, and the management's important task is to resist these developments so that deviations are under control.

By utilising the SOM maps we can focus the training activities and practical training so that all shifts can perform their duties well. By using the simulation feature, we can also find a means of improving the overall performance for a single shift.

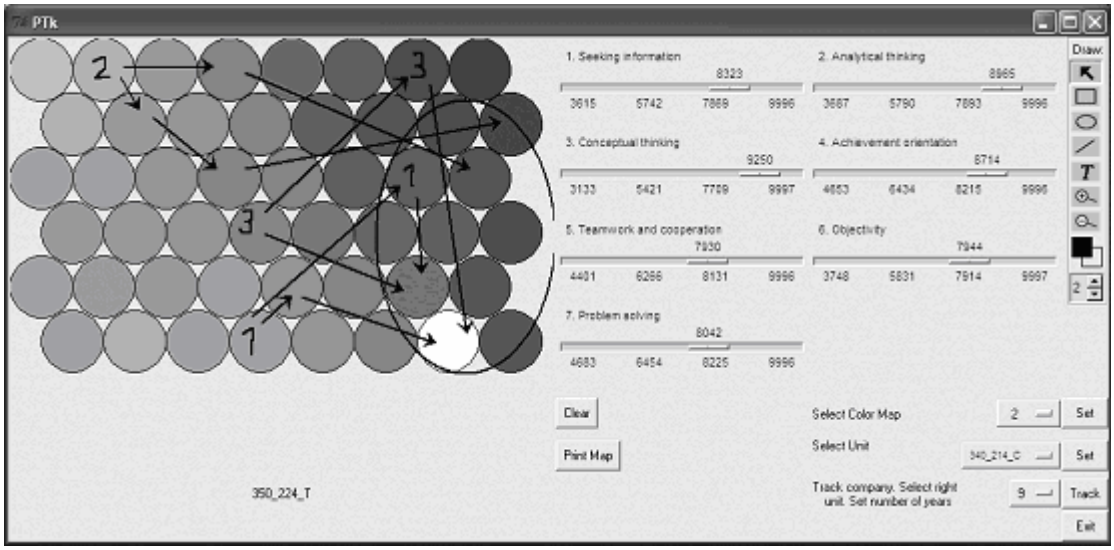

Figure 5. An example of competence simulation

Based on the empirical results, it can be concluded that competence-based Deltoid self-evaluation application clearly recognises individuals' own current reality and their development needs (personal vision). Consequently, the competency-based self-assessment tool created for this study, i.e. the Deltoid-application, is suitable for the planning of basic training and retraining of control room operators. It is also a good working tool when forming shift crews with an even competence distribution, thus satisfying the demands of the control room work. The Deltoid method could also be used to assess factors related to disturbance management during simulator training, for example.

3.3. Competencies of the maintenance personnel

As Reiman and Oedewald argue, maintenance activity at the NPPs is complex, distributed, and difficult to coordinate and control both safely and efficiently. However, it has been surprisingly little studied and developed within the human factors paradigm. The work activities are very much based on the (unofficial) organisation, the proficiency of the personnel and the culture of maintenance at the particular plant. Due to these features, it is often hard for a single worker to see the big picture and how one's own work contributes to the overall safety and reliability of the plant. Furthermore, the safest and most efficient way of maintaining the plant and organising the maintenance activities is not self-evident. Thus, maintenance has been organised and reorganised in various ways across the nuclear industry (Bourrier 1999; Reiman & Oedewald 2004a; Reiman & Oedewald 2004b; Reiman & Oedewald 2007).

Human resource management, organisational climate and culture were also the issues that were deemed as most important challenges in the context of safety management by NPP managers in five European countries (Kettunen et al.

2007). Vicente (2004, p. 189) writes that “a technological system won’t succeed unless sufficient attention is paid to organisational issues, such as how decisions about safety are made in the face of outside pressures”. Accident investigations have also uncovered many organisational (cultural) antecedents of the accidents. The following research is partly based on the empirical results of the master’s theses by Jaakko Nirhamo (2002), Sami Saarela (2002), Pasi Mäkiniemi (2004), and Päivi Rinne (2008).

3.3.1. Maintenance organisations

In implementing planned maintenance strategies, the most important “tool” of company management is the maintenance organisation. Maintenance must be able to carry out its assigned duties efficiently and flexibly, while avoiding unavailability costs. Maintenance operations can be carried out in a central or distributed way, or maintenance can be separated into its own unit. Moreover, the many variations of the above are possible. All models are always company-specific, and they are affected by, among others, the company size, number of production plants, and company location (Hagberg et al. 1996, pp. 42–50).

In a central maintenance model, maintenance functions as an individual organization unit separate from operation. It is characteristic to this organisation model that the operation personnel runs the equipment and the maintenance personnel is called to repair it. In a distributed maintenance model, maintenance functions are fully under operation. This keeps the maintenance resources close to operation, which allows for short maintenance response times. (Rossi 1993, s. 25).

In a separated maintenance model, a company uses maintenance or its parts to form a separate profit centre, which is later many times turned into a company of its own. The ownership of the separate company can be distributed between the company and external owners, or the separate company can have full ownership. The latter alternative is the case of pure outsourcing.

The internal information transfer between the electrical and instrumentation and control system maintenance department, as well as the interactive information transfer with other interest groups were studied by Nirhamo (2002). The results provided information about the information systems’ compatibility to maintenance and the atmosphere of the working environment. Moreover, open questions provided suggestions for development and improvement. The results of the survey show that, according to the personnel, the maintenance system – including the information systems, working environment, and working methods – is on average satisfactory (Nirhamo 2002).

The results of the study of Saarela (2002) produced a lot of information about information transfer inside and between departments, the use of information systems, decision-making, and the overall fluency of work at the plant. With regard to information transfer, a central result of the research was that information transfer works well inside mechanical maintenance but it is much less effective between mechanical maintenance and other departments. According to the respondents, maintenance information systems supported well the maintenance functions, and the information systems are used fairly often. However, the information systems and updating of documents in the system are complicated to use and, therefore, possibly the information in the systems is incomplete and not all information is recorded in the systems. According to the respondents, work planning and resource management are on a fairly good level, and maintenance operations are well organized Saarela (2002).

The results of the study of Reiman and Oedewald (2004a) showed that the maintenance personnel were committed to their tasks and they perceive their work as highly meaningful. The personnel were able to perceive very well how their tasks contribute to the organisational goals. Most of the workers were also very proud of their plant and their own proficiency. General job satisfaction was quite good. Weak sense of collaboration and a perceived lack of positive feedback were experienced as the most negative aspects of the culture. Perceived lack of sufficient resources and an unequal distribution of labour were experienced as lowering the sense of control and causing work stress (Reiman & Oedewald 2004a). Younger people consider themselves as having a higher development orientation, but they do not see the company as supporting this. Instead, they experience the maintenance organisation as strongly emphasising the values related to hierarchy (Reiman & Oedewald 2004b).

The study of Reiman et al. (2005) aimed at characterising and assessing the organisational cultures of two Nordic nuclear power companies' maintenance units. The study pointed out that job meaningfulness was found to exhibit a high, significantly positive correlation with job motivation and job satisfaction. Maintenance work appeared to produce a feeling of meaningfulness when there are technical problems to solve with safety significance and time pressure. This is a paradox in the sense that one of the goals of maintenance is to avoid problems and keep the technology running reliably. The maintenance task should be focused on maintaining the entire plant, not some individual pump or valve (Reiman et al. 2005).

However, this approach to maintenance is too linear in terms of work psychology and current activities. When equipment-specific thinking guides maintenance activities, it is naturally important that the equipment for which the maintenance personnel are responsible operates flawlessly. This, in part, affects worker satisfaction. The meaningfulness and job motivation are also

based on the control of well-operating technological process and the ability to solve problems when they occur. Since the requirements for the training of maintenance personnel do not match those of operating personnel, the personnel do not always have the necessary competence to understand the significance of the equipment in terms of the overall system, or the safety significance of the equipment. Developing maintenance activities is left to too few experts. Managing the overall system, safe and disturbance-free operation, and understanding the prioritising of work could significantly increase motivation and work commitment.

The strengths and weaknesses of the maintenance culture were studied in the survey as well. The maintenance personnel at the other company saw their strengths mainly in the know-how and experience of the workers and in the attitude and motivation (responsibility) of the personnel. In addition, ability to react to problems, methodical approach, and flexibility were emphasised, as were good tools and procedures and the good condition of the plant. The current age structure of the personnel and inadequate attention paid to the problems of knowledge retention were perceived as central weaknesses. Furthermore, leadership and personnel values of the organisation were identified as needing improvement (Reiman et al. 2005).

According to Nakajima (1989, p. 1), in the 1950s and 1960s the Japanese applied the preventive maintenance (PM) concept originating in the United States to their companies for improving equipment maintenance. Later, the concept of productive maintenance (also PM), reliability planning, and other equivalent maintenance methods were applied. Thus, of the advanced maintenance philosophies, Total Productive Maintenance (TPM) is, in fact, based on the American productive maintenance (PM). It is a version modified for the Japanese culture and business environment. In most American organisations, the maintenance personnel handle all the maintenance work and the employees are divided into two groups: operation and maintenance. The Japanese companies have improved on this American PM concept in a way that allows every person in an organisation to participate in the maintenance work at their plant.

TPM is often said to be productive maintenance carried out by all personnel. The concept is based on the principle that each member of an organisation must participate in improving the equipment – from line management to top management. Therefore, operating personnel perform maintenance on the equipment they use or participate in the maintenance work for other equipment. They also make sure that the equipment remains in good condition and they develop their skills to identify potential problems before they lead to equipment failures (Nakajima 1989, Willmott 1994, Willmott & McCarthy 2001).

TPM is an approach for managing personnel, the use of equipment, and maintenance. It is a sequence of functions that prevent quality errors and failures while making work safer and easier for the personnel (Shirose 1992, p. 7). The transition from preventive to productive maintenance clearly improved the results, but it did not eliminate errors and failures. TPM was developed in order to target these areas. TPM is primarily based on the operation of small groups, but it changes productive maintenance to involve all the personnel of a company. It increases co-operation at all organisational levels (Shirose, 1992, p. 9).

In practical situations, one may hear someone say “That’s not my problem” when a maintenance issue arises. This kind of language indicates that there are discrepancies between the interests of operation and maintenance. Previously, the system may have been missing a “problem owner”, but in TPM, each problem has at least one person who has taken or been assigned responsibility and who can say “This is my/our problem” (Hagberg et al. 1996, pp. 104–105).

Thus, TPM is a way of managing “maintenance people”. It creates the right kind of atmosphere for working together and aims to provide an environment in which people care more about their work and workplace. TPM creates methods for changing attitudes and undesired working habits. The principle of TPM is to provide a tidy, challenging, and motivating working environment that supports and contributes to performing work (Nirhamo 2002).

3.3.2. Competencies of the maintenance personnel

A generic competency model is formed based on general competencies, which can be used in different organisations. The model is created by utilising statistical analyses, and it is often based on quite extensive empirical studies. Such models have been developed and presented by, for instance, Boyatzis (1982), Spencer & Spencer (1993), and Zwell (2000). Mäkiniemi’s work aims to create a generic competency model for a serviceman working in maintenance, which could be utilised in different organisations as is or modified according to the special needs of an organisation. The objective is to create a task-related model that would specifically take into account the task requirements of the performing level of maintenance.

Competencies can be chosen by different methods depending on the situation and possibilities. One method is studying the top-tier performers at work and trying to define which of their qualities, characteristics, and behaviour models contribute to an excellent work performance. Another method is to form a group of top performers and their superiors, and compare their views on the required competencies (Zwell 2000, pp. 212–215). Of course, the formation of the model

can be supported by literary studies on competencies, and the available generic models (Zwell 2000, p. 215).

The construed servicepersonnel competency model is primarily based on the generic models presented in the competency literature, and the views of personnel working in maintenance (Mäkiniemi 2004).

In self-assessment, an employee evaluates his or her own abilities, skills, or strengths and weaknesses. It is thus based on the individual's subjective view of his- or herself as a performer of work. In several cases, self-assessment is better suited than other evaluation methods for determining many factors essentially related to performance, such as motivation and commitment to work. Many human resources and recruitment professionals consider self-assessment to provide important information about employees' suitability for certain duties, for instance (Liikamaa 2000).

The validity of results has often been considered a weakness of self-assessment. The subjective view of one's own proficiency should be utilised with care, for example, when choosing employees for specific duties. If self-assessment is used together with other evaluation methods, the validity of the results is often better in personnel recruitment (Smith 2000b, pp. 325-326).
The main advantage of self-assessment lies in the management of employees' personal development. It helps employees to develop their metacognitive evaluation skills and supports their reflective learning, which is a prerequisite of professional development. Metacognitive skills allow for precise and accurate self-assessment, which is characteristic of trained and experienced professionals (Smith, 2000b, p. 326).

The purpose of this research has been to form a model for the essential professional competencies of performing level employees and positioning them in the already developed Evolute application framework. The work focuses on servicemen, engineers, mechanics, and other maintenance employees who use their technical skills in the maintenance and service of machinery, systems, and properties.

The application being developed functions as a self-assessment system for maintenance personnel, in which employees evaluate their own current and target situations from the point of view of the competencies needed in their work. Thus, one central goal of the application is to determine for employees their personal creative tension, or the difference between the current and target situations. This information supports the metacognitive evaluation of one's personal work and the resulting reflective learning, which are essential for professional development. It may also provide valuable information about personnel training needs and the focus areas of the necessary training to the

persons responsible for training in the organisation. It could be utilised in recruitment alongside other methods for selecting a suitable person for a position.

The most significant individual competency class in Conchoid is the cognitive functions class. The reason for this is that when maintenance personnel work in technical duties, they often need to solve the problems causing equipment and system failures. A person successful in this kind of work often has a sensation/thinking cognitive style, in which rational deductions are made based on concrete sensory experiences. Therefore, the serviceman competency model also especially emphasises skills related to problem solving, cause and effect relationships, and rational thinking, which are clearly cognitive functions.
For the further development of Conchoid, it is essential to validate the system with an appropriate sample of maintenance professionals (Mäkiniemi 2004).

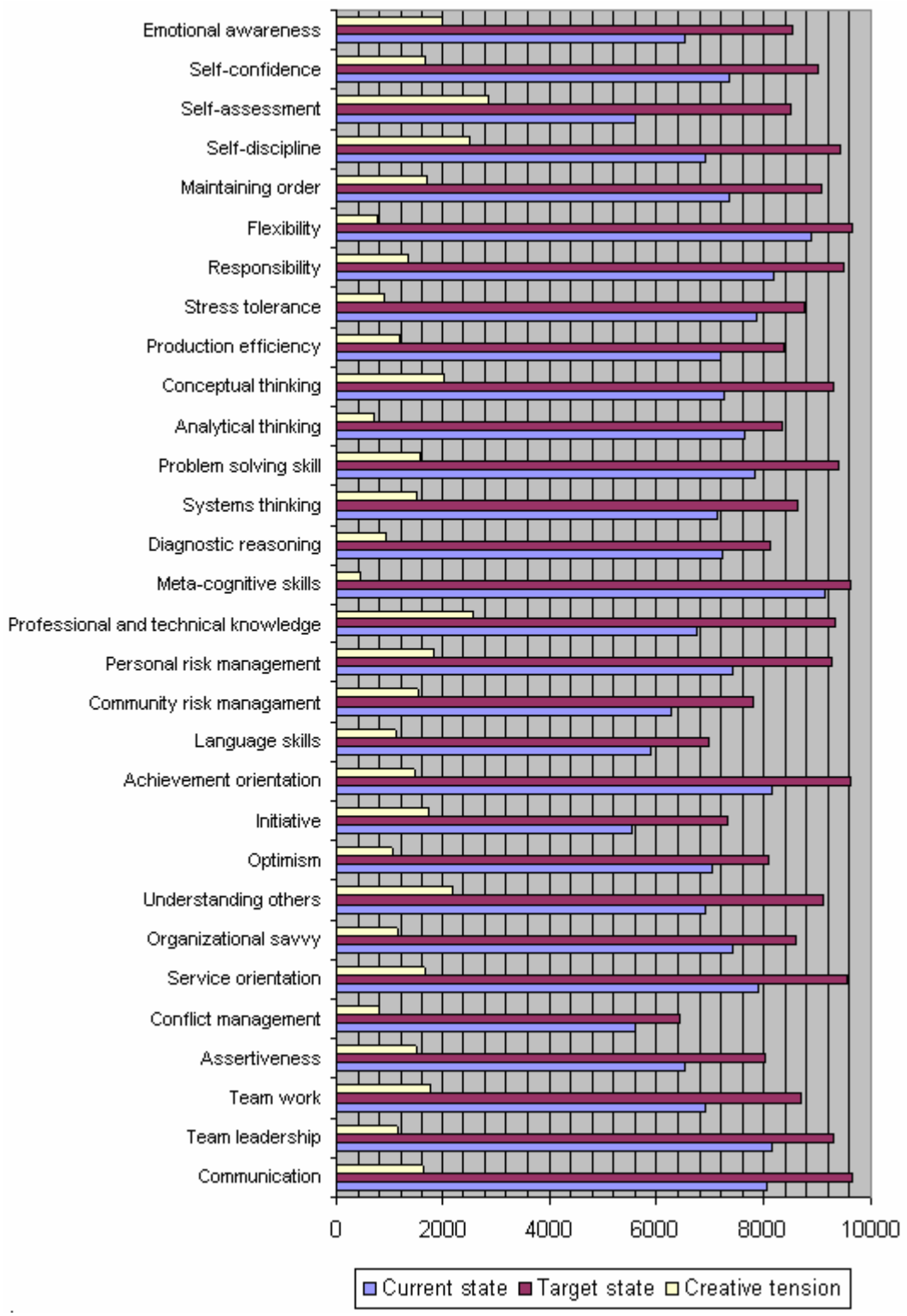

Figure 6. Service personnel's perception of their own competence level currently, in the future and creative tension (Mäkiniemi 2004)

3.3.3. Multimedia applications in future maintenance systems

The Digital Media Institute (DMI) of Tampere University of Technology (TUT) has developed a multimedia-based application of maintenance management: the “Multi Demonstrator”. The work belongs to a research project titled “The Use of Multimedia in the Development, Planning and Modelling of Working Methods in a Factory Environment” (Visa 2001).

The work has been continued in the “Maintenance and Management with Mobile Multimedia (4M)” project, which aims to study the use of wireless connections and multimedia in the field of maintenance. The work resembles a preliminary report by nature, and its purpose is to find areas for development in the current operation in the fields of information transfer and user-friendliness, and to present a suitable theoretical framework for constructing maintenance information systems. The result of the work should illustrate how maintenance operations could be carried out in the future with a more human-oriented system.

Kerttula states that there is no established definition or meaning for multimedia. Multimedia is still new, and it is used in many different contexts. In the technical sense, multimedia is an interactive computer application that processes and combines at least three of the following media: text, data, audio, graphics, static images, animation, and video (Kerttula 1996, pp. 11–13).

The multimedia application by DMI is a preliminary model of the possibilities of technology. Moreover, the study provides a review of current maintenance trends with regard to operating models, implementation philosophies, and maintenance systems. They indicate the direction of development for maintenance. However, maintenance is studied as a larger concept, a “maintenance system”, which more clearly shows the advantages and disadvantages related to the development work. The people who carry out maintenance must be more deeply involved in the review, as part of the overall system.

Maintenance information systems are missing a good theoretical framework. Moreover, the systems have not considered the significance of the nature of information enough. When creating or looking for a new information system for maintenance, it is possible to follow a new kind of approach for the field of maintenance and its management. This enables utilising multimedia in maintenance. The Multi Demonstrator has used three-dimensional graphics, videos, audio, images, and hypertext that provide a new kind of platform for constructing and developing information transfer and know-how in an organisation.

In the future, the number of retiring employees will grow, and the labour market will suffer from the reduced availability of proficient employees. The major issue affecting the operation of companies may be the availability of qualified, trained, and experienced personnel. Qualified young people can choose their employer from several options, and just salary is not enough to attract qualified employees or keep them in the company as a long-term resource. For many employees, salary is less important than a challenging and stimulating working environment, proper tools, active participation, good atmosphere at work, and opportunities for personal development. One of the largest challenges for companies is to understand that they need to provide working conditions and tools that are as attractive and user friendly as possible. This also applies to maintenance (Nirhamo 2002).

The Multi Demonstrator maintenance management software prototype has been applied in the three-dimensional modelling of a reactors' main recirculation pump, and the presentation of the service documentation. The ideas presented give preconception how these new tools can be applied in the nuclear power plant maintenance. Multi Demonstrator contains the entire service procedure for the main circulation pump. The service procedure text includes hyperlinks to descriptive photos and clarifying video clips. The easy navigation environment enables the user to view the documents in a hierarchical directory tree structure.

Users can open a service document by clicking the subject title of their choice in the directory tree structure. The application also includes digital video with an audio track recorded in connection with service procedures. The videos and photos have been linked to the hypertext documents by hyperlinks. The user can access the hyperlinks and use them to see the photos or videos. Moreover, the pages include computer-generated three-dimensional models of other nuclear power plant components.

The three-dimensional models provide a more illustrative visualisation of the main recirculation pump and its components than two-dimensional drawings. The models are used to provide the user with an opportunity to find information in a three-dimensional environment (Nirhamo 2002).

In the future, the use of a maintenance information system can be supported with a variety of equipment. A maintenance engineer can access all the databases with a laptop computer. He or she can use applications, such as Multi Demonstrator as well as a maintenance system based on a three-dimensional plant environment. Using a video display, he or she can navigate the three-dimensional plant model to find the necessary equipment, and select the relevant information about the equipment from a menu. Equipment ID enables the engineer to locate it on the plant floor plan, and the location can be

viewed on the three-dimensional model. He or she can display a piece of equipment, system, or subsystem. Maintenance personnel can find information about the equipment with the help of the remote diagnostics control room or by themselves (databases). They can also find information online about equipment suppliers or spare part availability. An expert working in the remote diagnostics control room or a different location can contact the maintenance person or other people, have conversations, and transfer information via the system (Nirhamo 2002).

A position-specific introduction and training programme should be developed for new employees. During these events, more experienced maintenance personnel and the organisational units responsible for training would teach the "newcomers" about the operation of the equipment and the plant. With applications such as Multi Demonstrator and three-dimensional plant models, new employees could familiarise with the plant before entering the plant area. In field work, experienced personnel should be partnered with the newcomers whenever possible. This kind of apprentice-journeyman model would transfer tacit knowledge. Older and experienced professionals can support the development of young employees through mentoring where they help the young obtain information and learn (Nirhamo 2002).

3.3.4. Comparison of two maintenance departments

The study aimed at characterizing and assessing the organizational cultures of Nordic nuclear power companies' maintenance units. Both companies can be considered as high reliability organizations by showing a good performance record and few incidents (Reiman et al. 2005).

At other plant, current maintenance organization evoked mixed feelings. Several interviewees complained about the matrix form and found it confusing. On the downside there were indications that the new maintenance organization had led to negative changes in the perceived ownership for the technology—previously the maintenance organization had been separate for each of the three stations. Several of the interviews included indications of a general cost pressure that affected the maintenance organization: "it is talk about costs all the time" and "costs have got a too high focus". On the other hand, several of the interviewees said that they were personally strong in their ambition to keep the plant in a state of high quality. 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). 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. Introduction of complex and large matrix organizations makes it more difficult to structure the communication. In fact, the more "matrix" used, the more important communication seems to become for supporting the functioning of the matrix (Reiman et al. 2005).

The study also gave implications that organizational changes do not seem to affect the safety climate or safety culture as defined by the employees valuing safety. Instead, the changes affect more the psychological work characteristics, such as meaningfulness of work and sense of control. Changes that seem to deteriorate safety are experienced as highly stressful, especially since safety remains highly valued. Developing only the safety values and safety attitudes of the organization is thus not beneficial, since the safety attitudes are at least as high as before the change (most likely even higher) (Reiman et al. 2005).

It is interesting to compare the results of this study with the results of the studies by Nirhamo 2002, Saarela 2002, and Mäkiniemi 2004. The differences of concern are related to:

- Gathering and interpreting systematic information of the entire plant condition
- Organizational changes do not seem to affect the safety climate or safety culture
- Only a few employees explicitly raised the safety thinking as strength and a few emphasized the managerial and leadership aspects
- The line manager "sells" the technician to the particular business area that needs the resources
- Work through routines and formal procedures

3.3.5. A recommendation for a maintenance philosophy

Maintenance should be developed gradually, following the principle of continuous improvement, towards a comprehensive productive maintenance philosophy. Out of the available alternatives, this type of maintenance philosophy is the most advanced and human-oriented, and it is based on co-operation, which improves information transfer. Operation and maintenance are essential functions in a nuclear power plant. These kinds of changes take more than one or two years to happen. It would be good to establish hyper information systems, according to Nonaka, to carry out change projects (Nonaka, I. & Takeuchi H. 1995). A phased plan must be developed for the project, and followed in phases according to its intermediate goals. Currently, maintenance is based on preventative maintenance (PM) and reliability centred maintenance (RCM), which is a short way from TPM. The earlier

implementation philosophies accumulate in TPM, so that all current efforts will be utilised.

During the last few years, the focus of skills has been shifted in maintenance due to the technological development. Technical systems involve even more digital instrumentation and control system, which has increased the number of maintenance and service tasks that require understanding of digital techniques and electrical engineering. This has also increased the requirements for know-how and skills, as the operation of instrumentation and control system equipment and their significance in the overall system must be understood better.

The duties clearly require two types of skills: comprehensive understanding of the plant operating processes, and special know-how of one's personal field. In addition, the skills that are related to project management and coordination during outages are required. In maintenance, digital instrumentation and control systems have become a wide field of know-how. A very important future area for improvement is work management, and its required independent work quality assessment procedures. Digital protection and control systems are more abstract than systems in mechanical engineering. The procedures of mechanical engineering and their verifications are the result of long-term development. Equivalent procedures must be developed for digital instrumentation and control systems.

For improving the safe operation, it is suggested that (Nirhamo 2002):

- A cross-functional workgroup should be established for the task when developing maintenance information systems
- The development of current systems should emphasise user-friendliness, information transfer options, and integration with current systems
- Training, information transfer, and information recording at the electrical and I&C department should be developed towards future ICT development
- The general maintenance philosophy should be developed towards the principles of total productive maintenance (TPM), or a human-oriented maintenance philosophy that in itself promotes transparency, information transfer, and cross-functional co-operation

The maintenance management should be developed in balance to ensure the safe and disturbance-free operation of a nuclear power plant by motivated personnel.

3.3.6. Conclusions

As a working environment, a nuclear power plant requires a comprehensive understanding of the operation and processes of the plant. Even though individual work tasks require special skills and knowing the details, the component or piece of equipment in question must always be understood as a part of the entire system. Therefore, each new employee must have a basic degree from a relevant educational institution. During employment, this basic degree should be complemented with know-how concerning the nuclear power plant processes, technical systems, safety features, and the special skills it requires. Traditionally, maintenance has been equipment centred. The operating personnel thoroughly understand the operation of the nuclear power plant. In the future, these two functions should be brought closer together through increased co-operation. The maintenance training programme should be developed into more systematic and equal in quality to the operating personnel training programme.

3.4. Safety Culture-Areas for improvement

Safety culture has been shown to be a difficult concept. It is especially vague to those carrying out practical safety work. Those involved in practical safety work require explanations concerning how safety culture will alter their work, and how it relates to any earlier means of promoting safety in a company. There are also many different definitions and emphasis areas in research. Researchers are still involved in the analysis of the concept and its neighbouring concepts.

Safety culture development is a change and learning process that is led inside an organisation. It draws upon both the quality management principles and behavioural sciences (in addition to earlier safety research). Safety culture can be indirectly measured using factors that are thought to reflect the culture. The emphasis of safety activities is shifting more and more towards anticipation and providing information. When problems start to appear during the development of safety management systems, more attention is usually paid to how people could be made to follow the created system, and for them to remain motivated towards safe behaviour. When a management system has been built, it is observed that the system will only work if the people are also managed. Safety management must be supplemented by safety leadership (Ruuhilehto & Vilppola 2000).

Due to the many aspects of the phenomenon, culture has many different definitions. One of the most common definitions is that “culture refers… to the habits, skills, tools and techniques that have been adopted by a community and are typical of it at a certain point in time” (Juuti 1994). A generally accepted idea

is that culture has a visible layer and an unconscious layer. The relaying factors are the values or ideas of what is desirable (Ruuhilehto & Vilppola 2000).

There is not just one, comprehensive benchmark or method for safety culture and it cannot be measured directly. Due to the complexity and layered structure of the concept of culture, such benchmarks are not likely to appear. Furthermore, cultural changes are slow and difficult to observe. The goal set for the measurement also affects the selection of the measurement method. Attitude or atmosphere benchmarks are usually requested when safety culture is concerned.

Instead of one comprehensive benchmark, safety culture researchers are aiming at methods that measure the different components of the culture. Safety culture can be indirectly measured using factors that are thought to reflect or indicate the culture. According to the different layers of the culture, these factors can be divided into, for example, visible activities, conscious attitudes, and unconscious beliefs. The safety culture model from Cooper (1998) provides a good, practical starting point.

In recent years, regulations have guided the safety activities of companies towards the systematic identification and management of their risks. Safety management is a concern for everyone, and it is an essential part in all of the company's functions. More and more often, the safety management or leadership systems are integrated into the company's other activity management systems. The systems are created using the principles of continuous improvement, and they include the appropriate goal-setting, planning, implementation, and follow-up procedures. Many companies have been able to remarkably improve their safety level by taking systematic action.

3.4.1. The management of safety at nuclear power plants

A good place to start is with the words of Admiral Hyman Rickover, father of the nuclear navy and founder of a safety culture with a remarkable record.

"Quality must be considered as embracing all factors which contribute to reliable and safe operation," he wrote. "What is needed is an atmosphere, a subtle attitude, an uncompromising insistence on excellence, as well as a healthy pessimism in technical matters, a pessimism which offsets the normal human tendency to expect that everything will come out right and that no accident can be foreseen -- and forestalled -- before it happens." (in Oberg´s commentary 2005, cf. Rockwell 2002)

Dr. Peter B. Lyons, Commissioner, U.S. Nuclear Regulatory Commission stated that: “In my remarks today, I quoted one such leader, who set the standard by which subsequent efforts have been measured: Admiral Hyman G. Rickover, the father of the nuclear navy and of commercial nuclear power. I recently read the fascinating account of how Rickover created his organization and the influence it had on the inception of nuclear power, by author Ted Rockwell in his book The Rickover Effect: How One Man Made a Difference. I’m sure that many of you have read this book. If you haven’t, I’d strongly recommend it. Although I’m not sure that the admiral’s personal leadership style would make many of today’s leaders equally effective, I was struck by the timeless quality of the principles upon which he based his organization. These principles ranged from absolute adherence to high standards; to maintaining strong technical capability; to constant training; to respecting radiation; to facing facts and learning from experience; and to taking total responsibility for one’s decisions and actions. My remarks today have a strong correlation with these principles. We must each commit to renew them, such that they remain alive in our thoughts and actions and form the core of our commitment and integrity that drives us to make a positive difference (Lyons 2008).

Nihil novum sub sole! There is nothing to add to the advice above. But looking at the complete citation in Ecclesiastes 1:9 “The thing that hath been, it is that which shall be; and that which is done, is that which shall be done; and there is no new thing under the sun” (21st Century King James Version) we should understand that accidents will happen if we do not try to prevent every way.

Anyway, let us take a domestic citation for the safety management. This is by Technical Director Tamminen from the Loviisa nuclear plant. In two words: “Be honest”.

In the same way as in the modern quality management, we need a variety of safety management tools to be able to improve safety of nuclear power plant operation. If we compare the tool-box of safety management with that of quality management we realise that we have a lot to do.

An interesting application of Self-organising map is presented in Figure 7 (cf. Kohonen 2001).

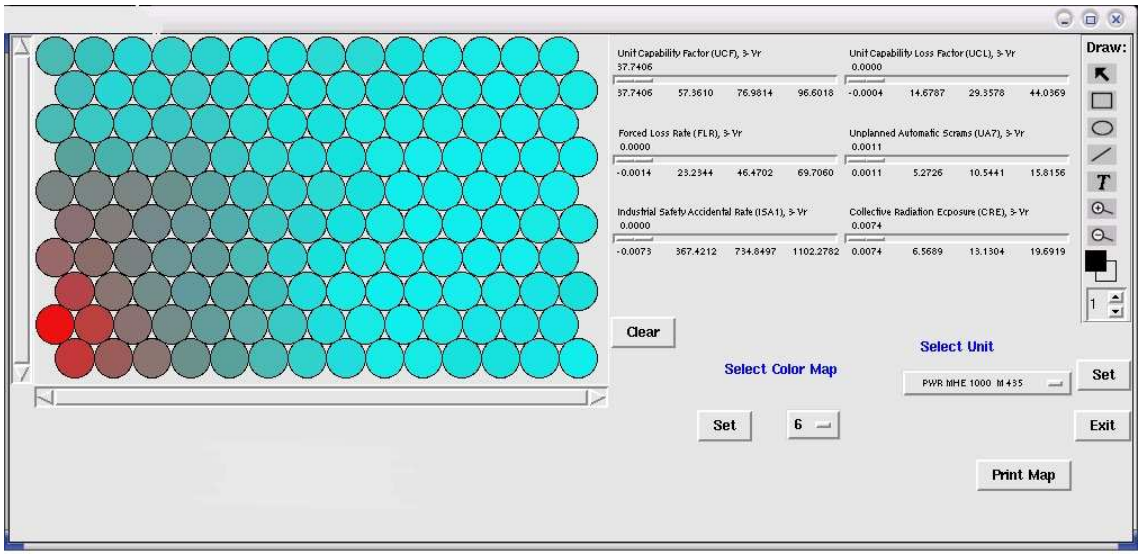

Figure 7. Position of a nuclear power plant compared with other plants regarding a performance indicator.

In this presentation, the data consists of six different variables from 435 nuclear power plants. Using Voronoi tesselation, it is possible to see n-dimensional data in a two-dimensional way (Preparata, F. P. & Shamos, M. I. 1985). The closest distance between the nuclear power plant unit values and the closest SOM cell defines the cell where it belongs. Similar units that are defined by these values are located in the same cell or near each other on the map.

WANO uses ten performance indicators in its reporting. All nuclear power plants report the indicator information to WANO. Each year, WANO publishes an extensive report where the indicator values for a nuclear power plant are presented as bar diagrams in comparison with other units.

However, information that is sufficient from a management perspective can be achieved more easily and in a descriptive format. Further information may be made available from the database that the bar diagrams are based on SOM methodology. The thesis works of Länsiluoto (2004) and Toivonen (2006) describe SOM methodology and its applications in more detail.

Six indicators were selected from an indicator database, while removing the information concerning years and the nuclear power plant identification information in order to maintain confidentiality. In Figure 7, the red ball represents the position of the selected nuclear power plant in relation to others when studying a certain indicator. This indicator value is in the best section of the SOM map. The test method also tried simulation. The new placement could be seen on the map by changing an indicator value. Therefore, when wishing to improve the overall result, the indicator that affects the ranking the most can be selected, and the required improvement can also be determined. When nuclear

power plants have several years of indicator information available, the change in indicators can be seen on the map, either individually or as an overall result. This allows us to see in a simple manner where the plant is located in relation to others, and what the direction of the change is; in other words, where we are and where we are going. Such information is, otherwise, not easily available.

3.4.2. What says Drucker ?

The industrial engineers in Japanese industry use the same methods, tools, and techniques as the Westerner to study and to analyse work. But the Japanese industrial engineer does not organize the worker's job. The Japanese worker very largely also takes responsibility for improving his tools. When a new machine or a new process is being introduced, the workers are expected to take an active part in the final adjustment, the final arrangement, the specific application of machine and tools.

The mechanism for making the worker take responsibility for job and tools is what the Japanese call "continuous training." Every employee, often up to and including top managers, keeps on training as a regular part of his job until he retires. The weekly training session is a regular and scheduled part of a man's work. It is not run, as a rule, by a trainer, but by the men themselves and their supervisors. The training session does not focus on any one skill. It is attended by all men on a given job level and focuses on all the jobs within the unit.

The Western concept assumes that the purpose of learning is to qualify oneself for a new, different, and bigger job. The nature of learning is expressed in a learning curve. Within a certain period of time this student reaches a plateau of proficiency, where he then stays forever.

In the Japanese concept the purpose of learning is self-improvement. It qualifies a man to do his present task with continually wider vision, continually increasing competence, and continually rising demands on himself. While there is a learning curve, there is no fixed and final plateau. All we have learned about learning in this century indicates that the Japanese concept is the correct one, and the Western concept actually a bar to true learning.

Japanese institutions are far more rigidly departmentalised and sectionalised than most Western institutions. The individual member of a department is expected to be completely loyal to it, yet the individual employee tends to see beyond the boundaries of his own speciality and his own department. He knows what goes on. He knows the work of others, even though he himself has never performed it. He sees a genuine whole, and he is expected to be concerned with the performance of every single job in this genuine whole. He, therefore, can see his own place in the structure and his own contribution.

Finally, continuous training creates receptivity for the new, the different, the innovative, and the more productive. The focus in the training sessions is always on doing the job better, doing it differently, doing it in new ways. The commitment to continuous training makes the entire work force in a Japanese institution receptive to change and innovation rather than resistant to it. At the same time, training mobilizes the experience and knowledge of the employee for constructive improvement. There is also impatience with poor working methods, desire to do a better job, demand for more intelligent, and more systematic management.

However, in Japan there is a tremendous fear of the consequences of personal misbehaviour, i.e., tremendous pressure for conformity and also genuine fear that the enterprise itself may go under. This makes the Japanese willing to go to very great lengths to maintain the competitive position of their employer.

3.4.3. Weaknesses inherent in the functional organisation

An integrated management system should provide a single framework for the arrangements and processes necessary to address all the goals of the organization. These goals include safety, health, environmental, security, quality and economic elements and other considerations such as social responsibility.

A management system, including organizational models, concepts and tools, should also cover human factor issues and other integrated management approaches that complement the traditional approach to achieving results, which was based on inspections and verification checks (IAEA 2006).

However, very seldom in practise analytical basis for the structure of the organisation is documented in such a way, that it is possible to understand the guiding principles for fulfilling the requirements above. Sometimes, when a new director coming from another industry starts as managing director, he or she may simply adapt the organisational model of the former company in spite that the goal of the organisations may be completely different.

In nuclear power plants various versions of functional organisation model are usual. There are some weaknesses which are inherent in the functional organisation. These are connected to processes and behaviors that cross organizational boundaries and that address organizational integration and interfaces. These cross-functional tasks are such as:

- Work management
- Plant modification works
- Equipment performance and materiel condition

- Plant status and configuration control
- Operating experience feedback
- Training
- Self-Evaluation and Corrective Action
- Human Performance
- Safety Culture

Therefore special attention should be paid to these cross-functional issues. The management should understand where the critical areas which may deviate from the ideal organisation are. This might be a challenge for future research, and in a limited scope what is a proper administration to fulfil the requirements stated above.

Event investigation is generally an efficient starting point for revealing the complex nature of safety management. The context of events reveals the complex interaction between people and technology in an organisational and cultural context. Event investigations should not only focus on events with high consequences; in most complex event a throughout investigation will reveal basic causes of great interest, particularly at the safety management level. Scientific studies of event investigation techniques and general descriptions of experience feedback processes have had a tendency to regard event investigations as too separated from a broader safety management context. Manuals for event investigation seldom describe how experience feedback techniques should fit into other safety management practices such as auditing, risk analysis, human resource management (Rollenhagen 2010).

3.4.4. Action programme

Some regulators have been active in developing general requirements regarding safety management and more detailed guidance to assess the approach taken by the licensee. They are using what can be called “process based regulation”, i.e. the regulation aims to make sure that the utility has the right processes, and the regulator checks that the processes ensure a high level of safety. To perform this, checking the regulator establishes the review and inspection procedures of the licensee processes. A different approach is when the regulator looks at the results of the processes of the licensee, which is termed “performance based regulation”. In this second approach, the regulator leaves to the licensee the establishment and control of the processes and checks if the results are acceptable. Both approaches have advantages and drawbacks. The main advantage of a performance based approach is that the licensee has complete flexibility on how to achieve the required outcomes; the main drawback is that when outcomes show degradation on safety, remediation can be painful. Neither of these methodologies looks into the scientific bases to

identify and understand the individual causes involved and their effects. We should focus on the importance of this approach using the potential of human behaviour and management sciences (Martin 1999).

Although there is no scientifically rigorous correlation available, it could be inferred with little risk that excellent management is the basis for good safety and performance. It is also apparent that pursuing just a single goal, even if it is safety and not considering the overall picture, will lead to an unbalanced and unsuccessful situation (Martin 2002).

Based on their assessment, Behavioural Science Technology, Inc. (BST) has developed a recommended plan for implementing culture change within NASA. The approach to cultural transformation is based on the following core concepts (Behavioural Science Technology 2004):

- Guiding principles must underlie the definition of the desired culture
- Guiding principles get to the essence of what needs to be given priority in order to assure that objectives are reached. Having guiding principles is important because achieving excellence requires relying upon many individuals making judgments continuously throughout their work. We cannot create rules for every situation and variation, thereby eliminating the need for judgment.
- Both climate and culture are important
- Leaders drive culture change (intentionally or unintentionally) through their behaviour
- There should be one, single culture change initiative

BST's recommended approach involves a comprehensive plan to achieve cultural transformation within three years. This included specific implementation steps for the first six months and the longer-term plan (Behavioural Science Technology 2004).

3.5. Research papers

The empirical results of the research are presented in research papers which are attached to this thesis. A summary of each research paper is presented in the following.

The first research paper

The first research paper, entitled "*The Deltoid Application for Competence Analysis and Development of Control Room Operators"*, presents a new method to assess, develop, and test an application that enables better management in

the competence development of licensed control room operators in a nuclear power plant. This work has had three sub goals. The first sub goal was to specify the key competencies of control room operators and the unconscious factors behind them. The second sub goal was to create a fuzzy logic based self-assessment computer system, which makes it possible to see the current reality and personal vision more clearly. The third sub goal was to test the self-assessment tool on control room operators and to find any potential creative tension to guide the annual retraining programme.

Consequently, the competency-based self-assessment tool created for this study i.e. the Deltoid-application, is suitable for the planning of basic training and retraining of control room operators. It is also a good working tool when forming shift crews with even competence distribution thereby satisfying the demands of the control room work.

The second research paper

The second research paper, entitled "*Control Room Operators' Competence Evaluation Based on a New Methodology"*, is a continuation of the first one and it describes the analysis and visualisation of the group results using neural networks in order to determine relations and interrelations in the self-evaluation data, which would otherwise be difficult to uncover. Neural networks show which individuals' perceived current and future levels of occupational competences are close to each other. The Self-Organising Maps (SOM) were used for the visualisation and clustering of the self-evaluation data of the operators who participated.

The next step of the human resource management process involves competence simulation. Competence simulation allows for competence with a focus on and leverage for individuals, teams, and organisations. This means that the relative position to others on neural nets can be simulated as a result of alternative targeted development and training actions. Competence leverage for teams allows for finding rational and efficient educational paths for team members. The competence simulation also helps organisations in forming groups for training with a specific content, and developing future shift crews, as well as positioning individuals and teams within an organisation. This enables enterprises to become more responsive and realise better returns from the development and training of human resources.

The third research paper

The third research paper, entitled "*Simulation with Occupational Work Role Competences",* proposes that people should be involved in performing

simulation or a what-if type of analysis of those human-systems in which they are involved. The benefit would come from increased understanding provided by such a participatory approach. The presented competence simulation illustrates some exciting new possibilities for competence focus and leverage to be applied in the future.

Modern enterprises support the personal goals of their employees and, consequently, integrate them into their business strategies. The self-evaluation process that reveals the creative tension of employees is the starting point. In the beginning of this process, the personal and organisational goals may not match and, therefore, competence simulation can be used to find a better solution. Competence simulation helps to plan and build the target training to fit the organisational strategy, resources, and current situation in a co-evolutionary way.

Competence simulation can also be used to test the impact of training and education packages, which are being used already, and the ones which are available inside an organisation and through external training organisations, such as universities, training centres, etc. An overall impact of the alternative training methods can be assessed by simulation, which allows for the integration of all trainings over all individuals. It is valuable to know if training has the impact that it is expected to have. Many targets and applications for the validation of training and education can be seen in future. The bottom-up perceived impact of training may differ from the view that an organisation has.

The fourth research paper

The fourth research paper "*Utilisation of Process Operators' Innovativeness in a Nuclear Power Plant"* shows that, based on the empirical results, the people who are working in shift crews seem to be innovative, creative and, therefore, willing to develop their working environment. Typically, a nuclear power plant environment is placed in the area of a non-innovative environment. However, the development proposals made do not generally involve any radical changes. In other words, they mainly follow the principles of continuous improvement. In nuclear power plant operations, small and justified changes are recommended because of safety reasons. This also supports the classification of incremental innovations.

Most of the proposals are related to the improvements of operation procedures, correction of printing errors, improvement of usability of procedures, or improvement of the whole procedure system to meet practical work requirements. This is understandable because operation procedures are the

most important tool for operators and contain the technical and practical know-how of the operation department.

Process control improvements are the second biggest group, and most of them are related to the optimisation of control of nuclear power plant operations. Quite few improvements are proposed regarding the better use of human resources or work management. This can be interpreted as a certain kind of reluctance to change working habits. There seems to be quite a strong tendency to preserve familiar working routines.

When it is examined as to who in the operation department has done most of the proposals, a conclusion can be drawn that about ten per cent of the operators are very innovative. Therefore, on the basis of these results, the nuclear power plant environment cannot be immediately classified as being a non-innovative environment.

The fifth research paper

The fifth research paper, entitled "*A Self-Evaluation Tool for the Development of Maintenance Personnel's Competences",* focuses on a new kind of web-based self-evaluation tool which can be used as a performance indicator to support maintenance personnel's competence development. The self-evaluation tool comprises those competences which are important in maintenance personnel's work. Some of these competences are generic, while others are differentiating. The self-evaluation tool utilises linguistics and is based on fuzzy logic. When using the self-evaluation tool, maintenance personnel evaluate their perceived current reality at work and the vision they have for the future. This difference between personal vision and current reality is called creative tension.
The self-evaluation tool has been used in a case study where a number of sixteen mechanical maintenance personnel made the self-evaluation. Some examples of the results of this case study are also presented in this paper.

Self-organising maps (SOM) were used to visualise and cluster the group results. The SOM is a two-layer neural network that maps multidimensional data onto a two dimensional topological grid. The data are grouped according to the similarities and patterns found, typically using the Euclidean distance as a distance measure. The results are displayed as a map. The map consists of nodes which can be divided into clusters. The SOM is an unsupervised neural network with no target outcome defined. The SOM is allowed to freely organise itself based on the patterns found in data. This makes the SOM an ideal tool for data analysing to illustrate the essential features of a data set, just as in its clustering structure and the relations between its data items.

The sixth research paper

The sixth research paper, entitled "*FOLIUM - Ontology for Organisational Knowledge Creation",* focuses on knowledge creation and learning concepts with the help of a new Folium application, which is ontology for organisational knowledge creation. Folium is built on the generic web-based fuzzy application "platform". The development work of Folium is based on a solid theoretical framework, which is called Co-Evolute theories. They were developed at the Tampere University of Technology in Pori. With the help of Folium, a bottom up view is formed to capture the real understanding of an organisation's knowledge creation activities. Folium can be used to help the organisation's management in the decision making process, when target development plans are made to improve and support organisational knowledge creation. In this paper, the first test results from Tampere University of Technology in Pori are also presented.

The seventh research paper

The seventh research paper, entitled "*Evaluating the Organisation's Environment for Learning and Knowledge Creation",* focuses on organisational learning and ability to create new knowledge. It is vital that the organisation's management has a systemic picture of the organisation's daily working environment. The objective of the research has been the better management of developing a responsive environment for learning and knowledge creation.

For this purpose, a new kind of decision support system was developed, the so-called Co-expert system, which can be used to capture the bottom-up view of the organisation's environment. The development work of the Co-expert system is based on Evolute's theoretical framework, which has been developed at Tampere University of Technology, Pori. The new system facilitates the use of real knowledge instead of presumptive real knowledge in making decisions concerning development efforts. This paper also presents the results from the system's first preliminary tests.

The eighth research paper

The eighth research paper, entitled "*Transfer of Nuclear Safety Culture",* addresses the question of what the main difficulties are that should be taken into consideration in the transferring of nuclear safety culture from a Finnish supplier to Russian nuclear power plants. First, the concept of 'Organisational Culture', focusing especially on 'Safety Culture', is described. After that follows a short description of the concept of 'Project Culture'. Then, the discussion goes on describing how the safety culture is transferred. And, thereafter, the discussion deals with the research methodology and research results. The

paper ends with the conclusion, according to which the assessment of the present situation, sharing the same vision, close co-operation based on equality, and complying with the decision-making system of the receiving organisation are of vital importance in order to implement the safety culture transfer project successfully.

The ninth research paper

The ninth research paper, entitled "*Showing Asymmetries in Knowledge Creation and Learning through Proactive Vision",* focuses on knowledge creation and learning concepts that are difficult to articulate and manage in organisations. It first shows the asymmetries between how people in business and the academic world view their current situation, as well as how they would like to see the future. Subsequently, the paper presents the possibilities to use the established database to group the whole data set to show the asymmetry between the proactive vision and the current and future desires to improve knowledge creation and learning in the organisation. The paper also presents evidence supporting the use of this methodology to reveal the asymmetries and why it is so important to understand these in terms of management and leadership.

The applications developed follow modern new methods where knowledge is created in groups and teams and where learning is encouraged to support growth and development. The importance of both contents, i.e. knowledge creation and learning, can be very difficult to quantify.

The tenth research paper

The tenth research paper, entitled "*Responsive Organisations with Genius Management Applications",* focuses on organisational learning and knowledge-creating activities which are vital to the organisation in order to succeed in tough competition and to cope with today's turbulent business environment.

Organisations typically have their own unique characteristics, which define the environment in which employees learn and create new knowledge. Therefore, it is important that the learning environment is analysed in order to focus and direct development efforts towards the right areas and topics. This can be very difficult with traditional management approaches because an organisation's learning and knowledge-creating environment is of a highly abstract nature. This paper presents a new type of co-expert system, enabling the analysis of the learning environment, which organisations offer to their members. With the help of the created co-expert system, a bottom-up view is formed to capture the real understanding of day-to-day practices up to the management level. The co-

expert system forms a new kind of meta-classification of the responsive learning and knowledge-creating environment. This new methodology with its methods and new classification possibility helps managers to understand new important management issues, as well as the systemic viewpoint embedded in its constructs. The first empirical tests with the created co-expert system have been successful.

3.6. Summarising the research results

Safety culture is a difficult concept. The word is used commonly and fluently, but it still remains vague. There are also many different definitions and emphasis areas in research. Ruuhilehto & Vilppola summarise three main directions which can be found in safety culture research. These include 1) case studies, 2) comparative studies, and 3) psychometric surveys.

Safety culture development is a change and learning process that is led inside an organisation. It draws upon both the quality management principles and behavioural sciences in addition to safety research. Safety culture can be indirectly measured using factors that are thought to reflect the culture. The emphasis of safety activities is shifting more and more towards anticipation and providing information.

Safety depends essentially on how people perform in their work. Is safety valued in general? How is it visible in everyday activities? Those involved in practical safety work require explanations concerning how safety culture will alter their work, and how it relates to any earlier means of promoting safety in a company.

Safety management refers to organisational measures that seek to identify, assess, and control risks in order to guarantee nuclear equipment, personnel and environmental safety. These risks include, among others, occupational accidents, accidental releases of radioactive substances and in the worst-case scenario, a meltdown of the reactor core.

Today, there is universal acceptance of the significant impact that management and organisational factors have on the safety significance of complex industrial installations, such as nuclear power plants. Many events with a significant economic and public impact had causes that have been traced to management deficiencies.

The objective of this research is to develop an application that enables better management of shift personnel development. The application supports individual development by focusing on the competencies required for successful performance in the task, and by identifying the individual’s current state and

personal goals. By understanding these personal qualities, shift personnel development, and training can be better targeted according to the desired and actual needs. A generic competency model for service personnel working in maintenance has also been created.

Nuclear safety

An analogy that should be followed is the “Systematic Approach to Training” that is used for training activities; as a result of the development, the nuclear power plant would have a documented “Systematic Approach to Safety”. This documentation would describe how safety is related to practical work. This would turn safety culture into a concrete tool. Documented safety thinking provides the organisation with a common starting point for future development.

Assessment of competences

A clear strength of the Deltoid method is that the shift crew’s attitude can be seen with a glance in the summary picture. No other method can provide the same information to support operations management or to assist in focusing training. If the creative tension is positive, we thereby know that the shift crew’s basic attitude is satisfactory. When the same information is presented in a Self Organising Map, the differences between groups or individuals can be clearly seen. For the management, a positive creative tension is always a good sign.

The Deltoid method is also suitable for determining shift compositions. Traditionally, the aim has been to ensure competence from different technology branches on the shift, and to provide equally strong competence within the shift. There used to be no method for this; the division has been based on a subjective assessment from the supervisor. The Deltoid method provides an opportunity for seeking a good composition by means of simulation. The shift personnel clearly showed creative tension, which means that the shift personnel have the desire and energy to develop themselves and their working methods. In the future, more attention should be paid to shift personnel training and on directing the training appropriately.

The purpose of the competence assessment method is not to replace the procedure used for recruiting shift personnel. The method is based on the creative tension proposed by Senge, which is a fairly simple model in itself. The calculation model is based on fuzzy logic. The overall starting point is one of positive self-improvement. The result is an illustrative image of the direction of personnel competence development, as well as the areas for improvement. The method should be used in periodic follow-ups in order to assist personnel management.

Human performance related training of operators

When developing working methods, the aim should be to achieve a systematic method that can, at a minimum, prevent common human errors of a certain type. On a more general level, cross-functional tasks are considered possible sources of errors and disturbances.

In enhancement of human performance the following training themes might be useful:

- Revising human error prevention strategy and techniques
- Detailed training in how and when to use the error prevention tools to teach self-checking, peer checking, and independent verification
- Case studies to reinforce an understanding of the subject matter
- The importance of professional behaviour and attitudes
- Providing training in the importance of maintaining situational awareness
- Understanding how to make systematic decisions and advice on how to diagnose faults
- Understanding how to maintain alertness and combat fatigue when working shifts
- Improving team skills, including a team building exercise
- Avoiding groupthink and other undesirable team behaviours
- Understanding individual error inducing tendencies
- The study of various human error models in current use
- Human error reduction management techniques
- Worker human performance standards and expectations.

These are examples of how to improve the existing training programmes. Knowledge management should empower plant staff to integrate learning processes into their work practices and habits to improve the organisation’s performance and capabilities.

As a working environment, a nuclear power plant requires a comprehensive understanding of the operation and processes of the plant. Even though individual work tasks require special skills and knowing the details, the component or piece of equipment in question must always be understood as a part of the whole. Therefore, each new employee must have a basic degree from a relevant educational institution. During employment, this basic degree should be complemented with know-how concerning the nuclear power plant as a whole, its processes, and the special skills it requires. Traditionally, maintenance has been equipment centred. The operating personnel thoroughly understand the operation of the nuclear power plant. In the future, these two functions should be brought closer together through increased co-operation. The maintenance training programme should be developed to be more systematic and equal in quality to the operating personnel training programme.

In the investigations of aviation accidents performed by The National Transportation Safety Board, the crucial role of maintenance in safety has been found many times. So why would the maintenance of nuclear power plants be less important?

Recommendation related to maintenance practice

Total Productive Maintenance is a way of managing maintenance people. It creates the right kind of atmosphere for working together and aims to provide an environment in which people care more about their work and workplace. Total Productive Maintenance creates methods for changing attitudes and undesired working habits. The principle of Total Productive Maintenance is to provide a tidy, challenging, and motivating working environment that supports and contributes to performing work. Total Productive Maintenance can be recommended as the main concept for maintenance.

Transfer of tacit knowledge

New employees should be recruited a few years before they have to take independent responsibility for their duties. It takes 2-3 years for new employees to learn the new duties well enough that they can take responsibility independently. For all experts, the work itself is a much more important way of learning than any course or training programme. Naturally, education is important, but its role should be seen as one teaching theoretical basics, which are elaborated upon and developed through practical work. Knowledge and know-how transfer should utilise the master and apprentice model, which combines several proven training and pedagogy-related elements. This model transfers both so-called tacit knowledge obtained through experience and more codified knowledge that can be expressed more easily. If nearly 70% of all learning takes place through informal channels, the change of the generation without losing an enormous amount of information is a critical factor.

Developed constructs

Based on the results (Deltoid), it can be said that the competency-based self-assessment system developed is useful for identifying individuals' current situation and personal targets.

The maintenance related study (Conchoid) aimed to create a generic competency model for a service personnel working in maintenance, which could be utilised in different organisations as is or modified according to the special needs of an organisation. The objective was to create a task-related model that would specifically take into account the task requirements of the performing level of maintenance. The construed serviceman competency model is primarily based on the generic models presented in competency literature, and the views of personnel working in maintenance.

The “Maintenance and Management with Mobile Multimedia (4M)” project aimed to study the use of wireless connections and multimedia in the field of maintenance. The purpose was to find areas for development in the current operation in the fields of information transfer and user-friendliness, and to present a suitable theoretical framework for constructing maintenance information systems. The result of the work illustrated how maintenance operations could be carried out in the future with a more human-oriented system. The Multi Demonstrator maintenance management software prototype has been applied in the three-dimensional modelling of the reactor main circulation pump, and the presentation of the service documentation. The ideas presented give a preconception as to how these new tools can be applied in the nuclear power plant maintenance. The software provides necessary procedures, direct access to the technical data needed without going through organisational levels, and offers guidance in videos, which contain the tacit knowledge of experienced workers. This is a proposed construct for future development.

Concluding remarks

The Deltoid and Conchoid competence evaluation methods and the indicator application are applications that can be taken into use quickly. Renewing the training programme, creating knowledge management practices, and developing practical applications based on knowledge utilisation according to Nonaka’s SECI model will take more time. Issues related to maintenance work tasks that are important for safety should be defined and documented.
In safety management, the following areas, among others, should be developed as a whole, as part of the safety enhancement programme:

- Observation of plant activities
- Plant inspection programme
- Screening process for non-conformities
- Corrective action programme
- Operating experience feedback
- Human performance

All of the above issues for their part transform some areas of safety culture thinking into practical tasks.

The methods presented in this thesis work do not overturn the present system that is used to ensure safety. According to the principle of continuous improvement, their purpose is to do their part in further improving the operational safety of nuclear power plants.

Table 3. Propositions and research results

Research proposition	**Research paper**
1. Safety culture as a management tool does not work unless in the task analysis safety relevance of each task is specified in advance.	Research papers VII, VIII, and experience from several plants support this proposition.
2. Human performance related training is not adequately taken into account in the training programme of nuclear power plant operations.	Research papers I, II, and III support this proposition. Such kind of training should be included in the training programme.
3. Importance of nuclear power plant maintenance to safety should be more adequately taken into account in the training programme.	Research paper V and VI support this proposition.
4. In the design of work organisation, learning from experience should also be taken into account to prevent risks of organisational accidents.	Research paper IV, IX, and X support this proposition. Experience from several plants also gives an indication that this aspect is not often included in discussions related to a change of working practices. The changes in nuclear power plant organisations should be based on a thorough analysis.
5. Knowledge management, knowledge transfer and knowledge creation is an integrated part of safety management.	Research paper VI supports this proposition.Knowledge manage-ment should give priority to the way in which people construct and use knowledge. It is closely related to organisational learning.

4. DISCUSSION AND CONCLUSIONS

A continuous high level of safety is a prerequisite for the use of nuclear energy. Operation of a nuclear power plant requires a sufficient infrastructure to cover the education and research needed in this field. Nuclear safety enhancement programmes provide the necessary conditions for retaining the knowledge needed for ensuring the continuance of safe and economic use of nuclear power, for the development of new know-how and for participation in international co-operation.

The objective of this reserach is the development of new management methods to increase the safety of nuclear power plant operation and development of a methodology to make safety culture and knowledge management operational to support the safe operation of nuclear power plants. The research results and methods are also assessed and suggestions for future research are made.

4.1. Contribution of the research

Based on the empirical results, it can be concluded that competence-based Deltoid self-evaluation application clearly recognises individuals' own current reality and their development needs. Consequently, the competency-based self-assessment tool created for this study, i.e. the Deltoid application, is suitable for the planning of basic training and retraining of control room operators. It is also a good working tool when forming shift crews with an even competence distribution, thus satisfying the demands of the control room work. The Deltoid method could also be used to assess factors related to disturbance management during simulator training, for example.
The Deltoid application is a new and flexible tool for human resources purposes. A clear strength of the Deltoid method is that the shift crew's attitude can be seen with a glance in the summary picture. No other method can provide the same information to support operations management or to assist in focusing training. If the creative tension is positive, we thereby know that the shift crew's basic attitude is satisfactory. When the same information is presented in a Self Organising Map, the differences between groups or individuals can be clearly seen.

4.2. Assessment of the research results

As a working environment, a nuclear power plant requires a comprehensive understanding of the operation and processes of the plant. Even though individual work tasks require special skills and knowing the details, the component or piece of equipment in question must always be understood as a

part of the whole. Therefore, each new employee must have a basic degree from a relevant educational institution. During employment, this basic degree should be complemented with know-how concerning the nuclear power plant as a whole, its processes, and the special skills it requires. Traditionally, maintenance has been equipment centred. The operating personnel thoroughly understand the operation of the nuclear power plant. In the future, these two functions should be brought closer together through increased co-operation. The maintenance training programme should be developed into more systematic and equal in quality to the operating personnel training programme.

The study presents knowledge management issues broadly, based on the Nonaka's model. The idea is that, as an analogous counterpart to the Japanese "quality circles", a "safety circle" should be introduced; this would allow for having discussions on safety issues related to the work, and for making improvement proposals related to them. A second analogy that should be followed is the "Systematic Approach to Training" that is used for training activities; as a result of the development, the nuclear power plant would have a documented "Systematic Approach to Safety". This documentation would describe how safety is related to practical work. This would turn safety culture into a concrete tool. Documented safety thinking provides the organisation with a common starting point for future development.

The main proposal of the thesis is that in all normal tasks, relevance to safety should be specified, training practices should be transformed to the direction of knowledge management, safety circles should be established and, for safety issues, a working methodology similar to TPM should be created.

The indicator application allows us to see in a simple manner where our plant is located in relation to others, and what the direction of the change is; in other words, where we are and where we are going. Such information is, otherwise, not easily available.

4.3. Assessment of the research strategy

In this research, both conceptual and constructive research approaches were used. The conceptual research approach was used to define the concepts related to organisational culture and safety culture. The constructive research approach was used when building assessment systems for the competencies of operation and maintenance personnel. Different case studies were used to find out how the developed constructs work in practice. Based on the research results, it can be concluded that this research presents new approaches to the management and safe operation of nuclear power plants.

4.4. Future research

There is growing interest in the nuclear safety field in the development and improvement of safety management systems. Accidents such as Chernobyl (Ukraine), Seveso (Italy, chemical), Challenger and Columbia (US space shuttles) have demonstrated the impact of human and organisational failures. These events made companies, public organisations, and the general public aware of the impact of organisational processes on risk and have reinforced the appreciation of the importance of robust safety management. Safety Management has thus been developed as a concept describing the systematic management processes through which the risks are controlled and a high level of safety is maintained in the day-to-day operations of an organisation.

There are some weaknesses which are inherent in the functional organisation. These are connected to processes and behaviours that cross organizational boundaries and that address organizational integration and interfaces. These cross-functional tasks are such as:

- Work management
- Plant modification works
- Equipment performance and material condition
- Plant status and configuration control
- Operating experience feedback
- Training
- Self-Evaluation and Corrective Action
- Human Performance
- Safety Culture.

Therefore, special attention should be paid to these cross-functional issues. The management should understand where, from safety point of view, the critical areas are. This might be a challenge for future organisational research.

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APPENDIX: RESEARCH PAPERS

I Kantola, J., Nurminen, K., Piirto, A. and Vanharanta, H., 2004, *The Deltoid Application for Competence Analysis and Development of Control Room Operators.* The IASTED International Conference on Neural Networks and Computational Intelligence, NCI2004 February 23-25, 2004, Grindelwald, Switzerland.
Proceedings of the IASTED International Conference Anaheim. ACTA Press. pp. 285-290.
Author's contribution: The current author's contribution included taking part in researching, designing and developing of Deltoid application and also arranging first preliminary tests.

II Piirto A., Paajanen P., Kantola J. and Vanharanta H., 2005, *Control Room Operators' Competence Evaluation Based on a New Methodology*, II International Seminar on Nuclear Power Engineering - Trust, Education, Development, NPEE - 2005, May 3-6, 2005, St. Petersburg and Sosnovy Bor, Russia. Materials of the II International Conference, pp.138-148.
Author's contribution: The current author's contribution included taking part in researching, designing and developing of Deltoid application.

III Kantola, J., Piirto, A., Toivonen, J. and Vanharanta, H., 2009, *Simulation with Occupational Work Role Competences,*
Proceedings of Conference on Grand Challenges in Modeling and Simulation (GCMS'09), July 13-16, 2009, Istanbul, Turkey, 8 p.
Author's contribution: The current author's contribution included taking part in developing of the simulation application.

IV Piirto A., Paajanen P. and Koskinen, K. U., 2007, *Utilisation of Process Operators´ Innovativeness in a Nuclear Power Plant*, the XVIII Conference on Innovation for Growth: The Challenges for East & West, In: Torkkeli, M., Conn S. & Bitran I. (eds.). Proceedings of The XVIII ISPIM Annual Conference, Warsaw, Poland, 17-20 June 2007 12 p. Warsaw, Poland.
Author's contribution: The current author's contribution included data collection and taking part in analysing research results of the case study.

V Piirto A., Paajanen P., Kantola J. and Vanharanta, H., 2005, *A Self-Evaluation Tool for Development of Maintenance Personnel's*

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VI Paajanen P., Piirto A., Kantola J. and Vanharanta H., 2006. *FOLIUM – Ontology for Organizational Knowledge Creation*, the 2nd Symposium on Management, Engineering and Informatics: MEI'06, In: Callaos et al. (eds.). WMSCI 2006, the 10th World Multi-Conference on Systemics, Cybernetics and Informatics. Proceedings VI pp. 147-152. July 16-19, 2006, Orlando. Florida, USA.
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VII Paajanen P., Kantola J., Vanharanta H. and Piirto A., 2004. *Evaluating the Organization´s Environment for Learning and Knowledge Creation*, the 9th International Conference on Human Aspects of Advanced Manufacturing, HAAMAHA 2004, Galway, Ireland, August 24-27, 2004. Galway, Ireland, 8 p.
Author's contribution: The current author's contribution included participation in some supporting studies.

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