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Evaluating safety-critical organizations – emphasis on the nuclear industry

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This report concerns a study which has been conducted for the Swedish Radiation Safety Authority, SSM. The conclusions and viewpoints presented in the report are those of the author/authors and do not necessarily coincide with those of the SSM.

SSM Perspective

According to the Swedish Radiation Safety Authority's Regulations concerning Safety in Nuclear Facilities (SSMFS 2008:1) "the nuclear activity shall be conducted with an organization that has adequate financial and human resources and that is designed to maintain safety" (2 Chap., 7 §). SSM expects the licensees to regularly evaluate the suitability of the organization. However, an organisational evaluation can be based on many different methods.

Background

The regulator identified a few years ago a need for a better understanding of and a deeper knowledge on methods for evaluating safety critical organisations. There is a need for solid assessment methods in the process of management of organisational changes as well as in continuously performed assessment of organisations such as nuclear power plants. A considerable body of literature exists concerning assessment of organisational performance, but they lack an explicit safety focus.

Objectives of the project

The object of the project was to describe and evaluate methods and approaches that have been used or would be useful for assessing organisations in safety critical domains. An important secondary objective of the research is to provide an integrative account of the rational for organisational assessment.

Due to the extent of the organisational assessment types, approaches and methods, the scope of this study is limited to the methods and approaches for periodic organisational assessment. In this study, the concept of periodic organisational assessment refers to any assessment dealing with organisational issues that the organisation decides to carry out in advance of any notable incidents. Also, periodic organisational assessments are the tool that the organisation can utilize in order to concentrate on the most safety critical issues.

Results

The project has resulted in a deeper understanding of the development and on human and organisational factors over the last decades, and how this development influences the view on safety-critical organisations. Reasons for and common challenges of evaluating safety critical organi-

sations are discussed in the report. Since there are no easy step-by-step model on how to evaluate safety-critical organisations, the researchers propose a framework for organisational evaluations that includes psychological dimensions, organisational dimensions and social processes.

The psychological dimensions are tightly connected to aspects of safety culture and examples of criteria of safety culture are proposed. As the researchers point out "the most challenging issue in an organisational evaluation is the definition of criteria for safety". As a starting point for the development of criteria the researchers propose a definition on what constitutes an organisation with a high potential for safety.

Effect on SSM supervisory and regulatory task

The results of the report can be looked upon as a guideline on what to consider when evaluating safety-critical organisations. However, the proposed framework/model has to be used and evaluated in cases of evaluations, before the guideline can be a practical and useful tool. Thus, a next step will be to use the model in evaluations of safety critical organisations such as power plants, as a part of research and to develop a more practical guideline for evaluation of safety-critical organisations.
The knowledge in this area can be used in regulatory activities such as inspections and the reviewing of the licensees' organisational evaluations, and to support the development of methods/approaches of organisational evaluations.

Project information

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1. Introduction

A safety-critical organization can be defined as any organization that has to deal with or control such hazards that can cause significant harm to the environment, public or personnel (Reiman & Oedewald, 2008). Control of risk and management of safety is one of their primary goals. They are expected to function reliably and to anticipate the operating risks caused by either the technology itself or the organizational structures and practices. The ability of the organization to monitor its current state, anticipate possible deviations, react to expected or unexpected perturbations, and learn from weak signals and past incidents is critical for success (cf. Hollnagel, 2007; Weick & Sutcliffe, 2007). Organizational evaluation is one way of reflecting on this ability.

Nuclear power plants are safety-critical organizations. In addition to the complexity of the technology, the overall system complexity depends on the organization of work, standard operating procedures, decision-making routines and communication patterns. The work is highly specialized, meaning that many tasks require special know-how that takes a long time to acquire, and which only a few people in any given plant can master. At the same time, the understanding of the entire system and the expertise of others becomes more difficult. The chain of operations involves many different parties and the different technical fields should cooperate flexibly. The goals of safety and efficiency must be balanced in everyday tasks on the shop floor. The daily work in a nuclear power plant is increasingly being carried out through various technologies, information systems and electronic tools (cf. Zuboff, 1988). This has led to reduction in craftwork where people were able to immediately see the results of their work. The safety effects of one's own work may also actualize on a longer time frame. These effects are hard to notice. When the complexity of the work is increased, the significance of the most implicit features of the organizational culture as a means of coordinating the work and achieving the safety and effectiveness of the activities also increases (cf. Weick, 1995, p. 117; Dekker, 2005, p. 37; Reiman & Oedewald, 2007). The significance of human and organizational factors thus becomes higher, but their effects and interactions also become more complex.

In addition to the inherent complexity, different kinds of internal and external changes have led to new challenges for safety management. For example, organizations keep introducing new technology and upgrading or replacing old technology. Technological changes influence the social aspects of work, such as information flow, collaboration and power structures (Barley, 1986; Zuboff, 1988). Different kinds of business arrangements, such as mergers, outsourcing or privatization, also have a heavy impact on social matters (Stensaker et al., 2002; Clarke, 2003; Cunha & Cooper, 2002). The exact nature of the impact is often difficult to anticipate and the safety consequences of organizational changes are challenging to manage (Reiman et al., 2006). The use of subcontractors has increased in the nuclear industry, and this has brought new challenges in the form of coordination and control is-

sues, as well as occasional clashes between cultures; between national, organizational or branch-based cultures.

Furthermore, reliance on technology creates new types of hazards at the same time as the nature of accidents in complex systems is changing (Dekker, 2005). They are seldom caused by single human errors or individual negligence but rather by normal people doing what they consider to be their normal work (Dekker, 2005; Hollnagel, 2004). Many safety scientists and organizational factors specialists state that the organizational structures, safety systems, procedures and working practices have become so complex that they are creating new kinds of threats for reliable functioning of organizations (Perrow, 1984; Sagan, 1993). The risks associated with one's own work may be more difficult to perceive and understand. People may exhibit a faulty reliance on safety functions such as redundancy as well as an excessive confidence on procedures. The organization may also experience difficulties in responding to unforeseen situations due to complex and ambiguous responsibilities. Due to the complexities of the system, the boundaries of safe activity are becoming harder and harder to perceive. At the same time, economic pressures and striving for efficiency push the organizations to operate closer to the boundaries and shrink unnecessary slack. Over time, sociotechnical systems can drift into failure (Dekker, 2005; Rasmussen, 1997). In other words, an accident is a "natural" consequence of the complexity of the interactions and social as well as technical couplings within the sociotechnical system (Perrow, 1984; Snook, 2000; Reiman, 2007).

This report suggests that the aim of organizational evaluation should be to promote increased understanding of the sociotechnical system. This means a better understanding of the vulnerabilities of the organization and the ways it can fail, as well as ways by which the organization is creating safety. Organizational evaluation contributes to organizational development and management. In the context of safety management, organizational evaluations are used to:

- learn about possible new organizational vulnerabilities affecting safety
- identify the reasons for recurrent problems, recent incident or more severe accident
- prepare for challenges in organizational change or development efforts
- periodically review the functioning of the organization
- justify the suitability of organizational structures and organizational changes to the regulator
- certify management systems and structures.

The different uses of organizational evaluations in the list above are put in descending order of potential to contribute to the goal of increasing the understanding of the organization. When the aim is to learn about possible new vulnerabilities, identify organizational reasons for problems, or prepare for future challenges, the organization is more open to genuine surprises and new findings. This does not mean that the three other goals are useless, but rather that, in addition to certification and justification purposes, evaluations should be conducted with a genuine goal to learn and change, and not only to

justify or rationalize. We will return to these basic challenges of organizational evaluation in the upcoming sections of this report.

This report will illustrate the general challenges and underlying premises of organizational evaluations and propose a framework to be used in various types of evaluations. The emphasis is on organizational evaluations in the nuclear industry focusing on safety, but the report will also deal with other safety-critical organizations. Despite differences in technology, some similar organizational challenges can be found across industries as well as within the nuclear industry.

1.1 Approaches to evaluation

The contemporary view of safety emphasises that safety-critical organizations should be able to proactively evaluate and manage the safety of their activities instead of focusing solely on risk control and barriers. Safety, however, is a phenomenon that is hard to describe, measure, confirm and manage. Technical reliability is affected by human and organizational performance. The effect of management actions, working conditions and culture of the organization on technical reliability, as well as overall work performance, cannot be ignored when evaluating the system safety.

In the safety-critical field there has been an increasing interest in organizational performance and organizational factors, because incidents and accidents often point to organizational deficiencies as one of their major precursors. Research has identified numerous human and organizational factors having relevance for safety. Nevertheless, the human and organizational factors are often treated as being in isolation from and independent of each other. For example, “roles and responsibilities”, “work motivation and job satisfaction”, “knowledge management and training” are often considered independent factors that can be evaluated separately. All in all, the view on how to evaluate the significance of organizational factors for the overall safety of the organization remains inadequate and fragmented.

All evaluations are driven by questions. These questions, in turn, always reflect assumptions inherent in the methods, individual assessors, and cultural conventions. These assumptions include appropriate methods of data collection and analysis, opinions on the review criteria to be used, and models of safe organization. (Reiman et al., 2008b) Thus an organizational evaluation is always based on an underlying theory, whether the theory is implicit in the assessor’s mind or made explicit in the evaluation framework.

Scientists in the field of safety-critical organizations state that safety emerges when an organization is willing and capable of working according to the demands of the task, able to vary its performance according to situational needs, and understands the changing vulnerabilities of the work (Dekker, 2005; Woods & Hollnagel, 2006; Reiman & Oedewald, 2007). In adopting this point of view, we state that managing the organization and its sociotechnical phenomena is the essence of management of safety (Reiman & Oedewald, 2008). Thus management of safety relies on a systematic an-

ticipation, feedback and development of the organizational performance, in which different types of organizational evaluations have an important role.

A considerable body of literature concerning assessment of organizational performance exists, but it lacks an explicit safety focus. Examples of these methodologies are Competing Values Framework (Cameron & Quinn, 1999), Job Diagnostic Survey (Fried & Ferris, 1987), SWOT analysis (see e.g. Turner, 2002) and Balanced Scorecard (Kaplan & Norton, 1996). These methods may provide important information on the vulnerabilities of the organization if analysed correctly and within the safety management framework. Also, many methods and approaches have been used for organizational safety assessments (Reiman et al., 2008b). Many of them are based on ad hoc approaches to specific problems or otherwise lack a theoretical framework on organization and safety. Some approaches, such as safety culture assessments (IAEA, 1996; Guldenmund, 2000) or the high reliability organizations approach (Weick & Sutcliffe, 2001; Roberts, 1993), have extended to a wide range of frameworks and methods.

As a consequence of the fragmented nature of the field of organizational evaluation, practitioners and regulators in the nuclear industry lack a systematic picture of the usability and validity of the existing methods and approaches for safety evaluations. The selection of the appropriate method is challenging because there are different practical needs for organizational evaluations, numerous identified safety significant organizational factors and partially contradictory methodological approaches. Furthermore, clear guidelines on how to utilise evaluation methods, collect data from the organization and draw conclusions from the raw data do not exist.

Figure 1.1 shows examples of methods, approaches and situations where organizational evaluations are typically carried out.

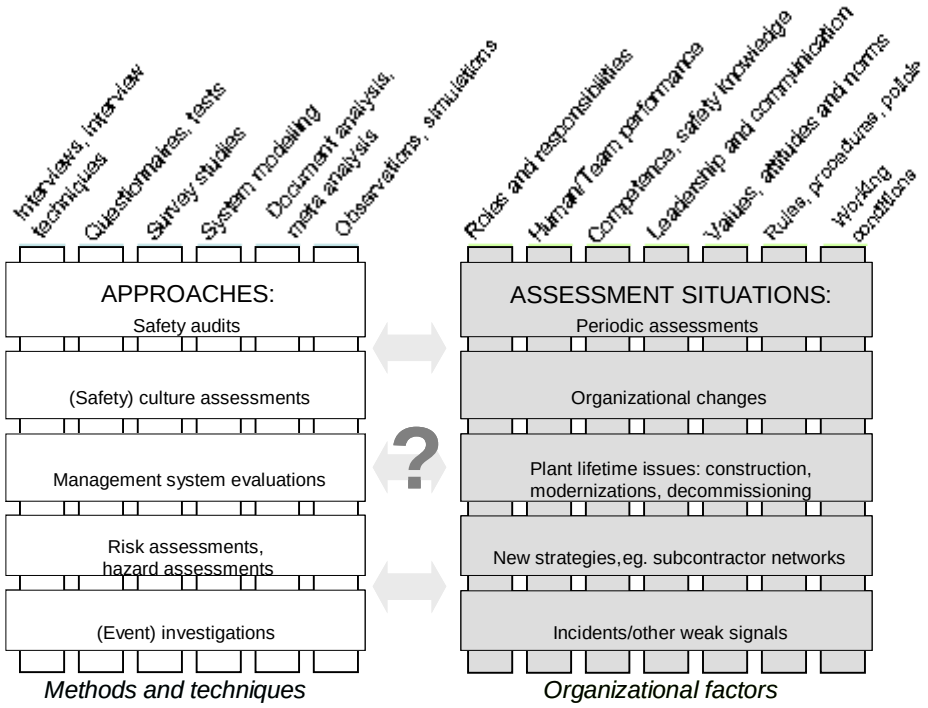

Figure 1.1. Illustration of various methods, approaches, situations and organizational factors related to organizational assessments in safety-critical organizations.

Figure 1.1 also depicts various organizational factors that are the object of evaluation. The focus and emphasis placed on the factors by the different approaches differs. Also, the interaction between the factors is seldom explicitly considered. It is unrealistic to assume that any organizational evaluation method could cover all the safety significant issues in the organization. However, the organizational evaluation should provide information on the comprehensiveness of its results in terms of overall safety. Thus an explicit model of the organizational dynamics is critical for both the appropriate use of any approach as well as for the evaluation of the results of the assessment.

1.2 Evaluating, diagnosing and assessing organizations

We use the term organizational evaluation in this report to denote the use of conceptual models and applied research methods to assess an organization's current state and discover ways to solve problems, meet challenges, or enhance performance (cf. Harrison, 2005, p. 1). This term is synonymous to what Harrison calls organizational diagnosis, and Levinson (2002) calls organizational assessment. These approaches all share an idea of organization as a system, the functioning of which can be evaluated against some criteria. They also all emphasize the need for multiple sources of information and multiple types of data on the organization. Evaluation is always qualitative. This means that the evaluator has to use him or herself as an instrument of analysis; the feelings and thoughts that surface during the evaluation are all sources of information to an evaluator who is able to analyse them. In this

inherently qualitative and subjective nature of evaluation lies one of the hazards of organizational evaluation: An evaluator who is not competent in behavioural issues can interpret some of his internal reactions and intuitions incorrectly. Another stumbling block of organizational evaluation is the myth of "tabula rasa evaluator", who is strictly objective and has no preconceptions and no personal interests of any kind. This evaluator supposedly can make decisions based only on his findings, without any interference from experience, good or bad. Most people acknowledge the absurdity of the myth, but it is not typical that all evaluators make their assumptions and background theories explicit. We will return to these challenges later in this report.

Organizational diagnosis emphasizes the idea of problem identification and solving, whereas organizational evaluation as we define it does not need to start with a problem, or end in concrete solutions. The production of information on the functioning and the current vulnerabilities of the organization is the primary goal of organizational evaluation. Care should be taken when coupling organizational evaluation with inspections and investigations. Accident investigations are a separate form of analysis, where responsibility and accountability issues may set a different tone for the data gathering and analysis. Furthermore, technical reconstructions, technical analyses and eye witness testimonies are not conducted according to organizational scientific data gathering methodologies (i.e. sampling criteria are not used, the participation of the researcher is not a key question, the use of memory aids and other tools to assist reconstruction is encouraged).

1.3 What is currently being evaluated in practice

Different organizational elements are currently recognised in the science and practice of organizational evaluation. More emphasis is still placed on the assessment of technical solutions and structures than on organizational performance and personnel-related issues. Furthermore, the evaluations themselves tend to be quantitative and "technical" in nature, compressing a lot of information into a few outcome measures or mean scores (cf. Reiman et al., 2008b). Organizational evaluations in safety-critical organizations have often targeted either the safety values and/or attitudes of the personnel, or the organizational structures and official risk management practices (Reiman & Oedewald, 2007). In addition to these, some methodologies and theories of organizational safety stress the importance of the personnel's understanding and psychological experiences in guaranteeing safety. These three main foci are illustrated in Figure 1.2 along with two other safety evaluation types: individual performance and technology.

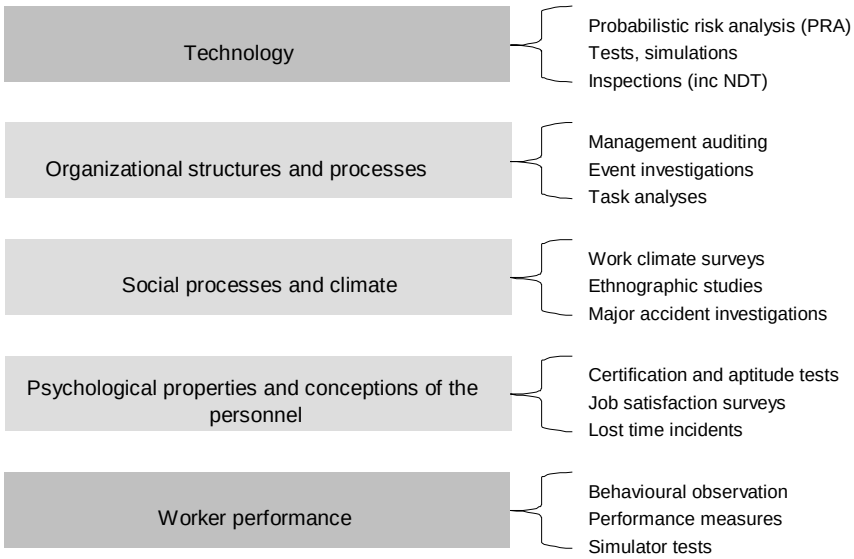

Figure 1.2. Several methods are used in safety assessments that variously target the three main organizational elements as well as technology and individual worker performance.

Figure 1.2 illustrates that several methods are used in safety assessments that variously target the three main organizational elements (we will return to these in Section 5 of this report) as well as technology and individual human performance. Only seldom are the findings from the different assessments combined into an overall evaluation of the organizational performance. Thus only seldom are the safety evaluations that organizations conduct truly *organizational evaluations.*

The fragmented state of the art of organizational evaluation is partly related to the typical organizational separation of human resources, occupational safety, nuclear safety and quality control and assurance into different organizational functions. Thus each use their own measures and own goals and do not always communicate with each other or share knowledge on organizational performance. This miscommunication is due to either goal conflicts, or power play, between the functions or to the lack of knowledge of what the other function would require and what they could offer in return.

1.4 Structure and aims of this report

The aim of this report is to identify and illustrate the basic principles and main challenges of evaluation of safety-critical organizations, with an emphasis on the nuclear industry. The report also provides guidelines for selecting and utilizing appropriate methods and approaches for conducting organizational evaluations in the nuclear industry, and provides a concise overview of the main issues and challenges associated with organizational evaluation.

The report is structured as follows: In Section two we will briefly outline the development of theories and models concerning human and organizational

factors in safety-critical organizations. This is an important background for organizational evaluation for two reasons: (1) it illustrates how the understanding of human and organizational performance, as well as knowledge of system safety, has progressed in several stages and how each stage has left its mark on the methods of organizational evaluation; and (2) it shows how all the approaches differently postulate their motive for evaluating organizations in the first place. In Section three we illustrate our analysis of the main reasons for evaluating safety-critical organizations. After pointing out the importance of organizational evaluation in the previous section, Section four focuses on the challenges of the evaluation. This sheds light on the various biases and implicit choices in organizational evaluation that influence its outcome and validity. Section five presents our theoretical framework for organizational evaluation. This seeks to provide dimensions as well as criteria for the evaluation of those dimensions so that the reasons for and challenges of organizational evaluation are met. In Section six we outline the basic requirements for carrying out organizational evaluations. These include the design of the evaluation, selection of methods, and data collection and analysis. The final Section provides a summary of the main points raised in the report.

The Challenger Space Shuttle accident case will be referred to in various places in the report to illustrate the challenges of organizational evaluation as well as safety-critical phenomena in organizations. A general description of the accident can be found in Appendix A of this report.

> The Challenger accident has been investigated by various groups of people. The official investigation by the Presidential Commission (1986) found numerous rule breakings and deviant behaviour at NASA prior to the accident. They also accused NASA of allowing cost and schedule concerns to override safety concerns. Vaughan (1996) shows in her analysis of the same accident how most of the actions that employees at NASA conducted were not deviant in terms of the culture at NASA. She also shows how safety remained a priority among the field-level personnel and how the personnel did not see a trade-off between schedule and safety (Vaughan, 1996). They perceived the pressure to increase the number of launches and keep the schedule as a matter of workload, not a matter of safety versus schedule. The decisions made at NASA from 1977 through 1985 were “normal within the cultural belief systems in which their actions were embedded” (Vaughan, 1996, p. 236).
>
> An example of secrecy that the commission found was the finding that NASA Levels II and I were not aware of the history of problems concerning the O-ring and the joint. They concluded that there appeared to be “a propensity of management at Marshall to contain potentially serious problems and to attempt to resolve them internally rather than communicate them forward” (Presidential Commission, 1986a, p. 104). The U.S. House Committee on Science and Technology later submitted its own investigation of the accident, and they concluded that “no evidence was found to support a conclusion that the system inhibited communication or that it was difficult to surface problems”. (U.S. Congress, 1986)

If communication or intentional hiding of information were not to blame, then what explains the fact that the fatal decision to launch the shuttle was made? The U.S. House Committee on Science and Technology disagreed with the Rogers Commission on the contributing causes of the accident: “the Committee feels that the underlying problem which led to the Challenger accident was not poor communication or underlying procedures as implied by the Rogers Commission conclusion. Rather, the fundamental problem was poor technical decision-making over a period of several years by top NASA and contractor personnel, who failed to act decisively to solve the increasingly serious anomalies in the Solid Rocket Booster joints.” On the other hand, Vaughan shows in her analysis how the actions that were interpreted by the investigators as individual secrecy and intentional concealing of information, or just bad decision making, were in fact structural, not individual, secrecy. Structural secrecy means that it is the organizational structures that hide information, not individuals.

The Nobel Prize winner theoretical physicist Richard P. Feynman was part of the Commission. He eloquently explains in his book (Feynman, 1988) how he practically conducted his own investigation in parallel to the Commission (while simultaneously taking part in the Commission), and wound up disagreeing with some of the Report’s conclusions and writing his own report as an Appendix to the Commission Report. The Appendix was called “Personal Observations on the Reliability of the Shuttle”. In the report he questions the management’s view on the reliability of the shuttle as being exaggerated, and concludes by reminding managers of the importance of understanding the nature of risks associated with launching the shuttle: “For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled” (Feynman, 1988, p. 237).

Jensen (1996) provides a narrative of the accident based on secondary sources, which emphasises the influence of the political and societal factors. For example, he points out how the firm responsible for designing the solid rocket boosters was chosen based on political arguments and how the original design of the space shuttle by NASA did not include booster rockets using solid fuel but rather a manned mother plane. A manned mother plane carrying the orbiter proved too expensive in the political climate where NASA had to fight for its budget and justify the benefits of its space program. Reusable rocket boosters were cheaper. As the rocket boosters were designed to be reusable after being ditched into sea water on each flight, NASA did not want to consider what “all the pipes and pumps and valves inside a liquid-fuel rocket would be like after a dip in the ocean (Jensen, 1996, p. 143)”. Thus it was decided that solid fuel instead of liquid should be used. Solid rocket motors had never been used in manned spaceflight since they cannot be switched off or “throttled down” after ignition. Moreover, the fact that the design had field joints at all had to do with Morton Thiokol wanting to create jobs at their home in Utah, 2500 miles from the launch site. There was no way of building the booster in one case in

Utah and shipping it to the Kennedy Space Center (Jensen, 1996, p. 179). Jensen also considers the network of subcontractors and NASA's deficient ability to control the quality of their work. Morton Thiokol, for example, signed subcontracts with 8600 smaller firms (Jensen, 1996, p. 156).

Jensen argues that the NASA spokesmen emphasised that the space shuttle did not require any new innovations, except for the main engines, for political reasons. Too heavy emphasis on the need for experimentation and risks associated with technological innovations would have made Congress wary of providing the necessary funding (Jensen, 1996, p. 158). The personnel at NASA were surprised by that kind of attitude at the management level when the engineer level was tackling a wide range of never-before-tried technical solutions. When the space shuttle finally became operational, Jensen (1996, p. 202) argues that "every single breakdown was regarded as an embarrassing exception, to be explained away and then be corrected, under wraps, as quickly as possible - so as not to damage the space shuttle's image as a standard piece of technological equipment". Jensen also tackles the long working hours and work stress that was due to the production pressures, and the bureaucratic accountability as a substitute for the professional accountability of the early NASA culture (Jensen, 1996, p. 363).

2. Development of human and organizational factors

2.1 Four ages of safety

The approaches to safety management and initiatives to evaluate safety have gradually developed over decades. It can be said that the human factors research and development started over a hundred years ago. Since then, many steps have been taken to reduce the failure of human-machine-organization systems. As shown in Figure 2.1, usability tests, aptitude tests, task design and training have been utilized in different domains for decades.

The investigations of major accidents have facilitated the development of new concepts and tools for analysing failures and protecting the systems from hazards of various types. The most notable accidents in terms of their significance for the development of the safety science field have been the nuclear accidents at Three Mile Island in 1979 and Chernobyl in 1986. The Challenger Space Shuttle accident was significant due to the in-depth investigation carried out at NASA, which shed light on many organizational risks of complex sociotechnical systems. Accident investigations have fuelled the development of the human factors and safety science at the same time as progress in safety science has widened the scope of accident investigations.

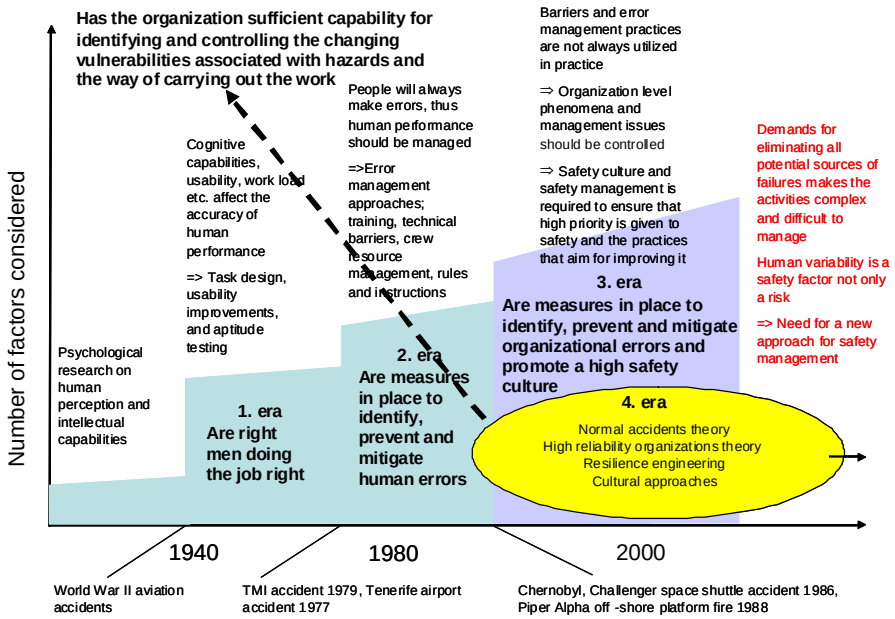

Figure 2.1. The progression of safety science through four eras shows the different emphasis on the nature of safety and the changing focus of research and evaluation

Figure 2.1 shows that the research and development work on human and organizational factors has mainly focused on controlling the variability of

human performance, especially in the first and second eras. The occurrence of human errors and their potentially serious consequences for the overall safety was identified early on in different industrial domains. Thus the research and development work focused on identifying the sources of errors and creating system barriers to prevent them and mitigate their effects. Organizational evaluation in this second era of safety was mainly concerned with ensuring that there are measures in place to identify, prevent and mitigate human errors.

The safety culture approach that followed the Chernobyl accident moved the main focus of research and development on organizational issues. The safety culture approach does not, however, essentially differ from the previous traditions (Reiman & Oedewald, 2007). In many cases, safety culture is understood as a framework for developing organizational norms, values and working practices that ensure that all the known failure prevention practices are actually utilized. In essence, the safety culture approach is often used to prevent harmful variance in organizational-level phenomena such as values and norms. Organizational evaluation in the third era of safety enlarged the focus to ensuring the measures to identify, prevent and mitigate human as well as organizational errors. Furthermore, an important addition in this era was the increasing focus on reviewing measures aiming at promoting safety and a safety culture.

The techniques, tools and practices that are used for managing risks have accumulated over time. At the same time, technological innovations have changed the logics of the sociotechnical system as well as the way of carrying out work in the system. Organizational structures, safety systems, procedures and working practices have become so complex that they are creating new kinds of threats for reliable functioning of organizations (Perrow, 1984; Sagan, 1993). For this reason, safety researchers have started to develop new approaches for analysing and supporting human and organizational reliability and the overall safety of the system. The fourth era of safety science strives towards a more realistic and comprehensive view of organizational activity.

The different ages coexist in organizations as well as the research and development field. Also, many of the methods originally developed for an earlier age have been adopted in the previous eras. Thus it is important to always consider the assumptions that underlie each method or tool that is being used.

2.2 Human error approaches

The impact that employees' actions and organizational processes have on operational safety became a prominent topic after the nuclear disasters at Three Mile Island (TMI) in 1979 and Chernobyl in 1986. These accidents showed the nuclear power industry that developing the reliability of technology and technical barriers was not enough to ensure safety. Reason (1990), and many others, have stated that accidents take place when organizational protective measures against human errors fail or are broken down. To facilitate the handling of human and organizational errors, researchers and con-

sultants have developed a variety of analysis models. These enable human errors to be categorised on the basis of their appearance or the information processing stage at which they took place. Reason (2008, p. 29) notes that errors can be classified in various ways based on which of the four basic elements of an error is emphasized:

- the intention
- the action
- the outcome
- the context.

Approaches that focus on (human) errors have prevailed in research, management and training practices to date. Thus many organizational safety evaluation processes seek to identify how the possibility of human errors is handled in the risk analysis, training courses and daily practices. In fact, in the nuclear industry, the entire concept of "human performance" is sometimes understood as error prevention programmes and techniques. It is important that the organizations and employees understand the possibility of failure in human activities and that they prepare themselves for it. The models developed for the identification and prevention of human errors have undoubtedly led to positive results in many of the organizations in which they have been applied. However, they have not done away with the fact that humans and organizations continue to be the number one cause of accidents, as shown by the statistics. It seems fair to say that organizational safety is much more than the ability to avoid errors. This should reflect the organizational evaluations as well.

Woods et al. (1994, p. 4) lists issues that complicate the human contribution to safety and system failure, and makes the simple concept of human error problematic:

- the context in which incidents evolve plays a major role in human performance,
- technology can shape human performance, creating the potential for new forms of error and failure,
- the human performance in question usually involves a set of interacting people,
- the organizational context creates dilemmas and shapes trade-offs among competing goals,
- the attribution of error after-the-fact is a process of social judgment [involving hindsight] rather than an objective conclusion.

The list above shows why safety work benefits from a systemic perspective. The performance of an individual worker is affected by the technology, the social climate and the conflicting demands of the situation, as well as the way the worker interprets and makes sense of these "factors". This suggests that safety evaluations should consider these elements together rather than as individual safety factors.

2.3 Open systems and organizational factors

Approaches based on systems theory have been used in organizational research since the 1950s and 60s (see, e.g., Katz & Kahn, 1966). Systems theory posits that an organization is an open system with inputs, outputs, out-

comes, processes and structure (a transforming mechanism) and feedback mechanisms (see Figure 2.2). Inputs flows can be in the form of energy, materials, information, human resources or economic resources. The system's ability to self-regulate based on the selection of environmental inputs is emphasized in the open systems theory. The system must be able to adapt to its environment as well as to meet its internal needs (for integration, role clarity, practices, etc.) (Burrell & Morgan, 1979; Scott, 2003; Harrison, 2005). Outputs include the physical products or services, documentation, etc. Outcomes of the system are, for example, productivity of the system, job satisfaction, employee health and safety. The feedback mechanisms are used for the self-regulation of the system (Harrison, 2005). The interactions of the system and its environment are considered mostly linear and functionalistic (serving some specific purpose or need).

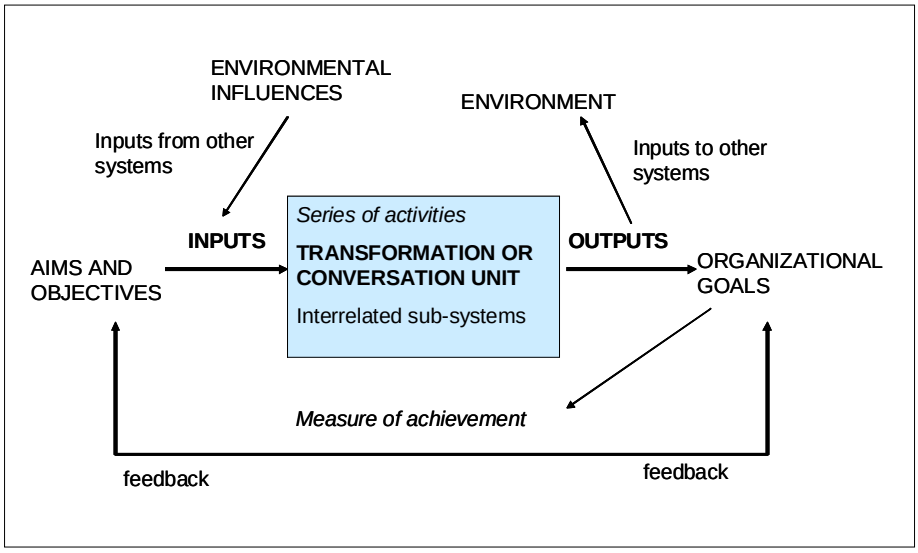

Figure 2.2. Simplified model of an open system (Mullins, 2007).

The organization can also be perceived as being composed of numerous subsystems. The environment of each subsystem then contains the other systems as well as the task environment of the entire system, called a supra-system. Further, the inputs of any subsystem can partially come from the other subsystems, and the outputs influence the other subsystems as well as the overall task environment.

In open systems models, errors and subsequent accidents are considered to be mainly caused by deviations and deficiencies in information processing, in the available information, or in the motivational and attitudinal factors of the decision makers. Collective phenomena such as group norms or values were also introduced as a potential source of errors (Reiman, 2007). An open system is a functional entity where accurate information from the environment as well as its internal functioning is important for its long-term survival. Homeostasis is the aim of the system, and all changes are initiated by inputs and feedback from the environment.

Organizational development and evaluations based on systems theory emphasises issues that differ from those highlighted by the error-oriented approaches. The error-oriented approaches aim to restrict and mitigate the negative variation in human activities. Research that draws on systems theory studies focuses on how the feedback systems of organizations, the technical presentation of information and information distribution channels can be developed so that humans can more easily adopt the correct measures. Task analysis is a popular tool used to model work requirements, task distribution between humans and technology, and information flow in different kinds of situations. The basic notion is that errors provide feedback on the functioning of the systems, and that feedback enables the activities to be adjusted. Most of the advanced event analysis methods are based on systemic models.

A weakness in systems thinking in the organizational context is that it sometimes puts too much emphasis on the functional, goal-related aspects of organizations and their attempt to adapt to the requirements of their environment. In practice, organizations often engage in activities that seem non-rational: politics, power struggle and 'entertainment'. With hindsight, such activities may have led to useful new ideas or solutions to problems. At other times, organizations may face problems because they use methods and thought patterns that have traditionally worked well but are no longer suitable due to changes in the environment. Internal power conflicts and lack of focus on important issues can also cause safety consequences. This is why the 'non-rational', emotional and political sides of organizational activities should not be excluded from organizational evaluations or management theories. Furthermore, systems thinking often takes the boundaries between e.g. the organizational system and its environment (which is considered another system) for granted. Systems thinking has formed the basis for the organizational culture approach, which pays more attention to the internal dynamics of organizations (Schein, 2004) as well to the socially interpreted and actively created nature of the organizational environment (Weick, 1995).

The sociotechnical approach to safety science emphasizes the internal dynamics of the organization as well as its interaction with the environment. Rasmussen (1997) has presented a multi-level model of a socio-technical system, with various actors ranging from legislators, over managers and work planners to system operators. The sociotechnical system is decomposed according to organisational levels. These levels have traditionally been objects of study within different disciplines, which should be better integrated. Rasmussen argues that in order to control safety it is important to explicitly identify the boundaries of safe operation, make them known to the actors and give them an opportunity to learn to cope with the boundaries. It is noteworthy that the aim is in giving people the resources to identify and cope with the demands of their work, not constrain it with excess of rules and barriers (Rasmussen, 1997; cf. Hollnagel, 2004).

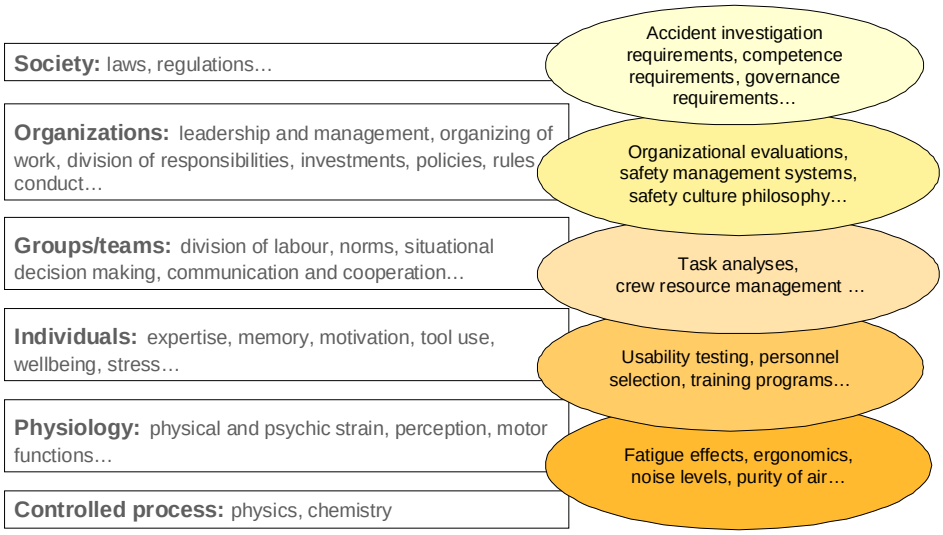

Figure 2.3. Levels of a sociotechnical system with examples of safety tools and methods that are applied in the various levels, adapted and modified from Rasmussen (1997) and Reiman and Oedewald (2008)

In this report the focus is on the organizational level of the sociotechnical system and its evaluation. Nevertheless, the requirements and constraints coming from the levels above and below the organizational level have to be taken into account. Since every level of the sociotechnical system has its own phenomena and logics of functioning, the challenge for evaluation is to take all the levels into account when considering the organizational level. For example, group-level phenomena such as communication and formation of norms influences the organizational performance to a great degree. Further, when organizing work and dividing responsibilities, the expertise of individual persons has to be taken into account, as well as the physiological limitations that people have. At the level of the society it is important to recognize the constraints and requirements that affect the ability of the organization to survive in its environment. Regulatory demands, cost pressures and public opinion are among the things that reflect on the organizational-level solutions.

The concept of *safety culture* bears strong resemblance to the open systems theory and its refinements (such as the organizational culture theory). The term was introduced in the aftermath of the Chernobyl nuclear meltdown in 1986 (IAEA, 1991). It was proposed that the main reasons for the disaster and the potential future accidents did not only include technical faults or individual human errors committed by the frontline workers. The management, organization and attitudes of the personnel were also noted to influence safety for better or for worse. The impact of the safety climate in the society was brought out as well. A proper “safety culture” was quickly required by the regulatory authorities, first in the nuclear area and gradually also in other safety-critical domains. The role of management in creating and sustaining a safety culture was emphasized.

The roots of the safety culture concept lie in the wider concept of *organizational culture*[1]. The culture concept was originally borrowed from the structural-functional paradigm of the anthropological tradition (Meek, 1988). This paradigm relies heavily on the organism metaphor for the organization and on the social integration and equilibrium as goals of the system. These characteristics were also found in the earliest theories of organizational culture (Reiman, 2007). Only shared aspects in the organization were considered part of the culture. These theories of organizational culture had a bias toward the positive functions of culture in addition to being functionalist, normative and instrumentally biased in thinking about organizational culture (Alvesson, 2002, pp. 43-44). Culture was considered a tool for the managers to control the organization. The safety culture concept seems to be derived from this tradition of organizational culture (cf. Cox & Flin, 1998; Richter & Koch, 2004).

The third era of safety science has produced many usable approaches for organizational evaluation when the target is some combination of human and organizational factors. These include:

- safety management system audits
- safety culture evaluations
- organizational culture studies
- peer reviews of, e.g., human performance programs, utilization of operational experience
- usability evaluations of control rooms and other critical technological working environments
- qualitative risk assessment processes.

A challenging issue is the evaluation of the organization as a dynamic complexity and not merely an aggregate of the above-mentioned factors. The fourth era of safety has shifted away from factor-based thinking.

2.4. Fourth era of safety; resilience and adaptability

The fourth era of safety science puts emphasis on anticipating the constantly changing organizational behaviour and the ability of the organization to manage demanding situations. The basic premise is that even in the highly controlled and regulated industries it has to be acknowledged that unforeseen technological, environmental or behavioural phenomena will occur. Accidents do not need to be caused by something failing; rather, unsafe states may arise because system adjustments are insufficient or inappropriate (Hollnagel, 2006).

Eliminating the sources of variability is not an effective and sufficient strategy in the long run. Performance variability is both necessary and normal. The variability of human performance is seen as a source of both success and failure (Hollnagel, 2004; Hollnagel et al., 2006). Thus safety management should aim at controlling this variance and not at removing it completely.

[1] For the history of the concept and various definitions and operationalizations of organizational culture, see e.g., Alvesson (2002) and Martin (2002).

The challenge is to define what knowledge and other resources the organization needs in order to be able to steer itself safely and flexibly both in routine activities and exceptional situations. Woods and Hollnagel (2006) argue that safety is created through proactive resilient processes rather than reactive barriers and defences. These processes must enable the organization to respond to various disturbances, to monitor its environment and its performance, to anticipate disruptions, and to learn from experience (Hollnagel, 2008). This is made challenging by the fact that the vulnerabilities are changing in parallel with the organizational change. Some of the organizational change is good, some of it bad. Organizational evaluations based on the three first eras of safety were static by nature. They aimed at guaranteeing that nothing has changed, and that all the safety measures are still in place. They did not acknowledge the inherent change of sociotechnical systems and the fact that yesterday's measures may be today's countermeasures.

The definition of organizational culture has been revised in less functionalistic terms (see e.g. Smircich, 1983; Hatch, 1993; Schultz, 1995; Alvesson, 2002; Martin, 2002). In contrast to the functionalistic theories of culture prevalent in the third era of safety, the more interpretive-oriented theories of organizational culture emphasize the symbolic aspects of culture such as stories and rituals, and are interested in the interpretation of events and creation of meaning in the organization. The power relationships and politics existing in all organizations, but largely neglected by the functionalistic and open systems theories, have also gained more attention in the interpretive tradition of organizational culture (cf. Kunda, 1992; Wright, 1994b; Vaughan, 1999; Alvesson, 2002). Cultural approaches share an interest in the meanings and beliefs the members of an organization assign to organizational elements (structures, systems and tools) and how these assigned meanings influence the ways in which the members behave themselves (Schultz, 1995; Alvesson, 2002; Weick, 1995).

Interpretation and *duality* (cf. Giddens, 1984) of organizational structure, including its technology, have been emphasized in the recent theories of both the organization and the organizational culture. Orlikowski (1992, p. 406) argues that "technology is physically constructed by actors working in a given social context, and technology is socially constructed by actors through the different meanings they attach to it". She also emphasises that "once developed and deployed, technology tends to become reified and institutionalized, losing its connection with the human agents that constructed it or gave it meaning, and it appears to be part of the objective, structural properties of the organization" (Ibid, p. 406). Creating meanings is not always a harmonious process; power struggles, opposing interests and politics are also involved (Alvesson & Berg, 1992; Sagan, 1993; Wright, 1994b; Pidgeon & O'Leary, 2000). Weick (1979, 1995) has emphasized that instead of speaking of *organization*, we should speak of *organizing*. What we perceive as an organization is the (temporary) outcome of an interactive *sense-making* process (Weick, 1979). Even the heavily procedural and centralized complex sociotechnical systems adapt and change their practices locally and continually (cf. Bourrier, 1999; Snook, 2000; Dekker, 2005).

Alvesson (2002, p. 25) points out that in the idea of culture as a root metaphor, "the social world is seen not as objective, tangible, and measurable but as constructed by people and reproduced by the networks of symbols and meanings that people share and make shared action possible". This means that even the technological solutions and tools are given meanings by their designers and users, which affect their subsequent utilization. It further means that concepts such as safety, reliability, human factors or organizational effectiveness are not absolute; rather, organizations construct their meaning and act in accordance to this constructed meaning. For example, if the organization socially constructs a view that the essence of safety is to prevent individuals - the weakest links in the system - from committing errors, the countermeasures are likely to be targeted at individuals and include training, demotion and blaming.

The fourth era of safety science has strong implications for organizational evaluation, both in terms of methodological requirements ("how to evaluate") as well as in terms of the significance of so-called organizational factors for safety ("why to evaluate"). Evaluation is no longer about finding latent conditions or sources of failure. Also, it is no longer about justifying the efficacy of preventative measures and barriers against human and organizational error or justifying that nothing has changed. Organizational evaluation has become an activity striving for continuous learning about the changing vulnerabilities of the organization.

We have emphasized the importance of considering the **organizational core task** in organizational evaluations. The organizational core task denotes the shared objective or purpose of organizational *activity* (e.g. guaranteeing safe and efficient production of electricity by light boiling water nuclear reactors). The physical object of the work activity (e.g. particular power plant, manufacturing plant, offshore platform), the objective of the work, and the society and environment (e.g. deregulated electricity market, harsh winter weather) set constraints and requirements for the fulfilment of the organizational core task. Different industrial domains have different outside influences, e.g. the laws set different constraints on the organization and the economic pressures vary. Also different suborganizations or units in one company have different functions. The contents of the work, the nature of the hazards involved in their daily activities, the basic education of the personnel and the role for the overall safety in the company differs. The core task of the organization sets demands (constraints and requirements) for the activity and should be kept in mind when making evaluations of the organizational solutions or performance.

3. Reasons for evaluating safety critical organizations

Harrison (2005, p. 1) summarizes the objective of diagnosing (i.e. evaluating) organizations: "In organizational diagnosis, consultants, researchers, or managers use conceptual models and applied research methods to assess an organization's current state and discover ways to solve problems, meet challenges, or enhance performance … Diagnosis helps decision makers and their advisers to develop workable proposals for organizational change and improvement." Thus organizational evaluation aims at improving organizational performance by gaining information about the current state and reasons for problems, as well as functioning of the system. Safety criticality brings additional importance to organizational evaluation. First, organizational design for safety is challenging due to the complexity and multiple goals of the system. Second, organizational culture has an effect on how safety is perceived and dealt with in safety-critical organizations. Third, the perception of risk among the personnel at all levels of the organization may be flawed in dynamic and complex organizations. Finally, a well-functioning organization can also act as a "safety factor".

3.1 Designing for safety is difficult

Multiple goals in a complex system

As was illustrated in the Introduction to this report, nuclear power plants are complex sociotechnical systems characterised by specialization, the tool-mediated nature of the work, and reliance on procedures, as well as complex social structures, technological complexity and changes. Furthermore, they have to simultaneously satisfy multiple goals. In order to be effective, an organization must be productive, as well as financially and environmentally safe. It must also ensure the personnel's well-being. These goals are usually closely interlinked. A company with serious financial difficulties will have trouble investing in the development of safety and may even consider ignoring some safety regulations. Financial difficulties cause insecurity in employees and may reduce their commitment to work and weaken their input. This will have a further impact on financial profitability or the reliability of operations. Occupational accidents are costly for companies and may lead to a decline in reputation or loss of customers. Economic pressures and striving for efficiency can push the organizations to operate closer to the boundaries and shrink unnecessary slack. According to Lawson (2001), over recent years, several serious accidents in various domains have been caused by time-related matters such as pressure for increased production, lack of maintenance, shortcuts in training and safety activities, or overstressed people and systems. Focusing on different types of safety (occupational safety, process safety, security) can create goal conflicts as well. The nature of different

"safeties", together with other goals of safety-critical organizations, adds to their social and technological complexity.

Technological and social changes
Changes in technology, public opinion, or task environment (e.g. competition, deregulation, regulation) can create new risks as well as opportunities for safety-critical organizations. The environmental changes are often compensated by organizational changes in the structure, practices, technology or even culture. These organizational changes can also be made in conjunction with the introduction of new management philosophies or technological innovations. Often, technological innovations precede a corresponding development in management theory or regulation (e.g. in the case of nanotechnology or early use of radiation), making technological and social change asynchronous. This can create new unanticipated hazards in the organization.

Another source of change is the ever-ongoing internal development of the organizational culture; "the way of doing work around here". Organizational culture is never static. Despite them sometimes looking static to the insiders, in reality, the safety-critical organizations are uniquely dynamic and constantly changing and adapting to perceived challenges and opportunities. As mentioned, changes that are seen in the task environment of the organization reflect on the organization. At the same time, technology and people age. This creates new organizational demands as well as potentially new technical phenomena. Finally, routines and practices develop over time even without any noticeable outside pressure or demand for change. People optimize their work and work practices, they come up with shortcuts to make their work easier and more interesting, they lose interest in the commonplace and reoccurring phenomena, and they have to make tradeoffs between efficiency and thoroughness in daily tasks (Hollnagel, 2004). These social processes are illustrated in more detail in Section 5 of this report.

Evolving knowledge on safety
As illustrated in Figure 2.1 and Table 2.1, organizational theory and safety science have progressed in their over-one-hundred year's history. The knowledge of what is safety and how it is achieved has also developed. The safety measures taken in high-hazard organizations a couple of decades ago are not sufficient today. The focus of the safety work has changed from component-based risk control to organizational resilience and safety. Today's organizations need to systematically ensure the reliability of the components on the one hand, and, on the other hand, understand the emergent nature of safety. Designing both safety perspectives in organizational structures and processes is demanding. Usually, outside influences are needed in order to get the new views into organizations.

3.2 Organizational culture affects safety

As we argued in Section 2, complex sociotechnical systems can be conceptualized as organizational cultures, where the focus is on systems of meaning and the way these are constructed in action and in interaction with people and technology. Organizational culture can be considered a "root metaphor"

(Smircich, 1983) for the organization - a way of looking at the phenomenon of organization and organizing (cf. Weick, 1995).

Organizational culture has a significant effect on nuclear safety. Organizational culture "affects"[2] the way hazards are perceived, risks evaluated and risk management conducted. "Known and controlled" hazards have caused plenty of accidents since they were no longer considered risky and attention was directed elsewhere. Further, the perceptions of hazards can further vary between subcultures, as can the opinions on the best countermeasures. For example, maintenance personnel often have different opinions on the condition and safety of the plant than the management or engineering levels. Weick has emphasized that "strong cultures can compromise safety if they provide strong social order that encourages the compounding of small failures" (Weick, 1998, p. 75; cf. Sagan, 1993, pp. 40-41) and further, drawing on the seminal work of Turner (1978), that "organizations are defined by what they ignore – ignorance that is embodied in assumptions – and by the extent to which people in them neglect the same kinds of considerations" (Weick, 1998, p. 74). One of the main reasons for regularly conducting organizational evaluations is the tendency of an organization to gradually drift into a condition where it has trouble identifying its vulnerabilities and mechanisms or practices that create or maintain these vulnerabilities. Vicente (2004, p. 276) writes:

> "Accidents in complex technological systems don't usually occur because of an unusual action or an entirely new, one-time threat to safety. Instead, they result from a systematically induced migration in work practices combined with an odd event or coincidence that winds up revealing the degradation in safety that has been steadily increasing all the while".

Organizational culture defines what is considered normal work, how it should be carried out, what the potential warning signals are, and how to act in abnormal situations. Cultural norms define the correct ways to behave in risk situations and the correct ways to talk about safety, risks or uncertainty. This influences the perception of risks and hazards, as well as the feeling of individual responsibility. The cultural standards and norms create an environment of collective responsibility, where the individual's main responsibility is not one of making decisions but one of conforming to the collective norms.

Organizational culture changes slowly, and changes are usually hard to notice by the insiders. This can lead to unintended consequences of optimizing work practices or utilizing technology differently than originally planned. Further, external attempts to change the culture are often met with resistance, or the ideas and methods are interpreted within the culture and transformed into an acceptable form.

One way of illustrating the influence of organizational culture on safety is with the Johari window that has been used to illustrate the various facets of

[2] The term "affect" is in brackets because, strictly speaking, the personnel's perceptions of the hazards are an element of organizational culture

personality. Figure 3.1 illustrates four sides or facets of organizations; open, hidden, blind and unknown. These facets are partly overlapping and partly exclusive. All organizations have all the facets to varying degrees. The extent of overlap and exclusiveness of the four facets of the organization are important empirical questions (as well as reasons for organizational evaluation) in terms of safety. For example, how much of its private self does the organization willingly expose to outsiders (i.e. how large is the open side window)? And how much of its behaviour, norms and conceptions does the organization itself perceive, and how much is implicit and so much taken for granted that it is ignored (how large are the blind and unknown sides)? Finally, what aspects is the organization is trying to conceal from outsiders, and are there some sides of the organization that are visible to outsiders but the organization does not acknowledge them (the blind side)?

	Known to self	Not known to self
Known to others	**Open side** Characteristics and tendencies of the organization that outsiders are able to perceive and that the organizational members are able and willing to express	**Blind side** Characteristics and tendencies of the organization that the personnel are unaware of or do not want to consider explicitly with anyone, but which show in their behaviour or organizational outcomes
Not known to others	**Hidden side** Characteristics and tendencies of the organization that are known to the personnel and considered as being important to the private organizational identity	**Unknown side** Characteristics and tendencies of the organization that the personnel are unaware of or do not want to consider explicitly with anyone and which have no visible manifestations or outcomes yet

in what the organization knows about itself, what it wants to publicly express or hide, and what it does not know about its own behaviour.

It should be noted that Figure 3.1 is only an aggregate figure or a mean score of the perceptions of the personnel throughout the entire organization. It can be argued that each subculture (unit, function, or branch) in an organization has its own Johari window (as does each individual!). Every subculture has an identity that defines who they are and how they interact with “outsiders” (who are mostly other subcultures from the same organization, see Section 5 of this report). Nevertheless, Figure 3.1 can act as a heuristic tool in reminding the evaluator of the different facets of the organization and of the importance of considering the validity and truthfulness of both the organizational self-image as well as its projected image.

The organizational facets also influence how the organization responds to the results of the organizational evaluation. For example, if the results concern a side of the organization that the members do not recognise (the un-

known or blind side), they may not believe in the validity of the findings. In a similar manner, results concerning the hidden side of the organization may be denied altogether.

There are several social mechanisms affecting the dynamics of what is known and what is not known, and what is accepted and what is not accepted in any given organization. We will return to these processes and their influence on safety in more detail in Section 5. Next we only briefly raise a couple of organizational tendencies related to risk perception that are relevant for organizational evaluation.

3.3 Perception of risk may be flawed in complex organizations

Risk perception refers to the way the personnel judge the characteristics and severity of hazards. Risk in an objective sense means the product of the probability and consequence of the hazard, taking into account the conditions and safety barriers, which both reduce the probability and mitigate the consequences. Risk as a subjective perception means how the hazards, barriers and conditions are conceptualized and interpreted.
Risk perception is influenced by the employee's duties, as well as his or her department and work role (ACSNI, 1993). Thus people may observe risks in their organization in systematically different ways. The expertise needed to work in a nuclear power plant is often described in general terms such as radiation protection, quality systems and introductory nuclear physics. The extent to which the workers should have specific technical or skills and how much each worker should understand the overall system safety is not solved. Organizations seem to develop heuristics in relation to which personnel groups should possess detailed knowledge on some equipment and which positions require a system-level understanding of the nuclear process and safety mechanisms. It is not very clear, however, what the safety impacts of knowing or not knowing these theoretical issues are, and how much everyone should know of the nuclear process at minimum.

> In the Challenger case, one of the challenges affecting decision making was that the problem with the O-rings was multidisciplinary. Still, both Morton Thiokol engineers as well as NASA engineers had very special, and narrow, fields of expertise. Expertise from both the Materials and Properties Lab (on the effect of temperature on the rubber O-ring) and the Structures and Propulsion Lab (on joint dynamic) were needed in order to understand how resiliency affected redundancy in the field joints' primary and secondary two O-rings. (Vaughan, 1996, p. 360)

Although, generally speaking, employees may understand that operations include risks, it may be difficult to see how one's own work or work group affects risks. Commitment to safety may be emotional, without fully understanding the practical implications and how to ensure safety in one's own tasks.

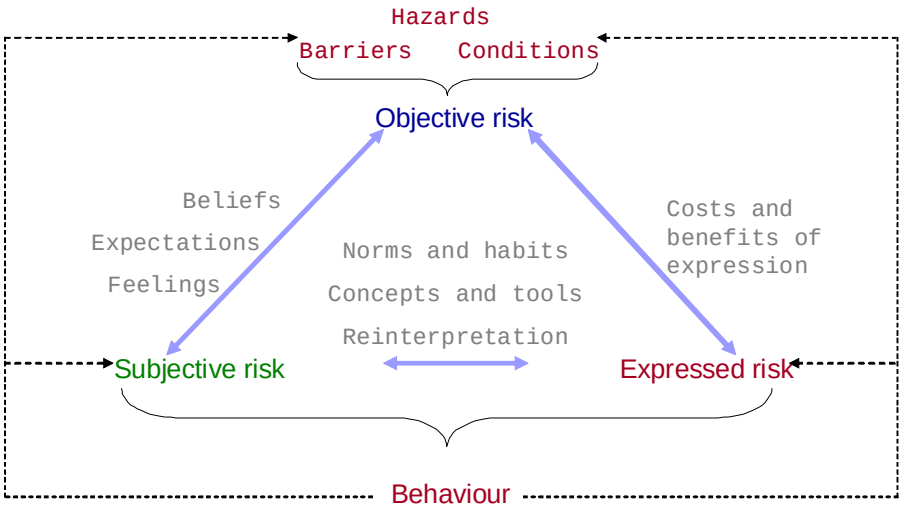

Figure 3.2. It is important to separate the highly interactive concepts of objective, subjective and expressed risk.

Figure 3.2 illustrates the interaction between risks, behaviour and subjective conceptions (cf. Waring, 1996). Individuals act in context, which includes both the culture ("norms and habits" as well as "concepts and tools" in Figure 3.2) and the particular situation (hazards, barriers and other conditions which define the objective risk in Figure 3.2). Each person perceives the hazards of a situation according to his/her skills, experience and mental states, including the beliefs and expectations concerning the particular task and his/her need to conform to the group norms and culture. Furthermore, situational factors such as fatigue or emotional state affect the feeling of subjective risk. Behaviour is an outcome of subjective and expressed risk (expressed risk is, strictly speaking, already 'behaviour') combined with situational possibilities for action (more about this in Section 5). This behaviour, in turn, influences the objective risk, either by reducing or aggravating it (e.g. by ignoring or belittling its seriousness).

The basic message of Figure 3.2 is that only such risks that are subjectively perceived and dared to admit publicly can be managed. The same goes for many evaluation methods; if evaluation relies solely on insider views, only such risks that the personnel perceive and are willing to admit can be found. The interaction of subjective and objective risk leads to the conclusion that even the objective risk is a subjective and social "product". The risk calculations, risk management tools, pre-job briefings and probabilistic analyses are useless if the personnel do not believe in the risks.

When people form expectations, they assume certain sequences of action are likely to happen (Weick & Sutcliffe, 2007, p. 41). These expectations and the associated assumptions are embedded into organizational roles, routines, rules, norms and strategies. Expectations create orderliness and predictability, and offer guides for performance and interpretation. However, expectations guide our attention and search for evidence, thus making it easier to confirm the accuracy of our original expectations by neglecting contradictory information. Expectations can undermine reliable, resilient performance

because they encourage confirmation seeking, reliance on existing categories, and simplification (Weick & Sutcliffe, 2007, p. 41). Under pressure, people are more likely to search for confirming information and ignore information that is inconsistent with their expectations. Organizations must continuously work to override the typical human tendencies to seek confirmation and avoid disconfirmation (Weick & Sutcliffe, 2007).

The expression of risk is influenced by the feedback from previous expressions of risks; whether or not colleagues and management have been receptive to them. The norms that create expectations on what people think others want to hear influence the risk expression in a form of self-censorship. For example, a worker who always points out risks and uncertainties may be labelled a troublemaker or "bird of ill omens". Another norm affecting risk expression in the other direction is the perceived need to upgrade expressed risk in order to get management attention. This, in turn, can lead to a cultural norm where the basic assumption is that people are always exaggerating the risks, and the feeling of subjective risk by whoever is listening is subsequently diminished.

When the subjective risk and expressed risk are not in line, the phenomenon is called cognitive dissonance. Whichever is more plausible and fits better with one's self-image and social identity - subjective risk or expressed risk - is taken as a foundation for reinterpreting the other (cf. Weick, 1995). Thus, if, for example, no one expresses a risk the worker subjectively feels, and this behaviour is in line with the norms of one's group, the worker gradually starts to internalize his expression and gradually believe that the risk is as he publicly expressed it (reinterpretation in Figure 3.2).

There are certain characteristics of work and hazard types that affect the subjective perception of risk (Reiman & Oedewald, 2008; ACSNI, 1993; Glendon et al., 2006). The following characteristics facilitate the underestimation of risk:
- recurring and "normal" events, phenomena or situations that have not been dangerous in the past
- events, situations or phenomena that one feels one has some control over
- tasks or events that one has decided to take part in
- tasks or events where there is a material or emotional reward
events or phenomena that are personal and where the hazards are targeted only to oneself
- situations, events or phenomena that one's own work group and peers do not consider risky

The following characteristics facilitate the overestimation of risk:
- abstract phenomena, such as radiation
- events or phenomena that one cannot control, e.g., sitting in an airplane or taxi as opposed to driving a vehicle by one's own
- tasks or events that one has not chosen freely
- event or phenomena of which it is easy to remember examples, due to, e.g., media attention or personal experience
- events with low probability and high consequence (disasters)
- events with low noticeable benefits
- events, situations or phenomena that one's own work group and peers consider risky

Organizations should determine the kinds of risks in which human activities must be restricted using technology or procedures and those that call for 'education' - that is, ensuring that employees have a concrete understanding of the risk and the uncertainties, as well as a clear picture of the connection between the hazards and their own work. Organizational evaluation should aim at illustrating the relationship and possible discrepancies between subjective, objective and expressed risk.

3.4 Organization can be a safety factor

Approaches to safety in safety-critical organizations seem to differ in their assumptions about the nature of organization: is organization a safety factor or a risk factor? The easy answer is that it is both, but still the methods and approaches seem to lean one way or the other. The proponents of the Normal Accident Theory (NAT) imply that the complexity of modern organizations, combined with typical human characteristics, makes them inherently unreliable (Perrow, 1984; Sagan, 1993). The advocates of the High Reliability Organization (HRO) theory propose that organizational management and leadership is able to overcome both human and organizational tendencies (see above).

Table 3.1. Competing perspectives on safety with hazardous technologies (Sagan, 1993, p. 46)

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

Sagan (1993) presents an overview of the main differences between HRO and NAT (Table 3.1). He (Ibid., p. 45) notes that many of the "specific con-

ditions that the high reliability theorist argue will promote safety will actually reduce safety according to the normal accidents theorists." For example, redundancy can make the system more complex and opaque. Furthermore, according to Sagan (1993), some of the characteristics identified by HRO as necessary for safety are considered impossible to achieve by NAT. For example, learning is hampered by denial of responsibility and reconstruction of the actual events to fit with the prevailing image of operations. Sagan (1993, p. 13) notes that the authors within each school by no means agree on all details concerning organizational safety.

HRO theorists have proposed five main characteristics of high-reliability organizations that promote mindful performance: sensitivity to operations, preoccupation with failure, reluctance to simplify, deference to expertise and resilience (Weick & Sutcliffe, 2007). HROs' determined efforts to act mindfully are the cornerstone of the success and their ability to manage the unexpected. They organize themselves in such a way that they are better able to notice the unexpected in the making and halt its development, contain it, or restore the system swiftly if the unexpected breaks through the containment. The five characteristics are elaborated next, based on Weick and Sutcliffe (2001, 2007).

Preoccupation with failure
HROs are focused on predicting and eliminating catastrophes rather than reacting to them. These organizations constantly entertain the thought that they may have missed something that places the organization at risk. HROs treat any lapse as a symptom that something may be wrong with the system, something that could have severe consequences if several separate small errors happened to coincide. They encourage reporting of all errors, particularly near misses. This focus on near misses differentiates HROs from other well functioning organizations. In HROs there are fewer barriers to data collection, less liability, and greater opportunity to analyze recovery patterns. HROs are wary of the potential liabilities of success, including complacency, the temptation to reduce margins of safety, and the drift into automatic processing. Worries about failure are functional because there are limits to foresight and success narrows this foresight further. Weick and Sutcliffe (2007, p. 53) point out that success is such a heady feeling that it takes a *preoccupation* with failure to keep it (i.e. the possibility of failure) in awareness.

Reluctance to simplify
HROs take deliberate steps to create more complete and nuanced pictures of what they face and who they are as they face it. They understand that the world they face is complex, unstable, unknowable, and unpredictable. Simplification is the essence of organizing (Tsoukas, 2005) and, as such, HROs have to actively differentiate and complicate their simplifications. They understand that their systems can fail in ways that have never happened before and that they cannot identify all the ways in which their systems could fail in the future. All personnel are encouraged to recognize the range of things that might go wrong and not assume that failures and potential failures are the result of a single, simple cause.

Sensitivity to operations
HROs are attentive to the frontline, where the real work gets done. Sensitivity to operations is about the work itself, about seeing what we are actually doing regardless of what we were supposed to do based on intentions, designs, and plans. This also means avoiding the drawing of a line between qualitative and quantitative knowledge. Maintaining "situational awareness" is important for staff at all levels because it is the only way anomalies, potential errors, and actual errors can be quickly identified and addressed. The "big picture" in HROs is less strategic and more situational than is true of most other organizations. Near misses are not viewed as proof that the system has enough checks in it to prevent errors because that approach encourages complacency rather than reliability. Instead, near misses are viewed as opportunities to better understand what went wrong in earlier stages that could be prevented in the future.

Commitment to resilience
The hallmark of an HRO is not that it is error-free but that errors do not disable it. HROs pay close attention to their ability to quickly contain errors and improvise when difficulties occur. Thus the system can function despite setbacks. An HRO assumes that, despite their anticipatory activities and considerable safeguards, the system may fail in unanticipated ways. They prepare for these failures by training staff to perform quick situational assessments, working effectively as a team that defers to expertise, practicing responses to system failures, and imagining worst-case conditions. Resilience demands deep knowledge of the technology, the system, one's coworkers, and oneself. Resilience involves (1) the ability to absorb strain and preserve functioning despite the presence of adversity; (2) an ability to recover or bounce back from untoward events; and (3) an ability to learn and grow from previous episodes of resilient action.

Deference to expertise
HROs cultivate a culture in which team members and organizational leaders defer to the person with the most knowledge relevant to the issue they are confronting. The most experienced person (in terms of, e.g., tenure or age) or the person highest in the organizational hierarchy does not necessarily have the information most critical to responding to a crisis. Decisions are made at the frontline and decision-making processes vary depending on the degree of urgency. Decisions come from the top in normal situations, and during critical conditions authority migrates to the member with the most expertise without regard to rank.

How can these two perspectives lead to such different conclusions about the safety of modern industrial organizations? Should we count on the organizations to provide a means to overcome human frailties, or should we instead try to promote individuals' personal responsibility for overcoming the organizational vulnerabilities and systemic biases? History has shown that the approach emphasizing the human as an irrational error-maker has not pro-

duced an adequate theory and practice for safety management. Dekker (2005, p. 79) argues that the tendency of psychology to attribute errors to irrationality or motivational factors of individuals (such as deliberately breaking rules) has led to neglect of organizational level issues such as cultural norms, organization processes and structure. Instead, the suggested remedies are usually more training or injunctions to follow rules.

> Vaughan (1996, p. 418) notes in relation to the Challenger accident that NASA exhibited most of the characteristics the HRO theorists postulate that a safe organization would. Their culture at that time "sounds very like the 'culture of reliability' that high-reliability theorists call for to assure uniform responses and predictability in time of crisis" (Vaughan, 1996, p. 418). Clearly the accident was not just bad luck either, nor was it an outcome of an evil wrongdoing individual. The accident was rooted in the culture of reliability at NASA, which had been functioning well up to the decisions leading to the accident.

One of the basic problems in many evaluation approaches comes from too narrow a definition of the proper actions of people and the effectiveness (including safety as well as efficiency) of organizations. Human error and compliance-oriented models seem to rely on the assumption that reliability is synonymous with avoiding errors or deviations of any kind. People are seen as a threat to safety because they may perform unexpected actions. This makes the *control of variation in human behaviour* one of the main challenges (though often only visible between the lines), which is a very problematic viewpoint. In modern working environments, the simplest tasks have been automated, leaving complex tasks that call for case-by-case analysis to humans (for example, recovery from technical failures when automation breaks down). The explanation for this is that humans are particularly capable of using their senses, emotions and social networks when operating in challenging environments. The variation, adaptability and innovation inherent in human activities enable complex organizations to carry out their tasks (cf. Hollnagel, 2004). More often than causing hazards, people carry out their duties exactly as they should in terms of their outcomes, fixing defects in technology, compensating for bad tool or work design, or stopping a dangerous chain of events based on intuition. This is why heavy constraints on normal human behaviour would most likely erode the activities of organizations and reduce work motivation.

Organizations in safety-critical fields must naturally try to carry out their duties in the right way, aiming at high quality and safety. Sometimes, however, the performance development and organizational evaluation could benefit more from a focus on the organization's strengths and daily work than a treatment of problems and exceptional situations. Especially when making inferences from the organizational evaluations and defining development initiatives, it is important to consider both actions that will promote and maintain the strengths of the organization as well as actions that will address and develop the weak areas.

4. Common challenges of evaluating safety critical organizations

Safety-critical organizations strive to predict the possible ways in which the system might face an accident. The concept of Design Basis Accidents (DBA) is used in the nuclear field to denote those accidents that are anticipated to be possible in the given design. DBA is a postulated accident that a nuclear facility must be designed and built to withstand, without loss to the systems, structures, and components necessary to ensure public health and safety. Beyond Design Basis Accidents are those accidents which have not been anticipated or are considered to be extremely improbable. After the accident scenarios have been defined, various physical, functional and symbolic barriers (Hollnagel, 2004) are set in place to prevent the event from developing into an accident. Far beyond the design basis accidents, mitigation of a radioactive release into the environment is the primary goal. Thus this kind of accident prediction is based on two principles: First, experience from various accidents is accumulated and barriers are set in place to prevent their recurrence. Second, risk analysis and various failure analyses are utilised in order to predict the mechanisms of possible system failure. Organizational evaluations are needed to guarantee the efficacy of the preventative measures. When considering safety as an emergent property of the functioning of the complex sociotechnical system, the role of organizational evaluation gets more complicated - and yet even more important. In this Section, the typical challenges in organizational evaluation are illustrated.

4.1 Premises and focus of the evaluation

When deciding on the focus of the evaluation, one needs to balance between focus on details and oversight of the entire organization in the evaluation process (Reiman et al., 2008b). In order to do this the evaluator has to keep in mind the specific goal of the evaluation on the one hand and, on the other hand, the nature of the hazards that are being evaluated. If the goal is to get an overview of the entire organization in terms of its influence on nuclear safety in a world with limited resources, some concessions must be made on the details that will be tackled.

It is important that the premises and focus of the evaluation are made explicit for all. A broad assessment that only covers the surface features of the organization might very well be beneficial for the organization as long as they understand that they are only dealing with surface features. On the other hand, an in-depth analysis of some specific issue often needs to be put into a larger context before implementing solutions that might have an effect on other parts of the organization (Reiman et al., 2008b).

The focus of organizational evaluations is usually on some combination of the following elements:

- organizational structure
- resources, systems and tools
- programs (for, e.g., preventive maintenance, human performance improvement)
- documents, rules and instructions
- visible behaviour
- tidiness and the visible condition of the plant
- climate
- staff attitudes and norms
- safety and performance indicators
- work practices
- skill, knowledge and abilities.

It is typical in organizational evaluations that the interactions between the measured dimensions are not made clear, or that the evaluation only focuses on one or two organizational dimensions. In some evaluations, conclusions regarding the overall safety of the plant are made from a combination of findings from, e.g., tidiness of the plant, safety indicators and official systems and programs. The methods for deciphering the findings or analysing data are not made clear. In short, the evaluation is lacking a theoretical model of an organization, including the applied research methods for data gathering (cf. Harrison, 2005).

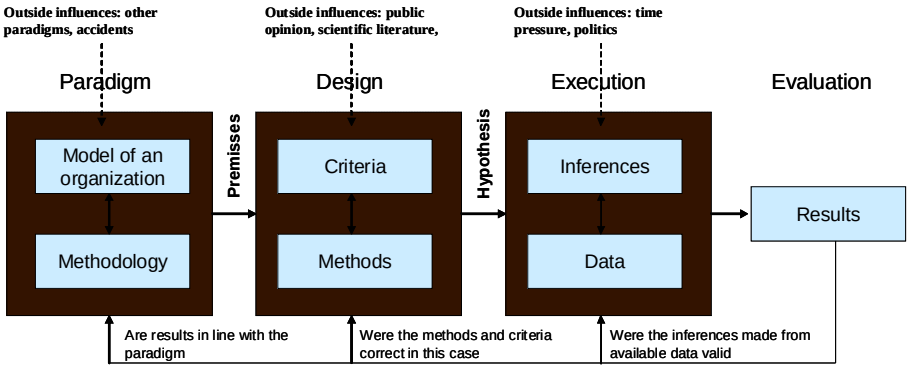

Figure 4.1. Organizational evaluation is influenced by the premises set by the paradigm used (implicit or explicit) in the evaluation.

Figure 4.1 illustrates how the evaluation paradigm influences the methods that are chosen, the focus and the criteria used in the evaluation, and subsequently, the data that will be gathered and the results achieved. The paradigm that is used in the evaluation can be either implicit or explicit. Everybody has a working theory on how organizations function and what issues are important in understanding them, as well as how to gain that understanding. We call this working theory the paradigm of evaluation (see left in Figure 4.1). Making this theory explicit enables one to reflect on the premises of the evaluation and compare the findings to those premises.

Power companies and the regulator both carry out various types of organizational evaluations. In these evaluations, more emphasis is still placed on the assessment of technical systems, structures and documents than on organiza-

tional performance (Reiman et al., 2008b). In order to understand the overall vulnerabilities of the system, there should be more work done to integrate the views. The technical solutions, organizational norms and values, and the workers' understanding of the overall task and the boundaries of safe activity should be analysed hand in hand because these organizational elements always affect each other. On the one hand, technical solutions affect the way people see their task and risks. On the other hand, the conceptions, norms and values of the personnel affect the way they utilize technology (see Section 5 of this report).

There has been a concern that the current strong focus on the importance of human and organizational factors may direct attention away from more traditional technical solutions to safety problems (Rollenhagen, submitted). According to Rollenhagen, strive for strong safety culture should never be an excuse for weak engineering. People, technology and organization together create safety (or accidents), and each of these three "factors" needs attention in safety management and organizational evaluations as well (Reiman et al., 2008b). Focusing on a safety culture does not mean trying to prevent people from causing harm to the reactor, or "safe-guarding the reactor against human error". A focus on human and organizational factors means that the influence of human performance on nuclear safety is considered at every level and task of the organization, including the people doing the technical design, the people managing the work and the people responsible for safety assessments, calculations and investment decisions.

4.2 Methods and techniques of evaluation

There are no step-by-step models of organizational evaluation (Harrison, 2005, p. 121). At least, not models that would be valid and offer a recipe for conducting the evaluation, analysing the data and making inferences in a way that all significant features of the organization are taken into account. Models and methods always direct attention to certain phenomena, and distract attention from other phenomena (see Figure 4.1). They already constrain choices about what to measure, and what to consider a good sign, what a bad sign, and what does not need consideration at all. For this reason, evaluations that are based on a single perspective or conducted by only one evaluator might be more internally consistent, but, at the same time, they might miss some crucial aspect or requirement of safe organization due to the fact that it is not included in the model the evaluator uses.

Katsakiori et al. (in press) have analysed the accident causation models and accident investigation methods. Their conclusion regarding the choice of method and the influence of models are also suitable for "safety investigation methods" and safety causation models:

> "when analyzing a specific accident, the mutual dependence between causation models and investigation methods must be taken into account. Models provide knowledge regarding the fundamental mechanisms which underlie the accident scenario and methods provide the necessary information to analyse the accident in a specific setting. However, the selection made on the former, restricts our selection on the latter, although there exist methods, which are not linked to a known accident causation model.

> The initial step for an investigator would be to select a particular model that fits him, which in turn guides him in selecting one of relevant methods. The choice of the particular method should be based on its particular advantages and limitations regarding the requirements … and can have a significant impact on the efficiency and effectiveness of an investigation because it can lead to conclusions about whether or not and how the method could meet the identified needs of the investigation. But the accident model and accident investigation method selection issues require attention. Aspects such as whether one seeks for a technical and theoretical understanding or is based on the contextual conceptions of the practitioners should be taken into consideration. Besides, the model and method selection should be tailored to the needs of the investigators (whom the findings should serve, his/her needs and ways of understanding).
>
> Since different models approach accidents in sometimes entirely different ways, methods linked to these models can provide us with only fragmentary information regarding the accident. It is therefore expected that using a combination of model-method pairs, rather than a single one, could provide a better and more reliable platform for the investigation and analysis of accidents."

Evaluation of the overall functioning of the organization has been considered demanding since simple methods and tools are rare and the validity of the various performance indicators is unclear. A comprehensive organizational evaluation requires integration of information from different sources and a well planned evaluation process. The most critical phase in the organizational evaluation is the understanding of what to look for, where and when, not the selection of the evaluation methods per se. Interviews, working climate surveys and descriptions of the actual work processes (e.g. those that can be seen in event reports) provide valuable information about the general challenges and help in creating possible risk scenarios. Furthermore, the subjective perceptions of the people working in these complex systems are indicators of the overall state of the organization.

When conducting an organizational evaluation, one usually has to use less complex study designs and methods than when conducting academic research. Furthermore, when making inferences from data, the evaluator needs to rely on experience and intuition in addition to scientific theories and methods of deduction (Harrison, 2005, p. 11). Still, the evaluator has to balance the requirements of scientific evaluation and judgments based on one's own background and personality. The balance concerns the evaluation design (questions that need answering) and execution (number of informants, timetable, and depth of the analysis) more than the selection and use of methods. The methods need to be scientifically valid and produce reliable and valid results. Furthermore, the evaluator needs to be competent in using the methods.

Applied social and behavioural sciences are not deterministic sciences. In fact, the entire field is still in its development stages, and few widely accepted and scientifically validated theories of human conduct in organiza-

tional settings exist. The theories that do exist seldom provide a means for making causal attributions or predicting behaviour. It is doubtful whether social scientific theories will ever be able to predict behaviour at the group or even individual level. At best, they can offer mechanisms and phenomena that help to explain certain organizational behaviour and make a hypothesis on the future course of events. Thus organizational evaluations can never provide a quantitative and precise measure of the safety level of the organization or a causal prediction of a future chain of events (i.e. activities leading to accidents or safety).

4.3 Evaluator's view of safety and human performance

The model of an effective and safe organization defines what is considered data and what criteria are used for the assessment (cf. Reiman & Oedewald, 2007). Often, this model is implicit in the assessor's mind. One of the challenges in defining criteria is that safety is a complex phenomenon that is not easy to define in measurable terms. Sometimes the definitions are simplistic in order to be able to more easily gather data on them, e.g. the number of workers spotted without adequate personal protective equipment (negative indicator of safety culture) or the number times a manager visits the shop floor (positive indicator of safety culture). The way the evaluator perceives safety and hazards shapes the choice of methods and, subsequently, the inferences that the evaluator makes from the data.

> Steele and Pariés (2008) have studied the safety beliefs in the aviation industry. They point out that some of the common assumptions about aviation safety [prevalent in the field] are either false or do not hold under certain conditions. They further argue: examples of the kind of assumptions we are referring to are: 'humans are a liability (and therefore automating the human out of the system makes it categorically safer)' or 'accidents occur as a linear chain of events' or 'following the procedures guarantees safety', etc. Many of the models and methods currently in use are based on these assumptions, and, therefore, they do not meet the needs of the modern aviation industry – they may in fact prevent further progress. … Most worrying of all is the fact that these assumptions are tacit: they are assumed to be 'truths' and are taken for granted without most people even being aware of them or considering them possible points for debate. An example is the notion that 'every accident has a cause'."

One common safety myth is that by focusing on preventing the near-misses it is possible to prevent the larger accidents as well. There is no scientific proof that major accidents, small incidents and near-misses have the same causes and organizational contributors. There is no scientific proof that by reducing near-misses one can also reduce the risk of a major accident. Even organizations that are seemingly safe can drift toward an accident. This drift is part of normal work and normal adaptation to changing circumstances. Accidents are not always preceded by small incidents and near-misses. Accidents are preceded by normal work.

Another myth that is connected to this is the myth of plenty of small incidents being a precursor of a larger accident. Sometimes a figure of 300 inci-

dents to one major accident is given. It is true, in general, that small incidents are more prevalent than larger accidents on an industry-wide level. Nevertheless, under slightly different conditions, even the small accident or near-miss could have led to serious outcomes in any given organization. On the other hand, some near-misses or occupational fatalities could not even in principle have led to a serious accident. If common denominators are to be found, they are found deep in the organization's culture, norms, attitudes and climate. Still, care must be taken when considering countermeasures; organizational factors that generate small incidents do not necessarily contribute to large accidents, and vice versa. Thus the absence of near-misses is no guarantee of safety. A major accident can just as well be the first or 301st event in the organization. The number of near-misses cannot predict the occurrence of an accident, i.e. there is as much reason for worry after the first near-miss as there is after the 299th near-miss. (van Fleet, 2000; Kletz, 2001; Dekker, 2005; Smith, 2006; Reiman & Oedewald, 2008)

The myth of human error states that over 80 per cent of all accidents are caused by human errors. It is clear where the preventative measures must be placed: on reducing human error. Looking for human errors is a "safe" choice, since one always finds them in hindsight. Looking and finding human errors makes it easier to find out who's guilty for the accident, who should be held accountable, and where preventative measures should be aimed. Unfortunately, the preventative measures are usually misaimed when the cause has been attributed to individual error. Accidents are a combination of many factors, which are not dangerous or erroneous in isolation but when happening together or when their consequences combine, they expose the organization to an accident.

Manuele (2003, p. 409) argues that safety audits do not pay enough attention to the low probability - high consequence incidents. Those "obscure hazards" should be identified better since they are also the probable causes of accidents after the more easily observed high probability hazards have been controlled. This requires going behind the surface levels and analysing the hazards the organization initially considers not significant. It also requires a good understanding of the technical features of the systems as well as the social system (creating hazards through human action or inaction). Further, going beyond the surface level of the organization requires adequate evaluation tools combined with an ability to use them correctly.

It is important to acknowledge the social nature of organizational reality and the fact that dissenting opinions, conflicts and ambiguities are a natural phenomenon in all organizations. The acknowledgement of conflict and ambiguity is made more challenging by the fact that the goal of the evaluations is often the independent evaluation of the organization (in singular) and a set of summary statements (e.g., does the organization have a good safety culture). Harrison (2005, p. 19) points out that "the quest for an independent viewpoint and scientific rigor should not, however, prevent investigators [evaluators] from treating the plurality of interests and perspectives within a focal organization as a significant organizational feature in its own right". The evaluation is not necessarily a failure if it does not find a unitary answer to

the questions it poses. On the contrary, one of the central outcomes of an evaluation is the illustration of how people in organizations are constructing their view of safety and risks; what issues they agree on, what issues they disagree on, and finally, what issues they do not consider important or meaningful.

4.4 Biases in evaluation and attribution of causes

Fundamental attribution error

A typical human (and organizational) characteristic is the tendency to blame someone else's mistake on the characteristics of that person (laziness, indifference, lack of ability), instead of the situation or work conditions. However, people explain and justify their own behaviour differently than others' behaviour. Fundamental attribution error is the tendency for people to overemphasize dispositional, or personality-based (internal), explanations for behaviours observed in others while under-emphasizing situational (external) explanations (Fiske & Taylor, 1991). People have an unjustified tendency to assume that another person's actions depend on what "kind" of person that person is rather than on the social and environmental forces influencing the person. This same tendency does not apply to one's own behaviour when that behaviour is considered successful. People claim more responsibility for successes than for failures. This bias also seems to operate on the level of social identities (see Section 5 of this report), which means that the successful actions of one's own group are merited to the group's characteristics, whereas failures area attributed to external conditions. Studies show that the more serious the event (to the individual or society), the more disagreeable is the idea of the accident being pure chance. Chance also implies that the same incident could target or could have targeted me. This is why people so readily stress the fact that an incident could have been prevented and the person involved must have caused it (Fiske & Taylor, 1991, pp. 67–86; Oedewald & Reiman, 2007a). In organizational evaluations, the attribution error should be considered when making inferences from the statements of various stakeholders. Further, it should be acknowledged that the evaluator is also prone to make errors in attribution, just like everybody else.

Bias of systematic distortion of information

Organizations tend to distort information to meet organizational needs (Bella, 1987). Information is systematically and routinely filtered out according to the rules and structure of the organizational culture in which the communication process is set. In the normal routine of organizational life, information passes through actors who "filter" the communication as regular throughputs at known rates of transmission, following the reporting lines as dictated by formal and informal structures and cultural rules (Smallman & Weir, 1999). Generally, more good news than bad news is reported upwards in the organization. Not everything can ever be reported, thus choices have to be made based on official reporting requirements, personal interests, social desirability, and whatever the worker has noticed or considered important in the first place. People usually do not know that they lack information, or if they do know, the nature and source of lacking information often remains obscure. The question is not only about information flow but also, and

more importantly, about what is considered relevant information and how people interpret and look for information in their work environment.

In terms of the validity of organizational evaluation, the systematic distortion of information has two main consequences: First, the people at various levels in the organization do not know all the "facts". Thus the evaluation is distorted by the same mechanisms, if it relies on the information that these people have. Second, it should be one of the aims of the evaluation to consider the systematic distortion of information and its potential effects on the organizational capability to guarantee safety.

Connected to this challenge is the so-called false consensus bias, which means that people typically believe that a consensus exists among other people of their group on issues that matter to them. Especially for managers, it is sometimes hard to get information on possible dissenting opinions in the organization.

> Vaughan (1996, p. 323) points out an important detail about the teleconference where the contractor for the Solid Rocket Booster, Morton Thiokol, expressed their concerns about launching the shuttle at such a low temperature. At the teleconference, engineers from Morton Thiokol presented their concern over the effect of temperature on the ability of the O-rings to seal, and concluded that they could not recommend a launch at a temperature below 53°F (≈12°C). NASA disagreed with the data and the launch delay recommendation the Morton Thiokol engineers (not unanimously though) presented. Managers at NASA used strong words in expressing their different opinion and in pointing out the flaws in Morton Thiokol's reasoning. However, they said they would not launch against a recommendation from a contractor. Morton Thiokol asked for a "caucus", where they went through the data they had and made a management decision (meaning that only the four managers (out of 14 participants at Morton's end) present expressed their final opinion). The teleconference resumed after a 30-minute break, during which the NASA participants were already preparing to call the launch off. However, to NASA's surprise, Morton Thiokol, represented by their vice president of the booster program, was now recommending a launch without any temperature constraints. **The personnel at NASA's end of the line were not aware that anyone at Thiokol still objected to the launch, and they were not aware of the decision-making process that eventually led to the change of recommendation**. A critical piece of information - that the decision was a management decision made against the somewhat inconsistent and ambiguous analyses and worries of engineers - was lost. The ambient temperature at the launch pad was 36°F (≈2°C) at the time of the launch, and ice had formed on the pad during the night.

Bias of relying on experience

Sometimes, evaluators "realise" the main problems with the organization very early in the process. They are able to do it based on their experience of working in, consulting or studying similar organizations in the past. The problems seem familiar and the solutions axiomatic. People at the target organization are usually impressed with the evaluator's expertise and experience since the problems and the solutions fit with the cultural image that

they themselves have (unless the evaluator relies on his experience from another industry or another national culture). Sometimes, the solutions really help the organization to improve.

There are some problems with the kind of reliance on personal experience described above. As mentioned in Section 3.3, a typical human tendency is to seek information that confirms one's expectations and assumptions and neglect contradictory information. If the evaluator has strong opinions on the organization before the evaluation, or forms these opinions very early in the process, these opinions have a strong influence on what the evaluator subsequently pays attention to, what he considers important, and what he ultimately finds out. Another challenge in experience-based evaluations is that they are hard to validate, as the rationale behind the findings is often implicit ("It was a clear case of complacency", "I saw immediately that they did not have a culture of continuous improvement", "an archetype of post-bureaucratic organization") and the line of thought is hard to track back. Experience also often narrows one's point of view to some "pet" theories or solutions that have worked well in the past. As experience accumulates, people learn what works well and what does not. These well-working solutions became personal preferences that are then applied to a wide range of situations.

Bias of good and bad intentions

Organizational evaluations tend to assume a straightforward connection between the safety performance of the organization and the attitudes of the personnel towards safety. In the case of performance failures, it seems to be easier to blame bad attitudes than lack of technical (safety) knowledge (Reiman et al., 2008b). Although nuclear organizations in general have highly experienced employees, it should be recognized that misunderstandings, narrow expertise areas, forgetting basic definitions and concepts, and the inability to follow the development of the technology can be found among the nuclear power plant personnel. The organizations may be unaware that misunderstandings about basic safety principles exist.

Not all accidents or incidents are due to bad intentions on the part of personnel or the management. In fact, it is a rare occasion when an accident has been caused by intentional negligence when the consequences of that negligence have been understood. McDonald (2006) has coined the phrase "well-intentioned people in dysfunctional systems", which catches the conundrum of organizational life well: Systems influence people who influence systems, but not always in the ways intended, and the corrective actions bring more unintended consequences.

Conflicting goals are one of the sources of risky behaviour in well-intentioned organizations. Safety and financial profitability, efficiency and thoroughness or occupational safety and process safety conflict in real life. On the other hand, the goals do not necessarily conflict, for example, in the sense that improvements to safety would always threaten financial profitability. Still, the goals do have different time perspectives in terms of return on investments. Investing in safety is a long-term return on investment, whereas

economic goals often actualize within a much shorter time span. The challenge in assessment is not in determining whether safety and economy are in conflict, but the ability to balance resources and focus attention on issues that most deserve it - be they safety, production or personnel-related.

4.5 Insiders or outsiders?

There are differing opinions on the possibility of an insider (a person that is working in the organization) to evaluate one's own organization. On the other hand, doubts have been raised about the abilities of outsiders to understand and gain access to organizations. There are researchers as well as practitioners (including consultants) for both positions. The question is not easy to answer, and it is made even more difficult by the political influences that it has: If insider evaluations are more effective and valid, what should all the consultants and researchers do? Of course, the issue is not nearly so black and white.

The ability and willingness of an insider to conduct a valid and objective organizational evaluation can be questioned on several grounds. The insider usually has overt or covert vested interests in the evaluation. He is accountable to some superiors and has to take their priorities into account in some manner. Depending on the outcome of the evaluation, he may gain power or lose something. His friends and peers are also in a position to be influenced by the outcome of the evaluation, and in a social position to influence him. Furthermore, having worked in the organization, he already has his preconceptions of the problematic issues (and problematic individuals), which might or might not be correct. The social identity of the insider affects whom he considers part of his group, and whom he considers experts and safety-conscious people (see Section 5 on social identity). The insider is also, as the name implies, an insider in the organization; thus he is prone to the same structural and cultural phenomena that influence and bias the ability of the personnel to perceive their vulnerabilities accurately.

Reiman et al. (2008b) note that an important issue in successful organizational evaluation is trust. Trust develops in social relationships, and a certain amount of trust is needed for the assessment to succeed and be valid. It is harder for an outsider to gain the trust of the personnel, and they might feel doubtful of the motives and competence of the external evaluator. On the other hand, organizations are composed of numerous subcultures. A certain level of mistrust can exist between these subcultures and one should not presume ad hoc that an insider assessor is trusted more than an outsider (Reiman et al., 2008b). Furthermore, social relationships always include phenomena such as power conflicts and groupthink (Janis, 1982). Groupthink is a form of tunnel vision, where the group seeks evidence confirming their assumptions and discards any opposing information. Power conflicts and hidden agendas affect the way individuals share information and cooperate on a wide range of issues. The assessor should not have any personal agendas or hidden motives in the assessment, but he should remain sensitive to the fact that some at either the worker or management level might have their own motives for sharing or not sharing certain information. If trust exists, organizations may be willing to show their private side (cf. Johari window)

in addition to their public side. Trust does not in itself guarantee that the organization or the evaluator will be able to describe the unknown side of the organization.

4.6 The political dimension

The political dimension refers to the above-mentioned fact that people in organizations have personal and group-based interests. Harrison (2005, p. 126) notes that "no matter how consensual relations are within an organization, some groups and individuals will benefit more than others from a diagnostic study, and some may be harmed by it". There are several ways in which an evaluation might benefit or harm somebody. When weaknesses in performance are uncovered, some people will probably be held more accountable for them than others. Furthermore, the act of making the weaknesses (or the strengths) explicit might change the power structures or personal relationships.

The recommendations that usually accompany organizational evaluations typically have political influences in the organization beyond those imagined or intended by the evaluators. For example, recommendations of more focus and resources to certain areas usually imply three things: First, the power and authority of the given area is raised. Second, the resources have to come from somewhere, and the 'some' area might lose power in the process. Third, the question of who is to be held accountable for the previous mismatch in focus and resources usually surfaces after the evaluation. All these outcomes might have unintended consequences for the organization in the long term.

The political dimension affects organizational evaluations in two important ways: First, the evaluator needs to address the political impact of the evaluation process and its results on the organization. The evaluator can decide not to take the impact explicitly into account and define his role as one of providing the organization with information. Still, in terms of the overall goals of organizational evaluation (e.g. to improve safety, to evaluate the safety effects of recent organizational change), the political dimension needs to be acknowledged. The second way the political dimension affects organizational evaluation is by affecting the possibilities for the evaluator to get valid and objective information from the organization in the first place. People are hesitant to disclose information that puts them or their group in a bad light. On the other hand, some may perceive the evaluation as their chance to advocate their own interests and personal goals. If the evaluator neglects the political dimension of organizational life, the interpretation of the available information might be distorted.

It is important to acknowledge the political dimension in organizational evaluations. The bias that it brings to evaluations can be reduced by making the goals of the evaluation clear, looking for conflicting interests, seeking second opinions, and asking for explanations and reasons behind statements. The outcome of the evaluation should not be the erasing of the political dimension from the results, but rather a description of the influence of politics on the everyday work and safety of the organization.

5. Framework for organizational evaluation

As we have emphasized throughout this report, an evaluation is always driven by a model of how the organization functions and what to look for. In order to be able to develop and validate organizational evaluations, this model needs to be made explicit. The aim of this Section is to propose one possible framework for organizational evaluation based on our research in safety-critical organizations.

We state that an organization has a good potential for safety when in organizational activity:

- safety is genuinely valued and the members of the organization are motivated to put effort on achieving high levels of safety
- it is understood that safety is a complex phenomenon. Safety is understood as a property of an entire system and not just absence of incidents
- people feel personally responsible for the safety of the entire system, they feel that they can have an effect on safety
- the organization aims at understanding the hazards and anticipating the risks in their activities
- the organization is alert to the possibility of an unanticipated event
- there are good prerequisites for carrying out the daily work.

The above-mentioned dimensions can be seen as criteria in an organizational evaluation. If an organization shows all the above-mentioned characteristics, it has a high-level safety culture and thus a high potential for managing its activities safely. In practice, however, organizations show varying degrees of safety value and motivation. Furthermore, the risk and safety conceptions are usually partially accurate and partially flawed. Thus the evaluator has to analyze the social and structural aspects of the organizations as well, and try to assess the reasons for current situation as well as the potential for improvement.

We have outlined a model of elements that should be covered in an organizational evaluation. Those are the organizational dimensions (structures and processes), social processes and psychological properties of the personnel (see also Reiman et al., 2008a). The basis for the criteria used in the evaluation is the fourth element of the organization; the organizational core task and production technology. This is the source of the inherent hazards of the sociotechnical system.

The elements are based on the model of the core elements of organizational culture created by Reiman and Oedewald (2007; Reiman, 2007). The revised model is called “OPS framework” (from Organizational, Psychological, and

Social elements)[3]. The OPS framework strives toward a dynamic and change-oriented model providing an opportunity for both evaluation and development. The aim of the OPS evaluation framework is to provide an answer to the questions "what is happening in the organization", and "how to make something happen in the organization". Thus the framework offers an action-oriented model for organizational evaluation (see Figure 5.1).

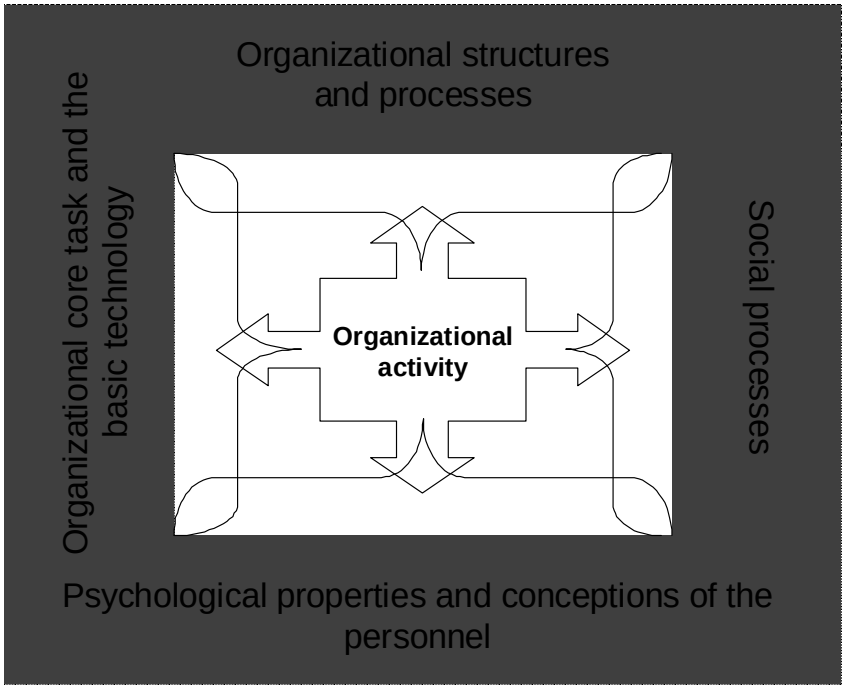

Figure 5.1. The four main elements of an organization define the frames of the organizational activity, which in turn influences the elements.

Figure 5.1 depicts the four main elements of the organization. These elements define the frames of organizational activity by setting constraints and possibilities for action. Activity, in turn, influences the elements over time. For example, how the organization conducts preventive maintenance on some equipment class depends on the interaction between the technical features of the plant, the understanding of those features by the personnel, the organizational process of collecting and analysing history data on the equipment class and defining a maintenance strategy, and how the personnel socially interpret the meaning and significance of the preventive maintenance activities. The above-mentioned elements frame the concrete activity of preventive maintenance that takes place on that equipment class. The activity that ensues affects not only the reliability of the equipment but also the way people's understanding of the technical features and their hazards develops. Further, the activity shapes the organizational process of planning and con-

[3] The main difference from our older organizational culture framework (Reiman, 2007) is that the current model serves as a checklist for assessing the organizational capability for high-level safety performance. The structure of the model is slightly different if the aim is to understand the dynamics of the entire organization or to evaluate the potential for safe work. The previous model did not describe in detail which properties of the organizational structure and management system should be covered in the assessment. Also, the personnel's conceptions and experiences are now described as "psychological properties". The psychological properties that illustrate a high-level safety culture in the organization are now identified, based on the research in different fields.

ducting maintenance, as well as how the personnel perceive its significance. This is exemplified in Figure 5.1 by the arrows going from organizational activity to the organizational elements, and by the arrows pointing from the elements to the activity.

5.1. Psychological dimensions

The performance of a worker in an actual work situation is based on the understanding and motivation of the individual who is about to take action. As will be illustrated below, the social processes and organizational dimensions have a strong influence on the individuals' interpretations, understandings and motivation. However, if safety is understood as a dynamic entity that is produced in the everyday work, the workers' psychological states are of crucial importance in creating safety. Thus the organizational evaluation should also be able to grasp the psychological dimension of the organization. We have identified seven dimensions that can be viewed as the core elements of an organizational safety culture.

1) Understanding the organizational core task is the cornerstone for effective and safe work. Understanding the organizational core task means understanding the objectives and goals of the nuclear power plant as well as the characteristics of the object of work (the nuclear power plant and its systems and equipment). It involves a view of how the various activities relate to the overall goals of the organization, as well as to the process control. Work performance is based on people's understanding of their particular work and the situation or context in which it is embedded (Sandberg & Targama, 2007, p. 10; Reiman, 2007). Organizational core task denotes this work in context. Sandberg and Targama (2007, p. 11) point out that "our understanding of a task and its context shapes our attention and determines what is interesting and relevant and what is not".

2) Task motivation means the amount of internal satisfaction a worker feels from spending effort on work-related issues. Work motivation is a necessary but not a sufficient requirement for a safety-conscious worker. Motivation cannot be enforced by management (or the regulator). Management can only try to encourage their workers to be motivated. People also need to feel motivated by safety issues, and not only consider them burdensome or meaningless. Safety should be considered one aspect of the work itself, and the motivation the worker feels should be directed at the content of the work and not contextual issues such as wages or co-workers.

3) Sense of control denotes the worker's perception of how well he or she is able to cope with the demands of his or her work. The demands include workload, the skills required by the task, coordination and communication requirements, and time pressure. Sense of control consists of the worker's interpretation of these demands as well as his or her experience in carrying out this kind of work. Uncertainty on the potential safety consequences of one's own work can also lower the sense of control.

A low sense of control can lead to compensating mechanisms, such as belittling the meaningfulness and importance of one's job, or to the narrowing of

one's interest in some specific aspect of the work, such as following the instructions to the letter no matter what happens (Oedewald & Reiman, 2007a). A realistic sense of control means that a worker knows the limits and strengths of his or her competence and has a feeling that the tasks are not too demanding and the time pressure is not too stressful. Realistic sense of control enables one to perceive one's capabilities and limitations, and to learn from one's job. Too high a sense of control can lead to overconfidence, whereas too low a sense of control can lead to stress and inability to do one's work. A realistic sense of control is an outcome of both good organizing of work and training as well as competent and hazards-aware people.

It is important for the personnel to understand that uncertainty is never caused by an individual alone but is rather related to the object of work, such as the condition of the technical systems at the plant or the reliability of the measurement data in process control. The object of work contains uncertainty; the progress and effects of work can never be fully predicted. This is why employees should feel a suitable amount of uncertainty when dealing with them. Recognizing and coping with uncertainty is related to the development of expertise (Klemola & Norros, 1997; Norros, 2004) and decision making in general.

4) Understanding of hazards includes understanding the possible functional failures as well as the failure modes of equipment. Failure modes means events that are reasonably likely to cause the functional failure, including both technical and human factors. It is also important to understand the failure effects and failure consequences of equipment (Moubray, 1999). Of special interest in a nuclear power plant is the equipment whose failure can have an effect on nuclear safety, either directly or indirectly (such as making a safety system non-operational). The way hazards are perceived shapes behaviour. Safety motivation and a high sense of control without understanding the hazards and mechanisms by which one's own work affects safety can be dangerous.

5) Understanding of safety is required in addition to the understanding of hazards. The personnel need to understand the complex nature of safety and the fact that they are creating it. Safety needs to be perceived as a dynamic non-event (cf. Weick, 1987), something that does not "happen" but needs continuous work to achieve. Otherwise, safety can be conceived as an individual ability or simple absence of errors, and no reason for sharing experience and treating errors as learning opportunities are perceived.

> As shown in our study of a Nordic NPP maintenance organization (Reiman & Oedewald, 2006), the meaning of "safety" is socially constructed, interpreted and embedded in the daily practices of the organization (see also Rochlin, 1999). For example, the personnel considered specialization safer than having wider responsibility areas and possessing general knowledge. They were thus "putting safety first" by resisting changes that endangered their ability to, e.g., specialize. For the management, this seemed like change resistance. They were of the opinion that, in terms of the effectiveness of maintenance, wider responsibility areas and general knowledge were needed. Thus the views on safety and the necessary means to

> achieve it differed between the field-level personnel and management. The personnel considered some of the new ideas and practices "dangerous" and explained their reluctance to adopt the practices by pointing out that "this is a nuclear power plant after all". However, they were not able to clearly explicate what safety in a nuclear power plant maintenance required, as the existing practices were also considered cumbersome and in some cases ineffective. For many, safety meant doing things as they had been done for the last twenty years. This understanding was deeply embedded in the daily practices, routines and computer systems, including the permit to work system.

The personnel's understanding of safety includes knowledge of human performance issues such as decision making, effects of fatigue, norms and social phenomena. It also includes a notion of what is regarded as human factors; are human factors a negative phenomenon to be avoided or are they perceived in a wider sense of indicating the human contribution to system safety. Further, if the personnel have a sophisticated understanding of safety, errors are conceptualised as being a natural part of work and as learning opportunities at the level of the entire sociotechnical system.

6) Sense of personal responsibility means a willingness to spend personal effort on safety issues and to take responsibility for one's actions and their outcomes, as well as a feeling that one is able and obliged to make a difference in safety matters. Formation of personal responsibility requires that one is able to perceive the outcomes of one's own work, and have an influence on that outcome. A sense of personal ownership for some equipment or an area of the plant (Kelly, 2005) can be considered part of personal responsibility. Sense of personal responsibility, however, extends to the safety of the entire plant.

Sense of personal responsibility does not mean that actions are taken or decisions made without relying on others. Schulman (1993, p. 43) argues that too localized a responsibility can be dangerous in NPPs, that "actions taken too soon, in too narrow a context, can jeopardize other parts of the system". On the other hand, diffusion of responsibility can mean that everyone, and therefore no one, will be responsible for doing the job (Snook, 2000; Sagan, 2004). Personal responsibility means making sure safety issues get attention in the organization and ensuring that important issues are also formally allocated to competent people. It can also mean raising issues that people do not want to hear. For example, individuals who express safety concerns could be interpreted as lacking confidence in co-workers or the system as a whole in organizations where collective responsibility is emphasised (Oedewald & Reiman, 2007a, p. 56).

7) Mindfulness refers to a state of mind where the worker is constantly on guard for unexpected events and trying to anticipate potential failure scenarios. The personnel should be alert to the possibility of unpleasant surprises and have a mindset that does not take the past as a guarantee of future success. (Weick et al., 2005) Weick and Sutcliffe (2007, p. 32) define mindfulness as "a rich awareness of discriminatory detail", which includes being aware of the context in which people act, of ways in which details differ, and

of deviations from their expectations. By mindful, they also mean somebody who is striving to maintain an underlying style of mental functioning that is distinguished by continuous updating and deepening of increasingly plausible interpretations of the context, what problems define it, and what remedies it contains (Weick & Sutcliffe, 2007, p. 18).

The opposite of mindfulness is mindlessness. However, this does not necessarily correspond to organizational routines. *Routine* and *mindless* are not synonyms; mindless acts are automatic, routine ones merely customary (Weick & Sutcliffe, 2007, p. 61). Mindful application of routines allows people to fit the routine into context and learn from it, if there is something to be learned. In preventive maintenance, for example, there is a danger that some of the tasks become mindless routines, where expectations govern what is ultimately done and what is found out.

5.2. Organizational dimensions

Organizational dimensions represent those key activities that the organization has to carry out in order to ensure safety. We have identified organizational structures and processes that can be identified as influencing the personnel's capability and willingness for risk-informed and safety-conscious behaviour. These are, for example; risk management practices, training, resourcing, change management and supervisory activity. They are the way of influencing the employees understanding and willingness. Psychological dimensions represent the "end states" of the personnel, which the organizational dimensions seek to create.

Figure 5.2 illustrates the specific contents of each organizational dimension. These contents include the organizational practices, tools and methods that facilitate each function. In evaluation, it is important to consider that each of these tools are based on the same underlying ideas of the psychological dimensions of a safety culture. Thus they have the same ultimate goal and their means are not in conflict with each other

Figure 5.2. Examples of the specific contents of the organizational dimensions

1) Management system refers to the formal safety policy, safety objectives and risk control measures of the organization. The management system includes definition of roles and formal responsibilities, risk assessment practices and procedures for auditing and self-assessment. The management system should include a description of work processes that cross the line organization and the critical success factors and indicators for each function.

2) Actions of the management to ensure safety refers to how safety considerations are included in management decision making, investments and allocation of resources. It also includes endorsement of the importance of safety by the management. This is done by consistent safety-oriented behaviour and rewards given for the safety-conscious behaviour of the personnel. Management at all levels has to interact with the field level and endorse the safety values and safe work practices. They need to talk to people, gather feedback and make their standards and expectations clear. Further, they need to keep themselves up to date on the way work is actually conducted in the field.

3) Safety communication means for example the management and safety department giving feedback to the personnel on near-misses and incidents. It means that management raises safety as a topic of discussion and regularly reminds the personnel about safety issues. Open communication on both positive and negative safety issues is an important prerequisite for the development of a sound safety culture. This also includes giving honest answers to safety-related questions and worries from the personnel and expressing the uncertainties and risks openly.

4) Actions of the immediate superior relate to the organizing of work and management of daily routines. It includes positive feedback on the safety-

conscious behaviour of the personnel, fair treatment of subordinates, and monitoring of the subordinates' coping skills, stress and fatigue levels, as well as technical skills. Trustworthiness is an important characteristic of the supervisor. Perceived trustworthiness has been defined as being composed of three dimensions: the ability, benevolence, and integrity of the supervisor (Mayer et al., 1995). In the safety-critical domain of health care, the behaviour of the superior has been shown to have an effect on how actively the personnel report near-misses (Firth-Cozens, 2006).

Superiors and foremen should strive at encouraging and rewarding positive safety behaviour and not just pointing out and punishing negative behaviour. Further, it is also important to reinforce and reward the "foot soldiers" and diligent work activities, not only heroic failure repairs, shutdown activities and such more visible behaviour.

5) Teamwork and information flow in units and between units is an important dimension dealing with the opportunities for cooperation and a climate that supports team work and knowledge sharing. Information flow means that relevant information is delivered both horizontally and vertically, and electronic means of distributing and storing information are utilised. The bottlenecks in the information flow should be identified and controlled, as well as the potential consequences of deficient information flow.

Reason and Hobbs (2003, p. 105) note that "a breakdown in coordination is one of the most common circumstances leading to an incident. In many cases, coordination breaks down when people make unspoken assumptions about a job, without actually communicating with each other to confirm the situation." Another challenge for coordination and cooperation emerges from the different social identities of the professional groups in safety-critical organizations (such as maintenance and operations).

Organizational secrecy and hiding of information is built into the very structure of organizations (Vaughan, 1996, p. 250). The division of labour between subunits, the hierarchy and the geographic dispersion segregate knowledge about tasks and goals. Physical as well as social distance interferes with the efforts to know the behaviour of others in the organization. According to Vaughan, specialized knowledge further inhibits knowing: "People in one department or division lack the expertise to understand the work in another or, for that matter, the work of other specialists in their own unit" (Vaughan, 1996, p. 250). Organizations take various measures to increase the flow of information, making the process of information sharing more formal and impersonal. These formal organizational efforts to communicate can lead to information being either not read due to an overwhelming amount of it or to loss of details and impoverishing of information due to ready-made categories of computer systems and other communication forms (Vaughan, 1996). The flow of information does not guarantee that sense is made of it; rather, the organizational processes should aim at promoting the seeking out of both positive as well as negative information at all levels in the organization.

6) Integration of the know-how of various professional groups requires that the professional subcultures appreciate each others' contribution to plant safety. The hands-on experience of technicians should be utilised by foremen, managers and engineers in their work and decision making. Also, technicians should provide foremen and engineers with information on the condition of the equipment and carry out the maintenance strategies developed by engineers. Integration of know-how requires that a variety of views and opinions is encouraged in the organization. The subcultures of the technical disciplines (I&C, electric, mechanic) are also often strong. This makes it all the more important to spend effort on trying to integrate their views and provide a joint social identity of nuclear power plant employee.

7) Resource management means ensuring the availability of sufficient workforce, and, on the other hand, keeping the tools and instruments up to date. Furthermore, human performance issues such as fatigue have to be taken into account in work schedule planning. Tasks should be distributed in a manner that promotes work motivation and skill development as well as the safe and efficient carrying out of the given task. This means, e.g., that all the demanding tasks are not systematically allocated to the same people, working in pairs with both skilled and less skilled personnel, and making sure that the personnel do not have to work (alone) on tasks they consider too demanding. Finally, resource management should aim at promoting the possibilities (e.g. availability of personnel, time, slack resources) for utilizing existing knowledge in everyday decision making (cf. Lawson, 2001).

8) Management of procedures aims at keeping the necessary rules related to safety and conduct of work up to date and easily accessible. The discrepancy between formal rules and actual work should also be continually monitored. Instructions should be easily available and written in a manner that they can be understood. Furthermore, the personnel should have the means to make sure that the procedure they have is up to date.

In safety-critical organizations, rules and procedures are often considered to be a way to make the activities of humans and organizations more reliable. This notion is based on the (as such, correct) notion of humans making mistakes and forgetting things. Rules and procedures try to control these 'human' characteristics. Rules and procedures are considered safety barriers to the troublesome variability of human performance (cf. Hollnagel, 2004). Also, the rule designers often think of procedures as tools for controlling the worker, not as tools for the worker to control his or her work (Dien, 1998, p. 181).

Training and safety management emphasise the danger in not following procedures. This message can be interpreted as non-compliance automatically having dangerous consequences. When the staff notice that this is not the case, their confidence in the correctness of the rules wavers. When considering the meaning of rules in the organization, it is important to understand what role is given to them and what the staff's attitude to them is. The quality and number of rules as such cannot be used to predict organizational ac-

tivity. The role of rules is understood in very different ways depending on the organization level and duties (Oedewald & Reiman, 2007a).

Reason et al. (1998) notes that good rules are sometimes broken, and not only by risk takers and sensation seekers. More important than to trying to completely prevent the rule bending and rule interpretation is to seek to understand those features of the organizational activity that promote or force people to act against the rules. An organizational culture that includes the structural elements of the work can be such that working strictly according to the rules would, in practice, be impossible. Often, this kind of rule bending is silently and implicitly accepted by the management, to the point where something bad happens.

9) Competence management and training requires a system for the identification of competence needs in the organization. Three kinds of training are required (cf. Mol, 2003):
(a) technical areas and systems (basic concepts, modernizations, new technology, new phenomena and newly identified faults and fault mechanisms),
(b) safety attitudes, safety culture and human performance-related issues,
(c) residual risk (hazards, nature of safety and accidents, inherent uncertainties of systems).
Competence management also includes the training and socialization of newcomers and transfer of knowledge from the experienced personnel to the less experienced.

Long tenures, experience and adequate training are often considered proof of high competence in many safety critical areas. However, long tenure and experience as such does not guarantee competence (cf. Klemola & Norros, 1997; Rogalski et al., 2002; Shanteau et al., 2002). Long tenure can also lead to routine. Experience is then no longer a benefit, but can actually be a source of errors when the work and its outcomes are not actively reflected upon (cf. Starbuck & Milliken, 1988, p. 323). Routine tasks are a major source of incidents (e.g. van Vuuren, 2000; Reason & Hobbs, 2003). Furthermore, new technology, new job contents and working practices, and new safety and efficiency demands placed on, e.g., maintenance activities set new requirements, which means that some of the old habits and out-dated conceptions have to be unlearned. Norros (2004) has argued that reflective as opposed to procedural orientation toward work facilitates learning. Training should encourage this reflective orientation (Oedewald & Reiman, 2007a).

10) Change management is becoming more and more important as the complexity of the environment increases along with competition and technological changes. Knowledge, attitudes and practices that were enough in a stabile environment might not be enough in a complex networked and competitive environment (cf. Rasmussen, 1997). Competition pushes the organizations to operate nearer and nearer the safety boundaries (Dekker, 2005, p. 2; Rasmussen, 1997; Reiman & Oedewald, 2007). At the same time, the boundaries of safe activity are more difficult to perceive, and they are in constant motion. An awareness of the safety state of the plant is hard to maintain.

Ramanujam (2003, p. 614) argues that the current explanations of the organizational origins of accidents understate the role of organizational change. He shows empirically how discontinuous change in a financial institution increased latent errors (deviations from procedures and policies), especially in "high-risk" units such as foreign exchange trading (in contrast to, e.g., savings accounts operations), in which the work was more demanding in nature. The latent errors were identified in internal audits. We have carried out studies in Finnish and Swedish nuclear power plants showing that employees experience organizational changes as stressful events that cause insecurity[4]. In many cases the change also affected the employees' confidence in the management's attitudes and commitment to safety. We noted that the opposition shown by employees is more than mere change resistance. It often involves real concern about the employees' own and the whole organization's safety. One of the main reasons for concern is the deterioration in organizational predictability. Tacit, and sometimes written, information about the organization's responsibilities and work processes, as well as the roles of cooperating parties, deteriorates in change situations, at least for a while. This can be seen, for example, in employees feeling that they have less control over their own work, or are unsure of what is required from them. Thus the influence of changes should be included in one form or another in all organizational evaluations.

11) Subcontractor management involves training contractors in safety culture-related issues, and ensuring their know-how in the field of interest. Furthermore, a record of subcontractor safety performance should be kept and utilised in decision making concerning contracts. One part of subcontractor management is the decision making concerning outsourcing in the first place. The knowledge needed in-house should be analysed and measures taken to maintain it. There should also be practices in place that facilitate learning from the subcontractors and gathering feedback from them, as well as to facilitate the subcontractors' own learning.

12) Risk management involves the design and implementation of safety barriers and the measures aimed at mitigation of the harmful variance in human performance and technical systems. Safety barriers can be technical (safety systems and redundancies), organizational (procedures and human performance tools) or social (norms and culture) (cf. Hollnagel, 2004). Risk management involves hazard identification, risk assessment, control measures and feedback. Furthermore, the process of risk management should make sure that the permit-to-work system and other organizational safety systems are adequate. Risk management should be carried out systematically, connecting all the organizational processes.

13) Practices of organizational learning include operating experience, reactive and proactive safety indicators, condition monitoring of equipment, continuous development of practices, and constant vigilance for weak sig-

[4] For the impact of organizational changes on safety, see Reiman et al. (2006), as well as HSE (1996), Baram (1998), Wright (1998), Bier et al. (2001), and Ramanujam (2003).

nals. Learning in a nuclear power plant cannot be driven only by errors and mistakes. More proactive measures aiming at improving the ability of the organization to recognise the boundaries of safe performance, and succeed in the future, are needed. At the same time, errors and near-misses should be considered learning opportunities and human performance issues should be tackled in event investigations. The challenge for organizations is to learn about the potential for future surprises and about the changing vulnerabilities.

> In the teleconference in which the fate of the Challenger was decided, the engineers at Morton Thiokol were trying to prove that temperature was a decisive factor affecting the O-ring damage. The problem was that their data was inconclusive. O-ring damage had happened at temperatures ranging all the way from 53° F to 75° F. Obviously, temperature could not be the only factor, if it was a factor at all, in contributing to O-ring damage. And what would be the effect of temperature in terms of numbers; how did it affect the O-rings, and which temperature level would suffice? For these questions there was no hard empirical evidence. The investigation board points out that if the engineers would have looked at all the flights, not only those with O-ring damage, a clearer picture would have emerged. Only three instances of thermal damage to O-rings had been observed on the twenty flights made in temperatures of 66° F or more. All four flights staged at 63° F or below had shown O-ring damage. They were more used to rapid corrective actions than trending and analysis.

Weick and Sutcliffe (2007, p. 72) point out that learning from unexpected events should not lead to more elaborate defences, such as new rules and restrictions, but more elaborate response capabilities. Recovery from event does not necessarily mean returning to the original position; rather, to a position where the original capability for successful recovery is not reduced.

The corrosion incident at Davis-Besse in 2002 is an example of an incident that could have been prevented with good operating experience practices and mindful personnel. For example, maintenance personnel regularly found rust particles clogging air-conditioning and water filters. Maintenance had to change the air filters every two days for two years, whereas the industry norm was to change the filters once a month (Perin, 2005, p. 216). This accumulation of rust was a weak signal of wider problems, which could have been detected had people been questioning the reasons for filter replacements (Weick & Sutcliffe, 2007, p. 46). However, rust accumulation was not a failure that people felt was significant enough to warrant a strong response (Weick & Sutcliffe, 2007, p. 48).

Remaining vigilant for incremental changes is important in complex organizations. The bending of rules or “innovative” utilization of tools may indicate that there is a genuine need for change in the practices. In many cases, the small, local adjustments to procedures are not negligence but usually done with good intentions (to get the job done, to save money). The work and the organizational processes can be such that employees have to bend the rules in order to get the work done. Management has to strive to understand the rationale for the workers’ behaviour and the conditions where they actually carry out their work before implementing new solutions or before

forcing compliance with existing rules. Sometimes it is the rules and procedures that need changing, not the workers' behaviour. According to Weick and Sutcliffe (2001, 2007), high-reliability organizations differ from other organizations in that they have adopted a philosophy of continuously reinterpreting the environment, possible problems and solutions. The main difference compared to typical organizational activities is that even weak signals get a strong reaction. Practices of organizational learning and management of change are thus closely intertwined. Furthermore, they both depend heavily on the social process of sensemaking.

5.3. Social processes

Social processes are phenomena that shape practices, create meaning and social order, and, at the same time, facilitate change. Social processes manifest as intentional changes, unintentional variations, trade-offs, gradual local adjustments and reinterpretations of organizational activities, demands of the work and capabilities for carrying out these demands. Social processes can be seen as social mechanisms that "quietly" lead the organization to its current state of organizational and psychological dimensions. We have differentiated six main social processes.

1) Sensemaking refers to the process where the so-called external reality is *enacted* by the personnel, where people create the "reality" they later perceive and interpret (Weick, 1995). Sensemaking is a process of active agents together structuring the unknown so as to be able to act. Reality is an ongoing accomplishment that emerges from efforts to create order and make retrospective sense of what occurs. Sensemaking means an attempt to tie actions and beliefs more closely together. Decisions are often justified by emphasising some "facts" over others, by reconstructing the pre-decision making history. Sensemaking is driven by plausibility and coherence rather than accuracy. People do not make sense of events only once, but rather engage in a continual revision of their understanding based on subsequent events (historical revision) and the interpretation of others (social influence) (Weick, 1995; Weick et al., 2005.).

> In the Challenger case, the problems with the O-rings were infrequent and a different cause was found each time there was erosion in an O-ring. This affected how the solid rocket booster work group made sense of them. Vaughan (1996, p. 149) writes: "The infrequent occurrence and the irregular pattern created a temporal sequence that was extremely important in shaping the construction of meaning in the work group: an incident would occur, followed by flights with no erosion, causing the group to conclude that they had correctly identified and corrected the problem. The effectiveness of the remedy affirmed their diagnosis."

Sensemaking is an ever-ongoing process, and it does not necessarily lead to shared consensus. This means that the organizational culture includes the dysfunctional solutions and discrepancies, as well as the attempts to solve or cover them. Informal leaders have a lot of influence on sensemaking and the formation of a social identity. Their behaviour and values are not always in line with official and formal leaders, but their influence on culture is, in many respects, larger. Organizations need to be aware of informal leadership, and if possible, utilize the informal leaders in safety work.

Sensemaking that is public and social generates commitment to its outcomes. Challenging the issues that have been settled after-the-fact is difficult since one has already shown commitment to a certain line of action. It is a matter of professional integrity (cf. Vaughan, 1996, p. 249) to maintain perceptions and performance that are in line with past decisions and commitments. For example, if a signal is collectively deemed normal, reinterpreting it as abnormal or potentially dangerous would require going against the "public opinion" as perceived by the person (cf. Figure 3.2).

Sensemaking also influences learning from experience and, especially, learning from incidents and events. Causal explanations of incidents and accidents have implications for organizational control (Vaughan, 1996; Perin 2005). Locating the responsibility for incidents in individual decision makers allows quick (and "dirty") remedies such as firing, transferring or retraining the individuals (Vaughan, 1996, p. 392). In terms of organizational learning, sensemaking of past events should go past individual blaming and hindsight into systemic issues. All too often, organizations learn to repeat their mistakes and to better justify why change is unnecessary. Small failures or errors reinforce the basic assumptions and conceptions of the personnel if the failure is attributed to a lack of commitment to the official organizational practices and values. On the other hand, serious failures can be attributed as being due to the influence of external circumstances, thus requiring no learning or change of practices or thinking. Defining failure and success are social and political processes, and by reinterpreting the history, each can be turned into another (Baumard, 2007; cf. Weick, 1995). Sagan (1993) reminds researchers and practitioners of "the resourcefulness with which committed individuals and organizations can turn the experience of failure into the memory of success".

2) Formation of social identity and norms means a process where the group defines who they are and what kind of behaviour is acceptable from their members. Social identity refers to a sense of belonging to a certain organization, profession or group in the organization, and the differentiations made between the in-group and other groups (cf. Haslam, 2004). Humans have a basic need to belong to a group and to be social and accepted by the group of people to which one feels like belonging. The motive to conform and avoid embarrassment affects the behaviour of individuals in groups.

Norms of proper conduct are one key mechanism that integrates the group. Norms are informal rules about how to behave inside the group as well as toward outsiders. Norms affect what is considered acceptable communication, e.g. how much uncertainty one can express and whether or not it is acceptable to question your colleague or your boss.

Social identity is also an important element of power in organizations. Power has implications for many aspects of organizational practice, including cooperation and sharing of information. Contradictions and different points of view stemming from politics and power conflicts inside the organization may lead to withholding of information or to decisions based not on "synthe-

sis of the most powerful arguments" but on "the arguments of the most powerful" (Waring, 1996, p. 52, see also Pidgeon & O'Leary, 2000). Too strong a social identity can also hinder learning from incidents that have happened elsewhere (at another plant or another work group in the same plant) in the form of "cannot happen here"-thinking.

3) Optimizing and local adaptation of practices refers to a process whereby the work practices are adapted to local goals and conditions, and multiple, incremental experiments to adjust the system are made (cf. Starbuck & Milliken, 1988). People constantly adjust their practices depending on perceived demands and resources, and they optimize by doing what they consider important and by devising new ways of achieving same results. The demands placed by the goals of safety, efficiency and production are socially negotiated in work situations. Compromises have to be made, and goals have to be weighted and prioritised. If these compromises and situational adaptations work and have no visible side-effects, they become the new informal norms or practice. From the perspective of the sociotechnical system, this can mean organizational drift. Snook (2000, p. 194) writes: "Practical drift is the slow steady uncoupling of practice from written procedure ... After extended periods of time, locally practical actions within subgroups gradually drift away from originally established procedures ... Constant demands for local efficiency dictate the path of the drift."

One of the main reasons for the danger of locally optimizing working practices are, first, the loose couplings prevalent in complex sociotechnical systems making it possible to change one part of the social system without immediate effect on the others, and secondly, the tendency of complex systems in some conditions to become tightly coupled. Loose couplings mean that, for example, some maintenance unit can change and optimize their work practices for a while without any effect on operations or other maintenance units. This is as long as the quality of their work (their output) remains approximately the same (or is enhanced).

The inherent features of complex sociotechnical systems that were discussed at the beginning of this Section also contribute to drift and migration of practices. Due to social and technical complexity, the demands of the work are not always obvious to the personnel at every level of the organization. The multitude of goals makes it necessary to balance them in daily activities. Habits and routines are formed in order to cope with the complexity and local adjustments are made to the practices in order to optimize them. Sometimes, rules are broken and new practices are created.

Psychological dimensions also influence the organizational drift in practices. If people are forced to work for a long period in circumstances where they feel a lack of control, they start to adjust the frames of their activity. This is an important mechanism for organizational drift. A low sense of control can change the conception of what is considered important in the work, and change practices accordingly. Therefore, the early detection of a declining sense of control is important for optimal long-term performance.

4) Normalization of deviance means a process where small changes – new behaviours, technical anomalies, or variations that are slight deviations from the normal course of events – gradually become the norm, providing a basis for accepting additional deviance (Vaughan, 1996). Normalization of deviance produces disregard and misinterpretation – neutralization – of potential danger signals. A signal of potential danger is information that deviates from expectations, contradicting the existing worldview (Vaughan, 1996, p. 243). Normalization of deviance is reinforced by cultural beliefs and expectations, routines of daily work and commitment to past decisions and past lines of action. Normalization of deviance is thus closely connected to sensemaking as well as to social identity maintenance and habit formation.

5) Embedding of conceptions means a process where certain ideas and conceptions concerning the proper way of doing work and taking care of risks are being maintained by the structural features of the organization. For the personnel, the objects and tools in the environment represent the history of their use. In other words, the tools *mean* whatever they have been used for in the past (Weick, 1993, p. 353; Hutchins, 1995). The influence of embedded conceptions in human thinking and activity is very seldom reflected. Embedding of the conceptions in the artefacts and structure of the organization makes it difficult to reflect on the meanings and alternative uses of the tools and practices in the organization (cf. Wright, 1994a; Hutchins, 1995).

> An example of the embedding of conceptions comes from NASA's flight readiness review (FRR) practices before the Challenger accident. There were four levels of reviews (IV-I), with the fourth and third level being the ones conducted by the contractors in charge of the solid rocket boosters, as well as the programs for the main engine and the external fuel tank. After the third and fourth level reviews, the items that were raised in the Marshall Space centre reviews were considerably compressed. According to Vaughan (1996, p. 94), one of the main official criteria for inclusion of items in the level II review was a so-called Delta review concept. It was informally called "management by exception", and it meant that the Project Managers were required to report at the level II and I reviews "any change, or deviation, from what was previously understood or done". Thus the formal procedure implied that, in terms of flight readiness and safety, only those issues that indicated a change were important. Known and recurring "problems" or deviations were not problems in terms of safety. This social process affected information flow up the hierarchy in a critical way. Vaughan (1996, p. 247) argues that, in addition to its technical functions, the FRR process also had "ritualistic, ceremonial properties with latent consequences that also reduced ambiguity, affecting the perceptions of risk held by work group members". According to her, "negotiating in FRR, creating the documents, making the engineering analysis and conclusions public, and having them accepted in an adversarial review system contributed to the persistence of the cultural construction of risk" (Vaughan, 1996, p. 247). The public and open nature of the review process generated commitment to its outcomes and legitimated the results in the minds of both engineers and managers.

6) Habit and routine formation means a social process where recurring tasks and works become routine, and certain habits and "ways of the house"

start to develop. Habit and routine formation leads to diminished reflection of working practices and conceptions, but also to a higher sense of control and predictability of the environment.

5.4. Evaluation with the OPS framework

The organizational dimensions are analytical tools for considering those aspects of organizational activity that can be intentionally managed, monitored, changed and reflected. Organizational safety management is carried out through these dimensions. The psychological dimensions can be used as leading indicators of a safety culture. In other words, they indicate the effectiveness of the organizational dimensions in managing safety and controlling the social processes. These psychological phenomena indicate how well the personnel are able and willing to take care of safety. Social processes can be considered mediating variables when evaluating the effectiveness of the organizational dimensions on the psychological dimensions. In terms of safety management, the influence of social processes is important to take into account and control or monitor as well as possible.

The aim of safety management is to develop and sustain optimal psychological dimensions. Organizational dimensions are the layer on which development activities are carried out and which can be managed by interventions, technological innovations and change initiatives. As illustrated in Section 2, many current models of safety management are based on a rational or a non-contextual image of an organization (Reiman & Oedewald, 2007). Waring and Glendon (1998, p. 175) criticize safety management systems that are based on an overly-rational image of the organization and argue that they may only be partly effective while creating an illusion that the risks have been fully controlled (see also Waring, 1996, p. 46; Dekker, 2005, p. 2; Perin, 2005). McDonald et al. (2000) argue that evidence from aviation maintenance indicates that the current quality and safety management systems seldom provide an adequate picture of the way the work is actually carried out (see also Hopkins, 2005). The work and the organizational processes can be such that employees have to bend the rules in order to get the work done. The unintended consequences can still be hazardous in the long or short term.

The organization is more like a living system or a culture than a machine. Parts of the organization are not replaceable, and the total is always more than the sum of its parts. An organization is an emergent sociotechnical phenomenon, where the perceptions and meanings of the personnel play a key role, not the “facts” or so-called objective things per se. An organizational evaluation should reach the level of these perceptions and meanings, and not just stay at the level of formal documents and management systems. The evaluation should also promote a more organic approach to safety management, which recognises the social nature of organizations.

Understanding of social processes is needed in order to get an overview of the rationale for the current dimensions, both organizational and psychological. Social processes can explain why the organizational dimensions have formed the way they have, and why the dimensions are having or not having

a certain effect on safety or on the psychological dimensions. Thus effective safety management requires *steering* the organizational dimensions, *controlling* the social processes, and *monitoring* the psychological dimensions.

An organizational evaluation should consider the three elements of the organization outlined in this Section, or make the choice of leaving some element out explicit. Organizational dimensions provide information on the sources of effectiveness and ineffectiveness in the organization. Social processes help to explain the dynamics of organizational life. Psychological dimensions are outcomes that denote whether change in the organizational safety culture is necessary, and whether the need is perceived by the personnel.

6. Carrying out evaluations - basic requirements

6.1 Defining the criteria and data requirements - premises

The issues of data and criteria both depend on the model of an effective and safe organization. The model defines what is considered data and what criteria are used for the assessment (cf. Reiman & Oedewald, 2007). Often, this model is implicit in the assessor's mind. It is important to acknowledge that people always have preconceptions and underlying assumptions about safety, organizational effectiveness and evaluation. The influence of the evaluator's paradigm on the selection of methods and criteria, as well as collection of data and drawing inferences from it, is illustrated in Figure 4.1 in Section 4 of this report. As was mentioned in Section 4, the possible findings and their significance are decided early, when the premises of the evaluation are set. Figure 6.1 presents a refined picture of the evaluation process from the methodological perspective. It is very important to make this perspective as explicit as possible since it influences the evaluation in great detail. Implicit premises hinder the communication and reflection of the results.

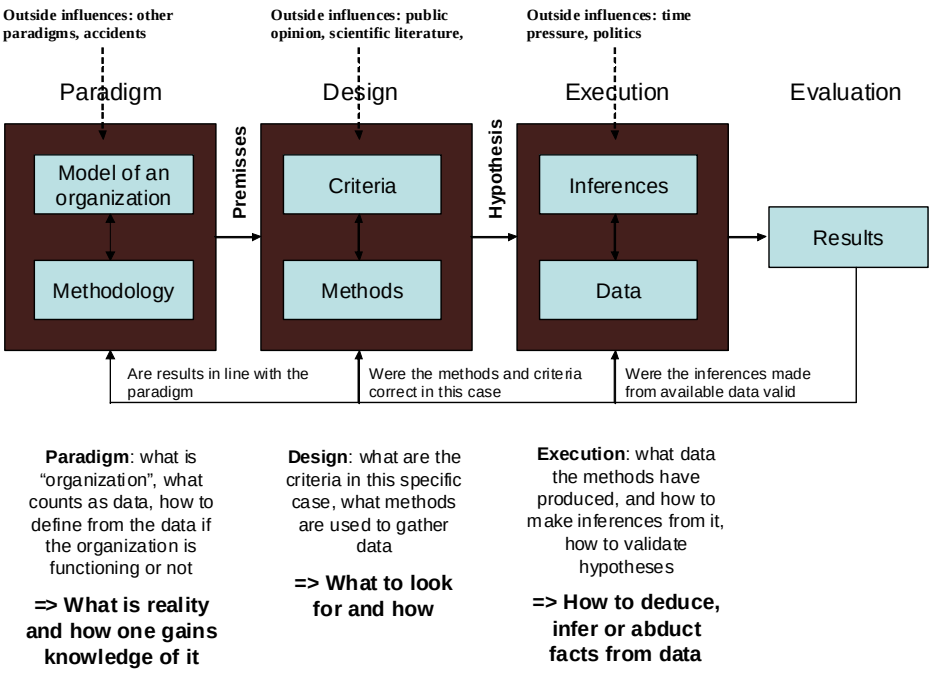

Figure 6.1. The design and execution of an organizational evaluation is influenced by the premises set by the paradigm used. This includes the criteria and methods, as well as data collection and inferences that are drawn from the data.

The evaluation paradigm defines what an organization is and what empirical findings count as data on the functioning of the organization. The design of the evaluation process includes the methods that are used to collect the data, and the criteria that will be used to evaluate the findings, as well as operationalization of the criteria. Operationalization means how good occupational safety attitudes or good organizational learning practices can be empirically measured in the evaluation.

One of the challenges in defining the criteria is that safety is a complex phenomenon that is not easy to define in measurable terms. Sometimes the definitions are simplistic in order to be able to more easily gather data on them, e.g. the number of workers without adequate personal protective equipment (negative indicator of safety culture) or the number times a manager visits the shop floor (positive indicator of safety culture).

The evaluation design needs to make a balance between focus on details and oversight of the entire organization. It is important to acknowledge the tension between depth and scope, and make the decision concerning the focus explicit. A broad evaluation that only covers the surface features of the organization might very well be beneficial for the organization as long as they understand that they are only dealing with surface features. On the other hand, an in-depth analysis of some specific issue often needs to be put into a larger context before implementing solutions that usually have an effect on other parts of the organization as well. The execution of the evaluation process will be tackled in more detail next, after the planning Section.

6.2 Planning the evaluation - design

There are several things that need consideration when an organizational evaluation is being planned. Some of the main things to consider (see also Harrison, 2005, p. 13) are presented below:

- **Reason and purpose of the evaluation**
    - What is the reason for the evaluation?
    - What are its goals, how are they defined?
    - What instigated the evaluation, is there a specific problem to be addressed?
- **Design of the evaluation**
    - How should the evaluation be done in terms of scope and depth?
    - What are the required resources in the evaluation (from both parties)?
    - What are the criteria that are used to evaluate the organization, and how are the criteria derived and operationalized?
    - What methods are used in the data collection?
- **Execution and feedback**
    - When should the evaluation be done?
    - How are the personnel affected by the evaluation process?
    - How are the results of the evaluation to be reported to the organization?

- Is there enough commitment in the target organization to allow a neutral evaluation, including access to sensitive information?
- Is the assessment team competent enough to complete the evaluation?
- How it can be decided whether the evaluation reached its goals or not?

The planning stage includes issues related to the overall purpose of the evaluation, to its design - including the theoretical premises - and to the actual implementation of the evaluation.

An important decision at the planning stage is the selection of the methods that are used in the evaluation. The selection of methods is heavily influenced by the paradigm used (see Figure 6.1) and, for some evaluators, the choice is very implicit since they always use certain methods, or do not know of any valid alternatives. However, it is important to acknowledge that the question of evaluation methods is always a question of choice, and that no one method has been shown to be superior to the other methods. The choice of methods should depend on the goals of the evaluation as well as on the constraints and requirements placed by contextual factors on the evaluation (e.g. time, resources, the amount of trust toward the evaluators). Table 6.1 lists the main methods and their advantages and disadvantages in an organizational evaluation.

Sometimes it is appropriate to target the evaluation to some specific part or function of the organization. For example, the evaluation could cover the maintenance unit, the safety department, outage planning process or management function. Evaluation of a specific unit is often practical in terms of resources and the depth of evaluation that is possible to attain in the evaluation. Furthermore, even if the overall aim is to evaluate the entire organization, it is sometimes beneficial to conduct it on a unit-by-unit basis. However, each unit or function in question must always be evaluated as part of the overall sociotechnical system, not as an independent entity. Thus it is important to consider the fit of the unit into the overall organization (Harrison, 2005, p. 77). This means considering the congruence and compatibility of the requirements, needs, practices and expectations of the different units.

Table 6.1. Selection of methods (see Harrison, 2005, pp. 21-22)

Methods	Advantages	Disadvantages
Questionnaires	Allows large samples in a cost-effective way. The results are easy to quantify and summarize. Can be used for comparisons across units or between time periods.	Relies on ready-made categories. Questions might be too general or abstract, and the evaluator remains unaware of how the respondents interpreted them. Difficult to obtain data on structures or behaviour.
Interviews	Personnel can describe their work with concepts that are familiar to them, and without ready-made categories. Evaluator can build trust in the organization.	Every interview is a unique event between the interviewee and the interviewer: social desirability, transference, personal favourite topics of discussion.
Workshops	The personnel can work with the evaluation results and increase their commitment to carry out them later. Evaluator can build trust in the organization. It is possible to observe the group dynamics and ways of decision making.	Formal and informal leaders influence the dynamics in ways that are hard to anticipate. Analysis of the outcomes and process of the workshop requires knowledge of the organizational culture (political dimension). If the group does not interact in real work, the process does not necessarily tell about day to day interaction.
Group discussions	Evaluator can build trust in the organization. It is possible to observe the group dynamics and ways of decision making. Group discussion is more economical data gathering method than individual interviews.	Formal and informal leaders influence the dynamics in ways that are hard to anticipate. Analysis of the outcomes and process of the discussion requires knowledge of the organizational culture (political dimension).
Task observation	Gives the evaluator a chance to perceive the conditions, constraints and requirements under which the personnel have to work. Provides knowledge on the content of the particular work.	Data gathering is difficult without forming simplifying observable categories. In organizational evaluations the scope of potential tasks to be observed is vast. Observations of one task cannot be generalised.
Meta-analysis of documents, events, and studies.	Uses existing and wide range of data. Can provide a historical perspective in terms of trends and interpretations made at the time.	The amount of available data is vast, but it varies in quality and in terms of explanations included. It is hard to make a summary of the data without a priori theoretical framework guiding attention.

It is recommended that the evaluators should rely on multiple methods when conducting the organizational evaluation. Moreover, personnel interviews should be part of any evaluation since they maximize the benefits of confidentiality (at least partly) and rich qualitative data.

6.3 Drawing inferences and making judgments from the available data - execution

The crucial question at this stage is how much is “good enough”? In other words, the evaluator needs to decide on the standards used to make judgments about the key findings. Even if one has clinched a set of elements of organizational safety, the data always needs interpretation. There is no valid

survey or interview technique that can provide a straightforward evaluation of such a complex phenomenon as organizational safety. For example, if one of the criteria in the evaluation were the employees' understanding of hazards and the evaluator finds that almost all the interviewed employees do understand most of the hazards, but none understand all of them, is it reasonable to expect a perfect understanding? Can the level of understanding be said to be high if there are gaps in it?

Another crucial issue at this stage is the connection between various criteria. The main question is: does the organization have to be good on every criterion, or is it enough to score excellent on a few? For example, if the evaluator in the previous example found that the employees are highly motivated towards spending effort on safety (criteria), feel personally responsible for the safety of the plant (criteria) and have received good training on safety issues (criteria), but feel stressed and overburdened by work (criteria), should she count a mean value from three high, one moderate and one low score? Or should she write a qualitative judgment from all the available information, which includes a warning on the long-term effects of stress on performance and work practices?

There are no strict answers to the questions posed above. The evaluation should provide information on both the effectiveness and ineffectiveness of the organization. We promote the use of both qualitative judgments and quantitative scores (of both mean values and standard deviations). The way of presenting the results and drawing inferences should be tailored to the goals of the evaluation as well as to the methods of execution. For example, if there are possibilities for presenting results to the organization along the way, one can start with more quantitative and fragmented results as a basis for discussion and joint interpretation, and at the end of the evaluation process present a more holistic qualitative evaluation.

Some generic cultural patterns in the safety-critical organizations reveal themselves gradually during the evaluation process. It is important to identify these patterns before making the final evaluation of the organization's ability to manage safety.

For example, *complacent* organizations usually show good performance records and the employees are proud and satisfied. However, the long-term safety of the organization may be threatened. Complacency means decreased reflection of the real practices and attitudes of the organization and an unfounded belief in the ability of the organization to cope with any challenges facing it. Usually, the plant management is the main "victim" of complacency (due to their limited knowledge of how the work is carried out in practice), but it is also possible for the personnel levels to develop an unfounded belief in the organizational abilities. Self-assessments made by complacent organizations generally do not produce valid results on organizational vulnerabilities, and critical results from peer reviews or external evaluations are not taken into consideration in complacent organizations. These organizations make evaluations with the motive of either showing how good they are, or to fulfil an official regulation. These are the organizations with the most

need for evaluation, but the least genuine motive. Unless done rigorously, the evaluation probably says more about the public and open side of the organization in Figure 3.1 than about the hidden or the unknown side of the organization. Complacency does not automatically mean that the organization is not performing well. On the contrary, complacent organizations are often very good at what they are doing. This makes complacency all the more dangerous since there are no easy objective indicators to show that they might be missing something.

> In the Challenger investigation, it was concluded that a "can do" attitude at NASA contributed to the accident by creating overconfidence in the organization's ability to perform for the personnel. Vaughan (1996, p. 234) discussed it with the project members from the Solid Rocket Booster project and they agreed that such an attitude existed and that it affected their decision making by reinforcing their belief in their technical analysis. Vaughan writes: "Describing it, several work group members stated, 'We believed in our people and our procedures.' They were assured in their decisions because they had 'long-term personnel with a history of hands-on hardware design that lead to experience and first-hand knowledge' … because 'we followed every procedure'; because 'the FFR [Flight Readiness Review] process is aggressive and adversarial, examining every little knit'; because 'we went by the book'; and because 'we did everything we were supposed to'." The Challenger was not supposed to explode. The risks were supposed to be acceptable. Even in hindsight, for many at NASA it was hard to see the risk as nothing but acceptable and their actions as justified.

The culture of nuclear power promotes *control and certainty* (cf. Perin, 2005; Oedewald & Reiman, 2007a). An emphasis on control and certainty is especially prevalent in plants that have been performing well in the past. Starbuck and Milliken (1988, p. 329), who have studied the culture at NASA before the Challenger accident, argue that "success breeds confidence and fantasy". Feeling safe is not, however, necessarily the same as being safe (Rochlin, 1999b, p. 10). On the one hand, a certain level of a sense of control is needed in order to be able to act. On the other hand, illusion of control is an error-provoking factor (Reason & Hobbs, 2003; Reason, 1990), as is a (real or perceived) lack of control (Clarke & Cooper, 2004).

In safety-critical organizations, *rules and procedures* are often considered a way to make the activities of humans and organizations more reliable. Thus most organizational evaluators consider rule following a criterion for the safety of an organization. It may be necessary to analyse when the rules are followed and when they are bent. Bending of rules is not necessarily a signal of low safety motivation or bad attitudes. It may be a symptom of more generic problems in work design. More important than judging the safety culture of an organization for rule bending is to seek to understand those features of the organizational activity that promote or force acting against the rules.

Diffusion of responsibility and ambiguities in personal responsibilities are typical in complex safety-critical organizations (Oedewald & Reiman,

2007a). In NPPs, the achievement of a sense of personal responsibility is complicated by strict rules and procedures, and a tendency to emphasize shared responsibility and collective action instead of individual initiative (cf. Rochlin, 1999a; Hackman & Oldham, 1980). A complex organizational structure, in turn, can affect the ability and willingness of the personnel to take care of the hazards. A particular risk resulting from the complexity of organizations is that an employee may start to rely on external control and believe that someone else ensures that even weak performance will not endanger the safety of the entire organization. Hints of such attitudes can be found in many studies (Oedewald & Reiman, 2007a; Vaughan, 1996) and in the fact that questions related to personal responsibility are particularly complex in safety-critical organizations (cf. Dekker, 2005). Hackman and Oldham (1980, p. 75) point out that "[t]he irony is that in many such significant jobs, precisely *because* the task is so important, management designs and supervises the work to ensure error-free performance, and destroys employee motivation ... in the process". Motivation may be dampened down if the procedures used in the organization create the impression that the actions of individual employees do not affect safety. 'Ensuring' that the employees' work is safe, using, for example, detailed procedures, redundant operations and independent inspectors, may weaken work motivation and the feeling of the safety impact of one's work, which, in turn, may influence safety in the long run. We have noted that the prescriptions guiding the personnel's conduct in some case organizations have been perceived as being so strong that the individual choice, which is needed for personal responsibility to be felt, was not perceived to be present (Reiman & Oedewald, 2006). On the other hand, the impossibility of procedurizing all the aspects of work and the inadequacy of the procedures to cope with the realities and surprises of daily work are acknowledged by the personnel in nuclear power plants (cf. Hirschhorn, 1993, p. 140; Reiman, 2007).

The question of *intentionality of risky solutions* may arise in the evaluation process. Does the organization intentionally carry out working practices the evaluator considers risky? Does the organization take calculated risks when they make operational decisions or design staffing, outsourcing or technical investments? Or is the risky solution due to a lack of understanding of the risks involved? Or is the organization unable to correct the risky solution for some reason? In many cases, intentional, calculated risk taking is considered to be a strong sign of a degraded safety culture. One should, however, keep in mind that it may be even more dangerous if the organization is not aware of the risks it is taking. Furthermore, in the case of an organizational inability to fix a risky solution, the possible social mechanism inside the organization that maintains the unwanted situation needs to be investigated closely.

The organization's ability to reflect on itself varies, as does the willingness of the organization to acknowledge its vulnerabilities internally or externally. *Defensive organizations* try to avoid information that could "hurt" their self-image and social identity. This defensiveness itself is part of the social identity, and as such is also guarded from outsiders. The information from organizational evaluations can be analysed in terms of how much the

organization is aware of its sources of effectiveness and ineffectiveness, and how much it wants to make this awareness public.

Balance between stability and change is one of the inherent challenges of any organization. The nuclear field has been traditionally slow to change, but in recent years a more dynamic approach to change has become prevalent. As noted in Section 5, adequate management of change is important for nuclear safety. The change management process should ascertain that the usability and maintainability issues of new technology, tools and modifications are considered in the design and implementation stages. Management of change involves the balance between modifying and innovating technical and organizational structures and keeping them stable. It requires decision making on when change is necessary, when not changing something would create more risk than changing it, and what kind of risks a change would bring.

> In the Challenger case, the problems of Solid Rocket Boosters (SRB) were known from the beginning. Some safety engineers proposed redesigning the entire SRB hardware. Instead, a decision that was influenced by cost considerations and schedule was made to test and correct the old design. Vaughan (1996, p. 116) writes: "Engineering decisions are biased toward making existing hardware and designs work, as opposed to scrapping it and coming up with a better design. But safety concerns also contribute to this bias. In the engineering profession, the belief that 'change is bad' is widely held. In the short run, a new design brings new uncertainties, not greater predictability. Because designs never work exactly as the drawings predict, the learning process must start all over again. A change introduced in one part of a system may have unpredicted ramifications for other parts. In the interest of safety, the tendency is to choose the evils known rather than the evils unknown."

One important component of managing change is the challenge caused by *personnel turnover* and key people leaving. For example, new managers or technical specialists seldom know the history of the organization, how it has developed its practices, what problems it has faced, how these have been solved, and what vulnerabilities still exist. They have to rely on compressed and somewhat biased information from their colleagues and official documents. A danger is that they do not understand the rationale for some important development initiatives or practices, and try to change them. Also, some things that have become deviant in the organization might seem (and are presented as being) normal to the new manager (Vaughan, 1996, p. 128). A positive possibility is that newcomers might bring new ideas and challenge the taken-for-granted conceptions the "older" employees have.

The inferences made from the data should thus involve:

- sources of effectiveness in the organizational dimensions
- sources of ineffectiveness in the organizational dimensions
- social mechanisms influencing and guiding the organizational dimensions
- outcomes of the current organization on a personnel level, e.g. motivation, understanding of hazards and sense of control.

The psychological outcomes provide information on whether something needs to be changed or developed in the organization. The analysis of social mechanisms and processes provides information on how changes are possible, and how the organization would change in time without intervention. The organizational dimensions - both the sources of effectiveness as well as ineffectiveness - provide information on what can and should be developed in the organization in order to influence the psychological outcomes and, eventually, nuclear safety. Together, these four types of inferences provide the prediction on organizational performance and safety in the future, as well as the proposed means to invalidate this prediction (cf. Reiman & Oedewald, 2007).

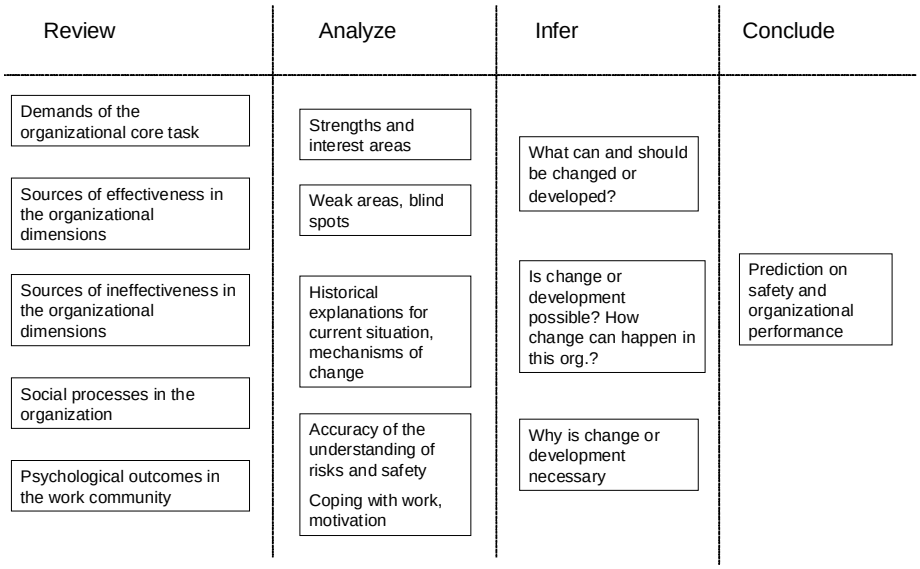

Figure 7.1 Model of the process of organizational evaluation

Figure 7.1 depicts the organizational evaluation as a four-stage process from review of data, to analysis, drawing of inferences and, finally, to conclusions. In the analysis stage it is important to identify the strengths of the organization as well as the weak areas or blind spots (cf. Figure 3.1), and the reasons for the state of affairs. Furthermore, the personnel's conceptions concerning hazards and safety should be analysed, as well as their psychological states. When drawing inferences from the analysis, it is important to not only point out areas where change is necessary but also to look for explanations for this need. It is also important to consider the way change is possible in the given organization. Understanding the social processes is important in this. When drawing a conclusion, the aim is to make a self-invalidating prediction (Reiman & Oedewald, 2007) in terms of the safety consequences of the organizational weaknesses.

7. Conclusions

An organizational evaluation plays a key role in the monitoring, as well as controlling and steering, of the organizational safety culture. If left unattended, organizations have a tendency to gradually drift into a condition where they have trouble identifying their vulnerabilities and mechanisms or practices that create or maintain these vulnerabilities. The aim of an organizational evaluation should be to promote increased understanding of the sociotechnical system and its changing vulnerabilities. Evaluation contributes to organizational development and management. Evaluations are used in various situations, but when the aim is to learn about possible new vulnerabilities, identify organizational reasons for problems, or prepare for future challenges, the organization is most open to genuine surprises and new findings.

It is recommended that organizational evaluations should be conducted when

- there are changes in the organizational structures
- new tools are implemented
- when the people report increased workplace stress or a decreased working climate
- when incidents and near-misses increase
- when work starts to become routine
- when weak signals (such as employees voicing safety concerns or other worries, the organization “feels” different, organizational climate has changed) are perceived.

In organizations that already have a high safety level, safety managers work for their successors (Amalberti, 2001). This means that they seldom see the results of their successful efforts to improve safety. This is due to the fact that it takes time for the improvement to become noticeable in terms of increased measurable safety levels.

The most challenging issue in an organizational evaluation is the definition of criteria for safety. We have adopted a system safety perspective and we state that an organization has a high potential for safety when

- safety is genuinely valued and the members of the organization are motivated to put effort on achieving high levels of safety
- it is understood that safety is a complex phenomenon. Safety is understood as a property of an entire system and not just absence of incidents
- people feel personally responsible for the safety of the entire system, they feel they can have an effect on safety
- the organizations aims for understanding the hazards and anticipating the risks in their activities
- the organization is alert to the possibility of an unanticipated event
- good prerequisites for carrying out the daily work exist.

An organizational evaluation should aim at reasoning the:

- sources of effectiveness in the organizational dimensions
- sources of ineffectiveness in the organization dimensions

- social processes in the organization
- psychological outcomes of the current organization on a personnel level, e.g. motivation, understanding of hazards and sense of control.

When drawing inferences from the organizational evaluations and defining development initiatives, it is important to consider actions that will promote and maintain the strengths of the organization as well as actions that will address and develop the weak areas.

Issues associated with data collection and choice of methods has been a topic of much discussion in the field of evaluation of safety-critical organizations. We argue that the problem of collecting data is not the most important problem in terms of facilitating valid evaluations. A more important problem concerns the criteria that are used, as well as the operationalization of criteria into something measureable. Too much effort has been spent on methods and too little on contemplating the question of valid evaluation criteria and a valid means of deducing from the data whether the criteria are fulfilled. In order to accomplish this, a valid evaluation framework is needed, which incorporates the idea of organization as a complex sociotechnical system. This report has been an attempt to illustrate the premises and key issues to consider in organizational evaluations. No method can compensate for a deficient understanding of what is being measured.

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Appendix: The Challenger Accident

(Vaughan 1996, Jensen, 1996; Feldman 2004, Report on the Presidential Commission on the Space Shuttle *Challenger* Accident 1986, www.nasa.gov)

Description of the event

In January 28, 1986, the NASA space shuttle Challenger was launched from Kennedy Space Center. The space shuttle was the second in its class of Space Transportation System that NASA had designed in the late 70s. Its sister shuttle, Columbia, made its maiden flight in April 1981. With the space shuttle program, NASA had promised "safe, cost-effective and routine access to space". The mission, 51-L, was the 25th launch of the STS into space.

Challenger exploded 73 seconds after launch. All of its seven crew members were killed. The cause of the accident was found to be a leak in the O-ring, which failed due to excessively cold temperature. The commission that was set up to investigate the disaster established the technical cause behind the loss of Challenger: A combustion gas leak through the right Solid Rocket Motor aft field joint initiated at or shortly after ignition eventually weakened and/or penetrated the External Tank, initiating vehicle structural breakup and loss of the Space Shuttle *Challenger* during STS Mission 51-L (Report, 1986).

The "gas leak" was caused by failure in the O-rings of the booster. The shuttle had several O-rings, made of a rubber compound, which were used to seal the Solid Rocket Booster field joints. The Solid Rocket Boosters are made in sections. There are two types of joints to hold the sections together: the permanent "factory joints" are sealed at the Morton Thiokol factory in Utah; the temporary "field joints" are sealed before each flight - at the Kennedy Space Center in Florida (Feynman, 1988). The O-rings measured 146 inches in diameter and were just 0.280 inch thick. Each one was moulded in one piece to span the entire circumference of the booster. Each solid rocket booster had three field joints, and the shuttle had two solid rocket boosters.

The official report describes the beginning of the chain of events in the following way: "Just after liftoff at .678 seconds into the flight, photographic data shows a strong puff of gray smoke was spurting from the vicinity of the aft field joint on the right Solid Rocket Booster ... increasingly blacker smoke was recorded between .836 and 2.500 seconds ... The black colour and dense composition of the smoke puffs suggest that the grease, joint insulation and rubber O-rings in the joint seal were being burned and eroded by the hot propellant gases." At 64 seconds into the flight, flames from the right Solid Rocket Booster ruptured the fuel tank and resulted in an explosion 73

seconds after launch (Report on the Presidential Commission on the Space Shuttle *Challenger* Accident 1986, www.nasa.gov).

The weather on launch day was exceptionally cold (36 F), 15 degrees lower than that measured for the next coldest previous launch, and the durability of the O-rings had not been tested at such temperatures.

Background

Post-accident investigations found that the resiliency of the O-rings was directly related to the temperature. The colder the ring, the slower it returns to its original shape after compression. Further, O-rings had caused problems for a longer period of time. The first erosion damage (0.053 inch, about one-fifth of the O-ring diameter) was detected in the field joint of the solid rocket boosters used on Columbia's second flight in 1981. However, no clear reason for the erosion could be determined. The worst possible erosion (0.090) was calculated at this point and tests were carried out to determine how much erosion the primary O-ring could tolerate. Tests put this value at 0.095. The *safety margin* was set at 0.090. Feldman (2004, p. 700) emphasises that the engineers were not sure why the erosion had been 0.053 the first time. They only stated this to be the case based on measurements. The safety margin was a kind of compromise achieved in the crossfire of different demands and groups: engineers, managers, high-level NASA officials, political decision makers and 'stubborn technology', which had already been developed and could not be significantly modified within the given time limit (Feldman, 2004, p. 700). NASA seems to have introduced the safety margin concept so that the demands of different parties could be discussed using shared terminology. This (seemingly) did away with the conflicts in the demands since the parties could now use a neutral (objective) quantitative concept.

In 1983, heat was found to reach the primary O-rings in both nozzle joints. Since no erosion was detected, the engineers decided that the problem was *within the experience base* - that is, it was not a *new* threat to safety. By this time, 14 flights (by either Challenger or Columbia) had been made, 3 of which had exhibited problems with O-rings. Neither the safety margin nor the experience base could explain the problem or shuttle operations. In other words, the concepts were of no use for predicting operations. The parties also did not use experience accumulated from other shuttle programmes or aeroplane design. The safety margin and experience base offered NASA measurable concepts for use in quantifying moral judgement (Feldman 2004, p. 701). One could claim that the responsibility for safety-related decisions at NASA was transferred to quantifiable abstract concepts instead of people taking personal responsibility.

New issues related to the O-rings were detected in the following years. In 1984 the primary seal was endangered for the first time when soot was blown by the primary O-ring to the nozzle joint. Erosion was also detected in two primary O-rings. In the 1985 mission 51-C, lubricating oils burned in both the primary and secondary O-rings. This was the first time heat reached

a secondary O-ring. However, not even this event changed the plans. Based on their experiments, NASA researchers determined erosion to be a self-limiting phenomenon, which would thus not endanger shuttle safety. The new incidents did nothing but strengthen this 'belief'. In addition, both incidents and the erosion in the primary and secondary O-rings came under the experience base and the safety margin. The engineers at Morton Thiokol said: "the condition is not desirable but it is acceptable" (Vaughan, 1996, p. 156). According to Feldman, it was still unknown when and where the erosion took place, although previous investigations had already shown that gas eroded the O-ring through putty. In Feldman's view, interpreting the phenomenon as a self-limiting one was not plausible in view of the new evidence. Damage to the secondary O-ring should have raised doubts as to the redundancy of the rings. This, however, was not the case (Feldman, 2004, p. 706).

The hypothesis that erosion was caused by cold weather was presented for the first time during the 1985 mission 51-C flight. On that flight, the temperature on launch day had been 51 °F, the coldest to date for a launch of the space shuttle. However, since there was no quantitative support for this hypothesis it received hardly any attention in the investigations - despite it being a 'known fact' that the rubber used for the O-rings hardens in cold weather, so reducing the effectiveness of the seal. According to the accident report, four out of 21 flights had shown damage to the O-ring when the temperature on launch day had been 61 F or higher. However, all flights in lower temperatures showed heat damage to one or more O-rings (Report on the Presidential Commission on the Space Shuttle *Challenger* Accident 1986).

Later, during flight 51-B in the spring of 1985, the primary nozzle joint O-ring burned and the secondary O-ring was seriously damaged. The primary O-ring had not sealed as expected. Erosion was also detected on the secondary O-ring for the first time. The primary erosion was 0.171, clearly exceeding the safety margin (0.090). According to Vaughan (1996), erosion and O-ring redundancy became related technical issues after this flight. The investigations into the incident determined that the primary O-ring could only have eroded this badly if the incident had taken place within the first milliseconds of ignition. This, in turn, was only possible if the primary seal had been in the wrong position from the start. According to the investigators, had the joint itself leaked, all of the six joints should have leaked identically. The investigators attributed the problem to inspections overlooking the incorrectly installed seal. Based on the report, the pressure used for seal checks was increased. Furthermore, a launch constraint was placed on the solid rocket boosters.

The joints had to be checked for leaks before liftoff since the integrity of the joints was a crucial design factor (Jensen, 1996, p. 277). As the problems with the joints began to crop up, the pressure was increased from 50 psi to 100 psi and, finally, to 200 psi. There were some concerns about the effect of the prelaunch pressure test on the seals. If the pressure from the test broke through the primary ring, it would blow tiny pinholes in the putty, which

could then be used by flames [coming from the inside of the rocket] moving in the opposite direction (Jensen, 1996, p. 277).

Feldman (2004, p. 711) points out that after the events of spring 1985, the significance of the safety margin changed to mean the durability of the secondary O-ring. Similarly, the experience base referred to events prior to spring 1985 and did not include the primary ring burn-through experienced in the previous flight (because it could be explained by an error made during the installation of the seal and not by the technical features of the seal). The finding was that an increase in the check pressure would cause erosion in the primary O-ring but should eliminate all erosion in the secondary O-ring. This convinced all parties that both redundancy and safety margins were in order. Feldman emphasises that a 'devaluing of memory' culture prevailed at NASA; the organization lacked the capacity for individual and organizational memory (Feldman, 2004, p. 714).

The weather on Challenger's final launch day was exceptionally cold. Citing cold weather, the engineers recommended that the launch be postponed to the next day, but the management team, which had no technical experience, decided to go through with the launch. The launch had already been postponed due to poor weather and a technical fault. In addition, NASA was behind the planned launch schedule (12 flights in 1986). Engineers at Morton Thiokol, the subcontracting manufacturer of the Solid Rocket Booster and the O-rings, also had their doubts about the cold tolerance of the rings. They expressed their doubts in a teleconference held the evening before launch.

Vaughan (1996, 409–410) summarises: "The explanation of Challenger launch is a story of how people who worked together developed patterns that blinded them to the consequences of their actions. It is not only about the development of norms but also about the incremental expansion of normative boundaries: how small changes – new behaviors that were slight deviations from the normal course of events – gradually became the norm, providing a basis for accepting additional deviance. No rules were violated; there was no intent to do harm. Yet harm was done." The organization gradually drifted to a state in which it no longer operated safely. Earlier danger signals had become part of 'normal' work and they were no longer noted.

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