NKS-262
ISBN 978-87-7893-335-5

Intermediate report of MoReMO
Modelling Resilience for Maintenance and Outage

Oedewald, P.(1)
Macchi, L.(1)
Axelsson, C. (2)
Eitrheim, M. H. R. (3)

1. Technical Research Centre of Finland (VTT);
2. Ringhals AB (NPP) Vattenfall AB, Sweden;
3. Institute for Energy Technology (IFE), Norway

February 2012

Abstract

Resilience Engineering (RE) is a new approach to safety that helps organisations and individuals adapt to unforeseen events and long-term changes. Such an approach is needed by nuclear power plants (NPPs) as they face demanding modification projects, high staff turnover and increased pressures to maintain and improve safety. The goal of the Modelling Resilience for Maintenance and Outage (MoReMO) project is to develop and test models and methods to identify and analyse resilience in safety-critical activities in natural everyday settings. In 2011, we have applied four approaches in different case studies: Organisational Core Task modelling (OCT), Functional Resonance Analysis Method (FRAM), Efficiency Thoroughness Trade-Off (ETTO) analysis, and Work Practice and Culture Characterisation. The project has collected data through observations, interviews and document reviews at two NPPs. Together, the four approaches have provided valuable insights for understanding the rationale behind work practices, their effects on safety, and the support of flexibility and adaptability. In 2012, the MoReMO project will complete the data collection and integrate results on how resilience can be operationalized in practical safety management tools for the companies.

Key words

resilience, maintenance, outage, OCT, FRAM, ETTO, work practice

NKS-262
ISBN 978-87-7893-335-5

Electronic report, February 2012

NKS Secretariat
P.O. Box 49
DK - 4000 Roskilde, Denmark

Phone   +45 4677 4041
www.nks.org
e-mail   nks@nks.org

Intermediate report of MoReMO

Modelling Resilience for Maintenance and Outage

Pia Oedewald, VTT- Technical Research Centre of Finland, Finland
pia.oedewald@vtt.fi;

Luigi Macchi, VTT- Technical Research Centre of Finland, Finland
luigi.macchi@vtt.fi

Christer Axelsson, Ringhals AB (NPP) Vattenfall AB, Sweden
christer.axelsson@vattenfall.com

Maren H. Rø Eitrheim, Institute for Energy Technology (IFE), Norway
Maren.Eitrheim@hrp.no

Abstract

Resilience Engineering (RE) is a new approach to safety that helps organisations and individuals adapt to unforeseen events and long-term changes. Such an approach is needed by nuclear power plants (NPPs) as they face demanding modification projects, high staff turnover and increased pressures to maintain and improve safety. The goal of the Modelling Resilience for Maintenance and Outage (MoReMO) project is to develop and test models and methods to identify and analyse resilience in safety-critical activities in natural everyday settings. In 2011, we have applied four approaches in different case studies: Organisational Core Task modelling (OCT), Functional Resonance Analysis Method (FRAM), Efficiency Thoroughness Trade-Off (ETTO) analysis, and Work Practice and Culture Characterisation. The project has collected data through observations, interviews and document reviews at two NPPs. Together, the four approaches have provided valuable insights for understanding the rationale behind work practices, their effects on safety, and the support of flexibility and adaptability. In 2012, the MoReMO project will complete the data collection and integrate results on how resilience can be operationalized in practical safety management tools for the companies.

KEYWORDS: resilience, maintenance, outage, OCT, FRAM, ETTO, work practice

TABLE OF CONTENTS

1. INTRODUCTION

One of the challenges of evaluating and developing safety in organisations is that organisations' practices and technologies evolve constantly based on experiences, requirements and new information concerning efficient and safe solutions. Change and adaptation are necessary. Safe and efficient energy production of a nuclear power plant requires taking into account a variety of internal and external information and pressures. Also ad hoc adaptations to new situations are needed since many activities cannot be thoroughly specified in beforehand. This has become evident when the focus of safety research, especially human and organisational factors studies, has broadened from process control to other activities such as maintenance work, design and overall management of the cross-functional activities of an organisation. Current safety theories emphasise that timely and risk-informed adaptations are key elements for the efficient and safe functioning of organisations when coping with normal and abnormal disturbances. (Hollnagel, 2006).

The backside of adaptations is that organisational practises gradually evolve posing a risk of organisation drifting into risky practices without even realising it (Snook, 2000; Dekker 2011). Drifting means that practices and behavioural norms that once were considered exceptional and situational become gradually normalised. As a result of drifting, the conception of risk and safety margin may change unintentionally. In many cases, drifting takes place locally which poses a challenge for the overall manageability of the activities: one part of organisation works with different premises from what is expected by other parts. However, Dekker (2011) points out that drift may promote creativity and diversity in a way that gives rise to success.

Managers and safety experts in any safety critical domain lack practical approaches for helping organisations to manage the unexpected, to carry out successful adaptations and still to maintain the overall manageability of the activities. In the nuclear industry traditional safety and risk assessment approaches, such as HRA/PRA, aim at assessing the reliability of the system in responding to *known threats* (e.g. design-base accidents). Also training and instruction are designed to provide the personnel with means for coping with the *likely disturbances and risks* at work. Further, emphasis on *compliance with written procedures* is strong; suggesting that almost everything the employees face is assumed to be covered by the rules and procedures. In complex and dynamic organisations as nuclear power plants, where adaptations and drifts are usual, to better safeguard against serious events it is necessary for the safety experts and managers to also have tools and methods that don't neglect the under-specification of work and complexity of actual practices in the organisation.

Resilience engineering is a new approach to system safety. It *looks for ways to enhance the ability of organizations to monitor and revise risk models, to create processes that are robust yet flexible, and to use resources proactively in the face of disruptions or on-going production and economic pressures (Woods et al., 2010).* Resilience engineering pays attention to the fact that local adaptations, human variability and innovative thinking are not solely threats to safety and reliability. Instead, adaptation and variability is necessary because they enable the smooth functioning of the system and sensible responses to unexpected challenges. Overall, one of the premises of resilience engineering is that safety research should pay more attention to what goes right. Learning from incidents and accidents is important, but in terms of safety development we miss a huge data and may be biased on our thinking if we don't analyse what makes activities to succeed. It is worth researching how the ideas of resilience engineering could be incorporated into the safety management and safety culture frameworks adopted in the nuclear industry and whether the resilience engineering premises – still on a rather generic level in their development – can be utilised in practical method development.

1.1 Characteristics of maintenance work when analysed from a system safety perspective

Maintenance represents very well a complex, underspecified activity where organisations' resilience may manifest itself (Reiman 2011). Maintenance activities include heterogeneous set of tasks with varying degrees of technical demands, safety significance and inter-couplings. In conjunction with the performance of their activities, maintenance workers need to identify, remove, control and prevent the various hazards associated with the work. In addition to the hazards and technical complexities the work procedures and the social organisation is complex in the nuclear industry. Especially during the annual refuelling outages, the social organisation of maintenance tasks becomes even more complex than usual since such substantial number of tasks needs to be accomplished in a short timeframe, involving a large number of external interconnections like contractors, modifications and suppliers.

Even though outages are planned in great detail, there is constant need for adapting the schedule to emerging problems. The master schedule usually contains slack time to accommodate minor deviations. If major problems emerge, additional re-planning and problem solving occurs that goes beyond moving the schedule to the left or the right. Since the duration of the outage has direct financial implications for the owners, there is a strong incentive to keep outage delays to a minimum. Even though all available resources are mobilized, there are often challenges in resource allocation (e.g. scaffolding, craft personnel), in particular in case of schedule changes or emerging issues.

For the safety of nuclear plants, effective and reliable maintenance activities are of crucial importance since maintenance provides the technical preconditions for undisturbed operations and functioning of the safety systems. At the same time, however, poorly executed maintenance is one of the sources of technical failures and initiating event for plant disturbances. In various safety-critical domains, including railway, offshore oil drilling, chemical, petrochemical, aviation and nuclear industries inadequate or faulty maintenance has been found as one of the main contributors to events by accident investigations (see e.g. Reason, 1997; Hale et al., 1998; Kletz, 2003; Reason & Hobbs 2003; Perin, 2005; Baker, 2007; Sanne, 2008a).

When studying the safety and resilience in maintenance activities there are several issues that deserve special attention.

First, the status of *maintenance work is not traditionally highly recognised in the organisations*. Maintenance work has a "dirty hands" image and it is often considered as manual labour (Oedewald & Reiman, 2003; Perin 2005). From system safety development point of view that may pose a challenge. Maintenance workers have a first-hand access to weak signals concerning the status of the plant, the technical phenomena affecting safety. Their knowledge, observations and reports are important material for the development of safety. This knowledge creation function of maintenance work shouldn't be forgotten.

Second, the role of workers' experience and tacit knowledge is usually emphasised when analysing the quality of maintenance activities (Orr, 1996). However, especially during outages and modification projects subcontractors' *knowledge and experience vary significantly.* There may be companies and workers who have specialised in certain tasks and components in the nuclear industry and they can be expected to know the work thoroughly. However, there are also newcomers and companies without prior nuclear industry experience. Mechanisms to convey the relevant knowledge concerning the work scope and quality and safety demands needs to be efficient. Especially the more experienced workers need to be able to explicate the technical and working practice demands in an accurate way and reply to the questions of the inexperienced colleagues. That is not always the case. Oedewald and Reiman (2007) showed that number of experienced maintenance workers replied insufficiently to written questions concerning technical concepts relevant to their plant. Their ability to communicate certain technical manoeuvres, findings or quality demands may suffer from the lack of conceptual knowledge. Still, even the inexperienced workers may be involved in situations where they need to adjust e.g. changing schedules and coordinate their activities with other parties constantly. These situations may represent risks if the knowledge of the workers is limited.

Third, maintenance teamwork often involves distributed, non-established teams. A number of locations involved in the outage need to coordinate, including the main control room and the work sites in the field. Teams that do not cooperate on daily basis need to build trust and rapidly develop structures and processes for working together efficiently (Hildebrandt & Koskinen, 2011).

Fourth, maintenance activities involve hazards that threat occupational as well as plant safety. In addition to that maintenance activities, as any other group, can be considered imposing security risks (e.g. risk of smuggling explosives into the plant area, risk of wrong persons getting the access to the information systems). Thus, when safety is emphasised it may *not always be clear what safety is in question*, i.e. what are the threats the workers should keep in mind. Halin et. al (2010) found that maintenance workers tend to talk about occupational safety measures when safety practices where inquired.

Fifth, *balancing and prioritizing concurrent goals* is a daily task for any maintenance organization. Procedures, schedules and work practices are all tools that help optimize one or several objectives. For nuclear power plant maintenance, several considerations have to be taken into account: efficiency, plant operability, nuclear safety, occupational safety and costs. A dilemma arises when multiple goals cannot be met concurrently. The situation is aggravated when the criteria for each goal are unclear, where clear rules or guidelines for prioritizations are lacking, or when it is unclear if a goal can be achieved. Whenever two or more goals are in conflict, the individual may have to make a trade-off decision, sacrificing in how well one or all goals can be achieved, or mobilize additional resources to achieve both goals. In some cases, the cost of sacrificing a goal is potential or probabilistic.

Hoffman and Woods (2011) have developed a model that aims to identify the fundamental trade-offs that bound human performance. The five trades-offs identified are:

1. Optimality-Resilience Trade-off: Increasing the scope of a routine (e.g. procedure) increases the opportunities for surprise at the boundaries. Optimizing over some demands leads to brittleness when encountering other demands. Resilience requires a capacity to adapt to surprising events, and preparing for surprise requires resources.
2. Efficiency-Thoroughness Trade-off: Knowledge defines plans. Efficient plans mark well-worn paths but it becomes cumbersome to incorporate contingencies and variations. Thoroughness expands the scope of the plans, expanding assessments, decisions and ambiguities.
3. Acute-Chronic Trade-off: Chronic goals tend to get sacrificed to acute goals, which in turn leads systems to miss how and where they are brittle.
4. Specialist-Generalist Trade-off: Responsibility defines roles. Specialist roles increase the ability to handle specific kinds of cases, but challenge the ability to connect the activities together to achieve continuity for cases that cut across roles. Generalist roles enable handling diverse situations, but less fluently for specific kinds of situations. Coordination expands scope of activities but must be balanced with new costs associated with coordination.
5. Distributed-Concentrated Trade-off: Distributing activities that define progress toward goals can increase the range of effective action, but increasing the distribution of activities entails some difficulty of keeping them coherent and synchronized. Concentrating activities in single roles can produce more immediate and definitive progress toward landmarks, but also reduces the range of effective action. The challenge is to balance micromanagement with delegation over echelons.

Although this framework has not been studied in the maintenance context yet, it may shed light to maintenance workers' practices, and it may help understanding the reasons behind balancing and prioritizing strategies.

1.2 Practical challenges in developing safety of complex, multi-actor activities

Resilience Engineering tackles some of the themes integral to safety culture models such as IAEA and DISC model (Oedewald et al. 2011). For example the notion that organisations need to consider safety as integrated in all activities – and in relation to productivity and efficiency pressures - is nowadays visible in safety culture thinking as well. Researchers of resilience engineering also emphasise continuous learning in organisations, the need to create more and more understanding on how the system actually works.

However, many safety culture models talk about safety of activities as if safe activities had generic, perceivable and tangible characteristics in the behavioural level. In this respect the resilience engineering approach has a different emphasis; it states that safety emerges from the complex interactions of different parts of the system. The interactions are more or less contextual and situational. An action that is executed according to prescriptions and usually results in a wanted outcome, may be inadequate in other contexts or situations and results in undesired and unexpected manner

Developing practical tools and methods coherent with the different resilience engineering premises is challenging. First, grasping “normal” activities, where things go right, poses *a challenge of focus of data collection and analysis*. Usually when somebody is analysing, observing and evaluating an activity there is at least an implicit assumption to look for problems or deviations from rules or behavioural standards. When the aim is to understand the dynamics of the activities and especially the success factors of it, it is insufficient to focus only on deviations from predefined standards. There needs to be a framework or frameworks which define the elements generally interesting for resilience and relevant in the activity in question.

Second, *resilience engineering employs systems thinking.* It is the interactions within and outside the system that needs to be understood. Thus, the scope of analysis easily becomes rather large and it may be difficult to decide the boundaries of the system to be analysed. There are few functions in a nuclear power plant that can work independently from other groups or with limited and simple couplings with them. The practical question is how much all the “neighbouring” functions need to be tackled in the models that primarily aim at understanding certain predefined activities.

Third, *generic versus contextual criteria for good performance* in evaluative studies is a challenge. When safety developers try to identify practices or markers of resilience they need to take a stance if some models or lists developed in other domains or other situations are good enough to be used in their specific work scope. Resilience engineering researchers have emphasised local and ad hoc solutions for creating resilience into the organisations. However, recently Hollnagel (2009) has talked about four cornerstones or abilities of a resilient system: **learning**, knowing what has happened; **monitoring**, knowing what to look for; **anticipating**, knowing what to expect; and **responding**, knowing what to do. The meaning and the applicability of the four cornerstones have been examined in couple of studies. The Halden Reactor Project supported a master’s thesis where these abilities were used as a framework for depicting how crews can be enabled to act flexibly in situations where procedures cannot be applied (Gustavsson, Johansson & Hildebrandt, 2011).

Fourth, *the question of timeframe needs to be solved.* The basic aim of resilience engineering is to improve the ability of the organisation to succeed better. Thus, the methods and models should provide useful and valid information for the future. The methods used to analyse past incidents or a specific activity taking place just now don’t always give explicit guidance about how to draw conclusions on the future performance. It is important to understand the role of situational variation and more generic patterns of the activity when making judgements of the safety of the activities.

1.3. Objectives and scope of the publication

The scope of this publication is to present the preliminary results of the MoReMO-project (Modelling Resilience in Maintenance and Outage). The results presented in this publication set the foundation for the continuation project work in 2012. The overall goal of the MoReMO project is ***to develop and test models and methods to identify and analyse resilience*** *in safety-critical activities in natural everyday settings.* The aim is to find models and methods that allow analysts to describe and understand how activities are carried out in practice, as well as to understand the local rationale of the practices and evaluate the possible effects of the practices on safety. These ***models and methods may be further developed into practical safety management tools*** for the companies and thus support flexible, adaptive work practices.

The MoReMO project studies the organisation and working practices of maintenance and outage organisations in Nordic nuclear plants. We believe that resilient practices are most readily observed where sharp-end activities are carried out. Therefore a bottom-up research approach is appropriate for the proposed project.

The MoReMO project involves two primary case studies concerning outage working practices; Ringhals and Loviisa power plants. In addition to that, results of set of case studies and literature surveys carried out by the same research groups will be used in complementing the findings, since they tackle the themes of NKS-MoReMO project. The additional case studies, which provide background findings, are carried out in Oskarshamn outage study, ETTO-project and a teamwork in outage study. Later in 2012, VTT performs maintenance working practices study at Olkiluoto as well.

This publication presents four different models and methods beneficial for identifying and analysing resilience. By presenting their application in different case studies, this publication aims at illustrating both their potential, and development needs.

2. MODELS AND METHODS

2.1 Organisational Core Task modelling

Oedewald and Reiman (2003; Reiman & Oedewald 2006) have proposed a methodology called the Contextual Assessment of Organisational Culture (CAOC) which applies two basic concepts, the *organisational core task* (OCT) and the organisational culture, to capture the systemic and complex nature of maintenance work. In MoReMO study OCT-modelling has been chosen and applied to gain generic criteria for discussing the possible safety implications of both practices and cultural features identified in the case organisations.

OCT-modelling aims at generating a generic definition of the organisation's mission, i.e. its core task. Furthermore, it aims at identifying and depicting the demands that are fundamental for safe and effective activities in the long term. The underlying assumption of this approach is that if the organisation manages to create a culture where the OCT demands are identified, kept in mind and taken into account in daily practices, their practices do not and will not drift into the unsafe zone (Figure 1).

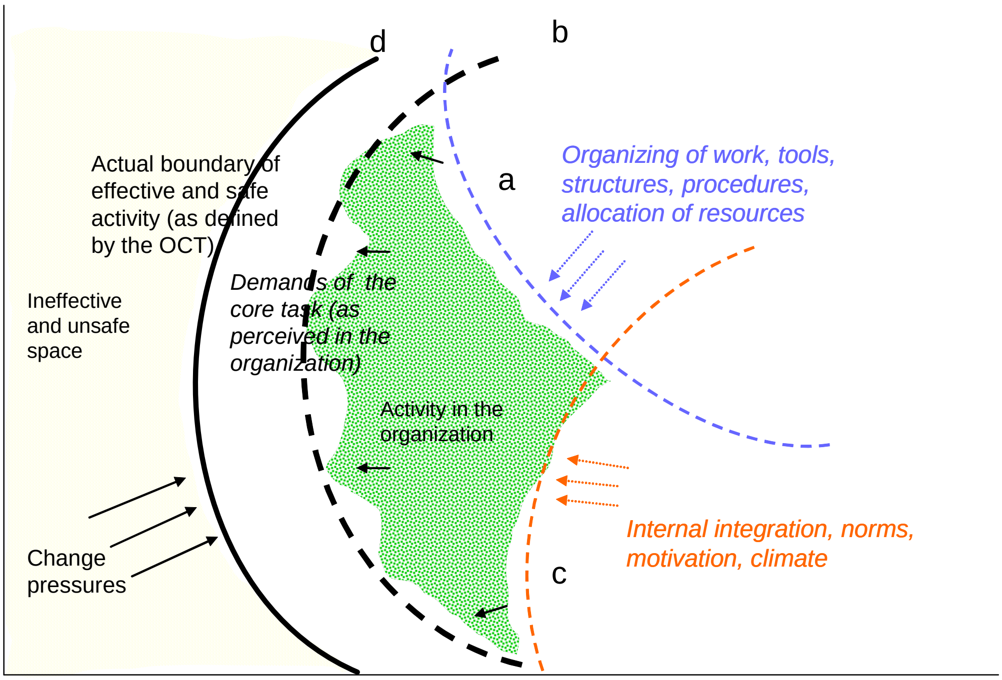


Figure 1 Reiman and Oedewald (2007) have illustrated the importance of identifying the core task and demands it set for the organisation with a figure inspired by Rasmussen (1997) model of migration. Different pressures in the organisations culture tend to induce drift towards unsafe practices unless there is a strong sense of where the boundary of fulfilling the core task demands lies.

In MoReMo project document analysis, interviews and literature were utilised in defining the core task of an outage organisation at one of the case plants. Documents covered the generic introductory training material (the researchers participated in the training) and company brochures containing information on the expectations concerning the working practices in outage, maintenance task description from organisational handbook, work orders and schedules for specific tasks in the outage 2011. Five semi- structured interviews were carried out. Interviewees included the head on I&C maintenance, a maintenance planner, two supervisors and a technician.

2.2 Functional Resonance Analysis Method

The scope of the Functional Resonance Analysis Method (FRAM) modelling activity was to capture, from a systemic perspective, the actual way in which the maintenance of a diesel engine generator took place during the 2011 outage at one of the case plants. The use of the FRAM adopts a systemic perspective meaning that analysis cannot be constrained to a specific part of the socio-technical system, but it has to consider a larger picture where the organization is considered as a whole rather than as an assembly of components. The FRAM analyses an organization as a socio-technical system (Trist, 1978) where technology is embedded in a social context that designs, tests, runs and maintains it.

In this phase of the MoReMO project, the scope of the FRAM modelling was to identify and describe the functions necessary to perform the maintenance of the diesel engine generator. The description of the functions according to the FRAM methodology provides understanding on the couplings and dependencies between the functions, and it can be used to support the reasoning of how small deviations and adjustments can resonate in the system and result in unexpected problems. On the other hand, the same couplings and dependencies can be used to illustrate some of the reasons why activities are successfully performed and how the maintenance activity is deeply interconnected with several activities performed during the outage as well as before the outage is started.

The data collection for the FRAM modelling has been conducted in three different phases. First, a two days site visit has been organized during 2011 spring. The scope of the visit was to get acquaint with the case organisation’s outage in general terms and specifically with the environment and task of diesel engine maintenance. During the visit, researchers had the opportunity to interact with the technicians servicing the diesel engine, and to start building preliminary understandings of both the maintenance task and of challenges and constraints technicians have to cope with during their work. The visit also allowed researchers to grasp some information about the connections between different roles, duties and ongoing activities during the annual outage. This facilitated the following interactions with maintenance personnel and helped to understand the nature of the activity to be modelled. During the site visit, official material and documentation has been collected, and a list of necessary information has been drawn up and agreed upon with the contact person. In particular the list of tasks, work permits and associated schedule has been acquired. This list has been used by researchers for the formulation of a preliminary draft FRAM model of the diesel engine maintenance.

The second phase of data collection consisted in a workshop held in the beginning of 2011 autumn. Researchers, the contact person and, most important, mechanical technicians who serviced the diesel engine participated in the workshop. The objective of the workshop was to discuss, revise and update the preliminary FRAM model that was developed based on the information gathered during the site visit and on the official documentation. The workshop helped researchers in identifying some of the functions and to specify their aspects (Input, Output, Control, Preconditions, Time and Resources).

The so-revised FRAM model has been further checked and improved during a second workshop in the late autumn 2011. The workshop aimed at completing the data collection and to further check the appropriateness of the functions, the correctness of their description, and finally to ensure that no fundamental part of the modelled activity was missing or had been misunderstood.

2.3 Identification of efficiency thoroughness trade-offs and other goal conflicts

One approach used in making sense of adaptations and performance variability is the analyses of trade-offs and goal conflicts in the activity (Hollnagel, 2009). To provide a conceptual basis for the study, two approaches were identified that could support the investigation of goal conflicts. The first is recent work on efficiency-thoroughness trade-offs (ETTOs) (Hollnagel, 2009). The other is a simple goal conflict typology developed by one of the authors for application in the off-shore oil industry (Skjerve, 2009).

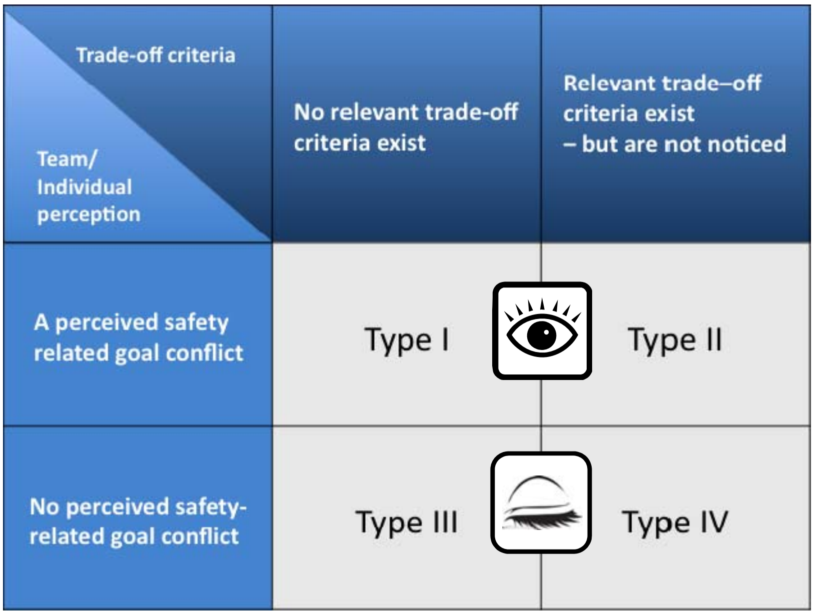
The Efficiency-Thoroughness Trade-Off principle (Hollnagel, 2004; 2009) states that

> "(…) *in their daily activities, at work or at leisure, people routinely make a choice between being effective and being thorough, since it is rarely possible to be both at the same time. If demands for productivity or performance are high, thoroughness is reduced until the productivity goals are met. If demands for safety are high, efficiency is reduced until the safety goals are met.*" (Hollnagel, 2009, p.15)

Hollnagel also identifies a list of individual, organizational and work-related ETTO rules, such as "It looks fine" (meaning an action or effort can safely be skipped) and "It will be checked later by someone else". An ETTO rule will only persist if the underlying assumption usually holds, or if the consequences of misapplying the rule are minor. When the consequences are high, the incentive to prioritize thoroughness increases. Thus, there will be situations when ETTO rules are applied inappropriately. The more common bias then is to prioritize effectiveness over thoroughness.

Ann Britt Skjerve (2009) has suggested a simple goal-conflict typology for high-risk industries which may be more sensitive of identifying actual trade off in nuclear plants than a straightforward inquire of ETTO's. The motivation for developing the typology was observations within the petroleum industry indicating a discrepancy between the standing order of prioritizing safety and incident reports concluding that safety goals are not always prioritized in practice. Based on the assumption that employees do not consciously make prioritizations which may sacrifice safety, Skjerve (2009) suggested that the balancing of safety goals against other types of goals was conceived differently by the employees, who make the trade-offs in real time, and the accident investigations.

Skjerve (2009) suggested that goal conflicts in work settings could be defined as situations in which a (safety) goal is in conflict with one or more other desired goal(s), as judged by individual(s) in real time and/or as judged based on the safety standards of the organization. The goal conflict comprises two dimensions: The first dimension is called Team/individual perception. It refers to whether or not an employee/team in real-time perceives that a safety goal conflicts with other goals. The second dimension is called Trade-off criteria. It refers to whether or not the organization in question has dedicated procedures (trade-off criteria), which specify how safety goals should be prioritized in the given situation. For the sake of simplicity, it is assumed that these procedures are perceived to be adequate, by the operational staff.



Trade-off criteria Team/ Individual perception	No relevant trade-off criteria exist	Relevant trade–off criteria exist – but are not noticed
A perceived safety related goal conflict	Type I	Type II
No perceived safety-related goal conflict	Type III	Type IV

Figure 2 - A Simple Goal Conflict Typology for High-Risk Industrial Settings (Skjerve, 2009).

Type I goal-conflicts imply that an employee accurately (i.e., based on the standards of the organization) perceives that a safety goal conflicts with another goal, and accurately assesses that no specific trade-off criteria exists for how the situation should be handled. This type of situation may arise, e.g. when an individual is asked to achieve multiple conflicting goals simultaneously, e.g., to perform a highly complex task fast and safely at the same time in situations where the standards of the organization does not help him or her prioritize between these goals.

Type II goal-conflicts imply that an employee accurately perceives that a safety goal is in conflict with another type of goal, but is unaware that relevant trade-off criteria actually exist (if the individual is aware of the trade-off criteria, he or she will not experience a goal conflict, but simply prioritize the goals involved in accordance with the requirements in the standards).

Type III goal-conflicts imply that the employee does not perceive any goal conflict in a situation where a goal conflict actually does exist, as judged based on the standards of the organization, and where no trade-off criteria are available (or sought after). This type of situation essentially arises when an employee has not adequately considered the situation at hand from a safety perspective. A type III goal conflict may, e.g., arise when a situation is new or unexpected to the employee, or when the employee does not have sufficient time (given the means available) and/or competence to establish an adequate situation overview (situational awareness).

Type IV goal-conflicts refers to a similar situation as type III goal conflicts, in the sense that the employee does not experience any goal conflict, while carrying out his or her task. However, as judged based on the standards of the organization a goal conflict does exist – as well as standards for how to address it.

This goal conflict typology may serve as basis for distinguishing different types of initiatives for facilitating adequate prioritization of safety goals in work settings. Goal conflicts of type I and II point to the need for making the standards of the organization readily available to the employees. Goal conflict type III and IV point to the need for supporting the employees in obtaining an accurate understanding the risks associated with the situation at hand. It should be stressed that goal conflicts in practice may also arise between different type of safety goals.

Based on the literature analysis and an elaboration of the plant needs, we developed an interview guide in order to address the following topics:

- whether interviewees experience ETTOs in their work
- what kind of ETTOs they experience
- the sources of these ETTOs
- what kind of goal conflicts the interviewees experience
- why many ETTOs are resolved in a positive way

2.4 Characteristics of working practice and culture

To collect manifestations of working practices likely to increase or hinder the resilience of the system, the researchers and the three power companies selected certain work scopes to observe during the annual outage 2011. Two or three researches observed certain outage jobs for one or two days. During the observations the researchers also interviewed workers and photographed the working environments and working situations. The observations were used for two purposes: first they produced material for the FRAM model. Second, they gave information on organisation’s way of handling everyday challenges and ability to identify and take into account outage organisation’s core task demands. Observations aimed at identifying practical ad hoc decisions, local adaptations and their backgrounds. In other words the observations were used to collect data on the working culture of the outage organisations.

The data collection method included pre-observation document review of the work scope. Further, an expert from maintenance or operations was interviewed prior to the observations to clarify the safety relevance of the work being observed, the background information concerning selection of the working group and informing on the possible challenges in the course of work. Researchers took notes during the observations which were reviewed in the end of each observation day.

A practical tool used to structure the observations was a list of maintenance working practice demands based on core task modelling by Reiman & Oedewald (2006). It was utilised since at this point of data collection the researches did not yet have a new OCT-model. It was completed with three demands which were considered important based on the researcher's latest experiences in the nuclear power plants. These were: 1) managing/supervising/collaborating with the contractors, 2) knowledge of the safety significance of the systems one is working with, and 3) mentoring/on the job training of the newcomers. (Table 1).

When analysing the properties of socio-technical systems one important viewpoint to take into consideration is culture. Culture can be viewed as multi-layered construct (Reiman et.al 2010). Culture manifests itself in the concrete structures of the activities, such as in the resources, working arrangements and in the instructions. Furthermore, culture sets social norms, defines what is considered important, how goals are prioritised and what the status of different groups is. The psychological states and the conceptions of individual workers are affected by the culture prevailing in the system as well. Feelings of being in hurry or perception of risk in certain situation are largely dependent of the safety culture of the organisation. The culture of an organisation frames the behaviors and situational decisions taken in real activities (Reiman & Oedewald 2009). Thus the different layers of safety/organisational culture (structural, social and psychological aspects) need to be covered when an analyst tries to explain resilience of the activities. To cover these aspects in the observations relevant topics to pay attention to were discussed beforehand (Table 1).

Table 1 - The check list researchers used in observations to pay attention to working practices which may be relevant from the core task point of view

Working practice demands for all activities in maintenance organisations	Pay attention to for example these in the observations
1. Co-ordinating timetables and resources within maintenance	Common meetings between groups? Access to information systems? Clear way to handle delays? Feeling of time pressure among the workers? The role that foreman has taken; his orientation and focus, multitasking?
2. Co-ordinating work between maintenance and operations	Is there a clear work permit process and knowledge of it (approval to start working, information on availability, and verification of operability)? Is it easy to communicate to operations? What are the channels (phone calls, face to face, papers), who can contact operations?
3. Co-ordinating work between technical support and maintenance	How is the relevance of the work communicated, in the papers or orally? Do workers know the reasons for modification, special quality requirements, safety significance
4. Defining responsibility areas	Is there a mutual knowledge of the contractors and the individual workers experience and competencies? Are roles clear for them? Are interfaces with other tasks and other systems defined and described. How good is the understanding the overall picture of the activities coupled

	to the job in question?
5. Keeping up with the maintenance program for the specific work scope	Do workers possess knowledge what is the meaning of this work and when the system is checked next, whether it's periodical/preventive maintenance or a fault repair? Do they report if deficiencies are identified?
6. Prioritizing the work tasks	Is the communication concerning schedules clear or is there mixed messages concerning the urgency and hurry? How delays are handled? Do they use informal organisation to speed up things? Is there any possibility to move resources from other tasks?
7. Co-operation between different technical disciplines within maintenance	Are the tasks described in same or distinct work orders/permits? Do groups have joint/different meetings? Multiple means to for communicating to other work groups?
8. Adhering to procedures and instructions	Are the work orders, instructions and manuals up to date? Are they at the work place or in the office? Do they review them?
9. Transparency of actions and documentation of the work and its outcomes	Are there specific checking practices (working in pairs; self checking vs peer checking, independent verification)? How is the work and the results documented for later purposes (on paper, in electronic format?) Who does it, maintenance, QC? Are qualitative descriptions of the findings done?
10. (safety/risk) Information management	Is work focused on the technical steps or are there steps for gathering and interpreting data concerning new phenomena? Are workers aware of expert analyses done based of outage findings, are those utilised in their work. Do they report deviances or near misses?
11. Managing/supervising/collaborating with the contractors	Are the tasks clearly managed and supervised by in-house personnel? Do contractors make decisions on their own or do they consult in-house staff? Do contractors have same access to rooms and information systems than in-house personnel? Is there informal connections, e.g. do they spend breaks together?
12. Knowledge of the safety significance of the systems one is working with	Is the safety significance of the system indicated in the documents? Are the workers aware of the functions of the system? Do they know what might be the safety consequences if their work doesn't go as planned?
13. Mentoring/on the job training of the newcomers	Has the organisation done succession planning concerning this job? Are newcomers, younger professionals involved with the work? Are they actively instructed or mentored during the course of work?

In addition to the themes mentioned in Table 1 each researcher approached the work situation based on her/his previous experiences and interests. It was agreed that observations may be done from rather grounded starting point. Thus, the group took notes concerning e.g. innovative adaptations, communication styles and deviations from behavioural expectations and housekeeping norms. It was considered important to focus the observations on examples of resilient practices which are normally hard to grasp by surveys or interviews.

3. RESULTS OF 2011 WORK

3.1 Organisational core task of an outage organisation

The application of the OCT modelling methodology allowed the researchers to agree on a preliminary definition of organisational core task of maintenance during outages. The preliminary definition reads: *The core task of maintenance during the outage is to provide the technical conditions for effective and safe operation of the plant until the next scheduled overhauls and fuel load. This includes tasks such as fuel reload, periodical inspections, planned overhauls and fixing detected faults.*

This definition is largely based on literature, the document analysis and interviews at one of the case plants. A first point deserving to be mentioned is how in the case organisation the modifications were rather clearly excluded from the scope of core task of outage organisations. However, the same maintenance groups perform installations during outages which are part of the modernisation projects.

Core task modelling requires as well the identification of the characteristics and requirements to be taken into account when an organisation takes care of its core task.
Based on iteration of all the data collected we summarised that the maintenance organisation needs to take into account certain characteristics of nuclear plants. These include:

- The need to remove the fuel residual heat; defence in depth needs to be maintained even though safety systems are intervened
- Radiation set access constraints and time limits for work as well as requirements for materials
- Couplings between subsystems
- The possibility of findings (corrosion, leaks) which are impossible to detect when the plant is in operation
- The technology is a mix of old and new and thus different types of expertise is needed
- Maintenance interval for many systems is years, thus it is hard to cumulate experience of the tasks
- Inherent occupational safety hazards e.g. electricity, heights, heavy objects
- Quality requirements of the work and materials differ sometimes from other industrial domains and workers may not be aware of that

There are other constraints for organising maintenance activities during outage:

- Costs cannot get too high, thus the outage schedule needs to be as short as reasonably achievable
- Many work tasks need to be accomplished at a short time window, meaning that the work cannot be done solely with in-house personnel. This is why lots of external contractors are utilised.

- Outages may take place during vacation season which makes it harder to find workers.
- Expertise is specialized. There are few “jack-of-all-trades workers” who can be flexibly moved from one work to another.
- Change of workforce generation is going on both in the power companies and in the contractors. Thus there are inexperienced workers involved in many stages of the activities.
- Nuclear safety, environmental and occupational safety regulations are extensive. The expectations that they are adhered to are high in nuclear industry.
- Media attention for nuclear industry is high. This increases the pressure to avoid even small deviations.
- If there are many unexpected tasks and thus the duration of the outage is extended, the fatigue of workers may become a significant constrain for good quality of work.

Based on the above lists the critical core task demands were deduced. A critical core task demand is a demand valid for all activities at all levels of the organisation. Most individual actors in the organisation contribute to its fulfilment. In our preliminary analysis we identified six critical core task demands for maintenance during the outages:

- Planning of the tasks, schedule and resources (which need to be as complete beforehand as possible)
- Coordination of the activities with the other parties (needs to be continuous)
- Monitoring of the plant condition while performing any tasks (needs to be a shared task)
- Knowing what is essential in each technical system one works with and knowing what might be the (safety) consequences if the work does not succeed
- Prompt reacting to unexpected findings at the plant
- Allocating resources in a flexible manner, redirecting attention and resources from task to another

In the continuation of the project, since other emphasis might exist, e.g. in the Finnish plants, these demands will be validated and complemented together with the definition of the organisational core task.

3.2 FRAM model of the maintenance performed on an Emergency Diesel Generator

The data collected have been used for developing a FRAM model of the maintenance performed on an Emergency Diesel Generator. The model is constituted by a set of functions that describe the activities carried out to service the engine as required by the outage schedule and requirements. The principle that guided the identification of functions is the need to achieve a description of the normal activities performed by the socio-technical system being analysed (Macchi, 2010)

Each function, graphically showed as a hexagon (Figure 3), represents one specific activity. For each function six aspects are described. The aspects refer to six different dimensions (Hollnagel 2004, Macchi, 2010):

- Input (I): that which the function processes or transforms or that which starts the function;
- Output (O): that which is the result of the function, either a specific output or product, or a state change;
- Preconditions (P): conditions that must be exist before a function can be executed;
- Resources (R): that which the function needs or consumes to produce the output;
- Time (T): temporal constraints affecting the function (with regard to starting time, finishing time, or duration); and
- Control (C): how the function is monitored or controlled.

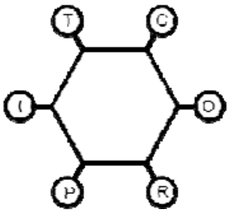


Figure 3 FRAM hexagon

The information for each function can be summarized in a very simple table (Table 2) that can be then used as a basis for further analysis.

Table 2 Function description

Function X	
Input	
Output	
Control	
Time	
Preconditions	
Resources	

Since the FRAM model describes couplings and dependencies between functions, it is necessary to ensure that the model is consistence and complete. This means that every aspect of every function is produced, as an Output, and used, as Input, Control, Precondition, Time or Resource, by functions identified and described in the model (Macchi, 2010).

The iterative process of data collection and modelling resulted in the identification and description of 25 functions here below listed:

- Isolate System (OP)
- Drain system
- Remove cylinder head
- Inspect cylinder liner & cleaning
- Assemble cylinder head
- Replace fuel injection pumps
- Replace hoses
- Fix identified problems
- Inspect auxiliary equipment
- Overhaul auxiliary equipment
- Grease auxiliary equipment
- Lubricate DC alternator supply
- Lubricate control rod to injection system
- Align system (OP)
- Test system (MA & OP)
- Monitor for problems
- Evaluate urgency of problems
- Spare parts management
- Experience/ Knowledge management
- Issue work permits
- Outage planning & control
- Test water
- Procedures management
- Assign personnel to functions
- Complete & sign off work permit

It is important to remember that any FRAM model is not a diagram or a flowchart, but the verbal description of the functions, including the six aspects. ***The complete description of the functions constituting the FRAM model is reported in appendix (Appendix 1) of this report.***

As described in Macchi (2010) FRAM functions can be differentiated according to their being part of the focus of analysis or part of the background. In the FRAM background functions provide support and means (i.e. Inputs, Controls, Resources and Preconditions) for the performance of the set of foreground functions. The systemic approach adopted by the FRAM therefore requires that both foreground and background functions are modelled with the same approach. The identification of background functions is based on the consistency check of the model and starts from the description of foreground functions. In this manner, it is ensured that all the relevant context-related aspects are taken into account while at the same time it is reduced unnecessary efforts in considering negligible factors.

Since the objective of this FRAM model is to represent the actual way in which the maintenance of an Emergency Diesel Generator took place during the 2011 outage, it is natural to consider the activities directly and specifically related to engine maintenance as the focus of the analysis. In this case the foreground functions of this model are:

- Drain system
- Remove cylinder head
- Inspect cylinder liner & cleaning
- Assemble cylinder head
- Replace fuel injection pumps
- Replace hoses
- Fix identified problems
- Inspect auxiliary equipment
- Overhaul auxiliary equipment
- Grease auxiliary equipment
- Lubricate DC alternator supply
- Lubricate control rod to injection system

The consistency check resulted in the identification of the background functions which provide means and support for these foreground functions. The background functions for this model therefore are:

- Isolate System (OP)
- Align system (OP)
- Test system (MA & OP)
- Monitor for problems
- Evaluate urgency of problems
- Spare parts management
- Experience/ Knowledge management
- Issue work permits
- Outage planning & control
- Test water
- Procedures management
- Assign personnel to functions
- Complete & sign off work permit

Since the distinction between foreground and background is relative background functions can become foreground functions when and if it is considered important to achieve a more detailed understanding of the functioning of the system. In such a case, a new relative background has to be identified.

Coupling between the functions:

The identification and description of both foreground and background functions results in the actual FRAM model for the selected activity. A first result that can be achieved at this stage is the appreciation of the couplings and dependencies between the functions. Figure 4 shows how the functions are connected (brown functions are background functions, grey functions are foreground functions). The position of the functions in this figure does not suggest any specific temporal sequence of execution of the functions, nor any cause-effect relations between the function. The figure serves the purpose of illustrating how serving a diesel engine during outage in a nuclear unit is a complex and complicated task. In a situation like this, where functions are so highly interconnected, it is easy to imagine how things can start to go wrong and resonate within the system. At the same time, by looking at this figure, it is evident how the accomplishment of maintenance tasks requires far more activities to be performed than the one represented in the official documentation of work permits.

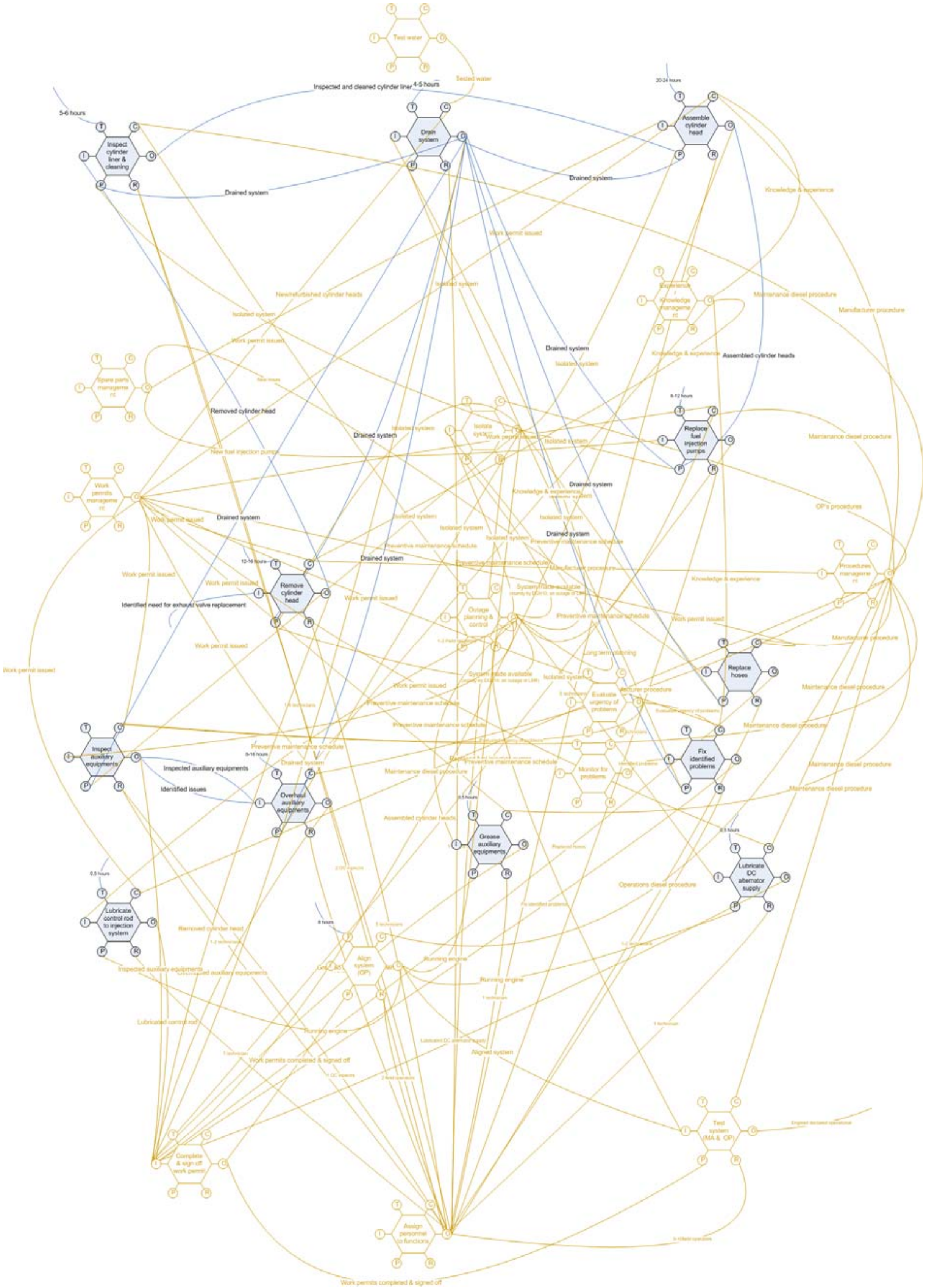


Figure 4 – The FRAM model of the diesel engine service.

3.3 Identification of ETTO and other goal conflicts in nuclear power plant maintenance

Eight maintenance staff at one of the case plants were interviewed specifically on the goal conflict point of view. The interviews focused on how they recognize safety goals, how they handle goal conflicts, and what supports positive work practices. The participants associated safety goals with the safety-relevant equipment they handled and performing the work in a professional manner, i.e. in accordance with norms of the group, the standards or their training, as well as application of human performance tools (e.g., pre-job briefings, stop-think-act-review). For planned work, the procedures support employees in performing the job safely. In troubleshooting situations no procedures may be available and they rely on the team's experience to solve the problems. Regarding personal safety, the interviewees mentioned incidents that could have been avoided if the precautions in the procedures were applied. They attributed the failure to follow the precautions to complacency and misperception of the risk involved.

To investigate possible efficiency-thoroughness trade-offs, we tried to identify other goals that might be in conflict with safety goals. All respondents agreed that they experience high workload and periods of time pressure. One respondent mentioned an example where a contractor did not perform the job according to standards because of perceived time pressure. However, the respondent believed this to be an excuse for not performing the work thoroughly, and that the underlying reason was complacency. Another respondent brought attention to administrative routines that delay the work progress without benefits in safety or thoroughness of the task. Overall, the respondents stated that time pressure does not affect the quality of their work, referring to the policy of "you have as much time as it takes". None of the respondents indicated that budget or financial goals were an important constraint of their work.

According to the interviewees, successful performance of work is related to individual characteristics such as the level of experience, perceived emphasis of safety and a questioning attitude; and team behaviour, such as cross-functional communication, mutual support and a positive team spirit. Obstacles to successful performance could be security routines requiring extensive foresight in planning, administrative burdens, ineffective coordination and individual priority issues.

The interviews did not provide strong examples of safety relevant trade-offs. As suggested in the literature (Hollnagel, 2009; Skjerve, 2009) ETTOs are often not conscious decisions, but resolved by habit, social norm or procedure. However, this resolution of goal conflicts may not be optimal, as shown by some respondents' remarks that procedures can be a hindrance and may not fit the situation well, thus providing limited improvement to the work performance. In such situations, teamwork was highlighted as an important cornerstone of safe work. Thus, future studies may look into ETTOs at the team and organizational level. In addition to obtaining a better understanding of how ETTOs can be managed in maintenance work, efforts should be directed towards developing new solutions that supports both thoroughness and efficiency, reducing the need to make trade-off decisions. Figure 5 shows different states in the efficiency-thoroughness space illustrating efforts to improve thoroughness and/or efficiency in maintenance work.

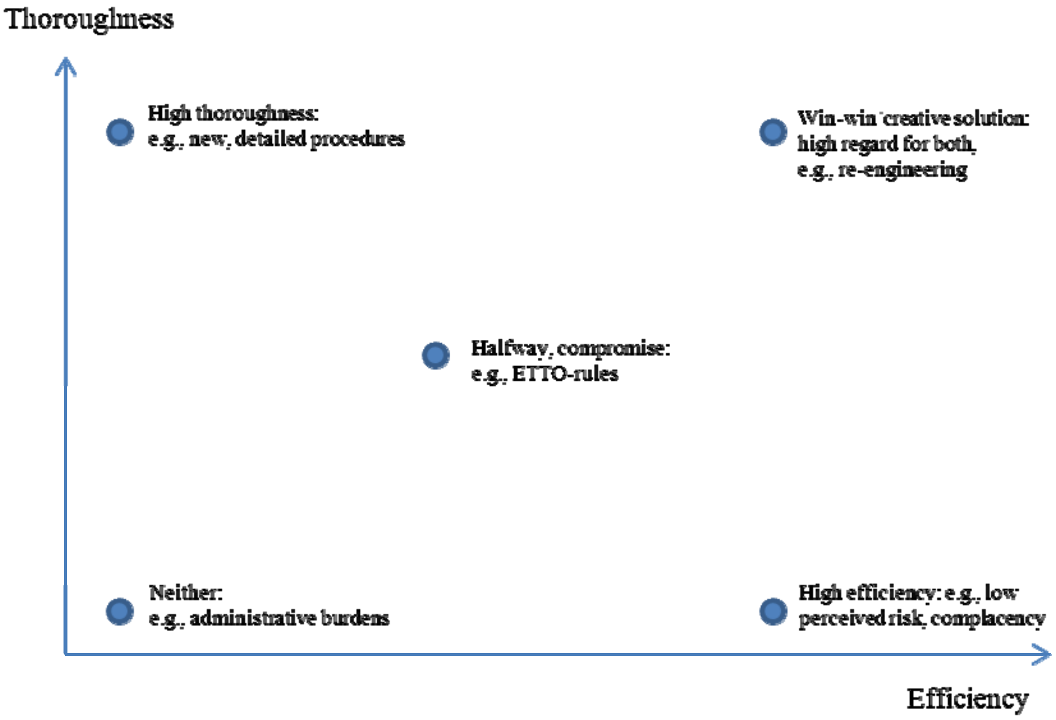


Figure 5 - The efficiency-thoroughness space showing different approaches to goal conflicts

3.4 Characteristics of working practice and culture

The observations at all the power companies provided rich data of situations which call for ability to anticipate and to cope with sudden changes and disturbances. Many of these events are so mundane and typical in maintenance work that the workers hardly paid attention to the fact that they lacked clear instructions on how to proceed. The tacit knowledge of the course of activities in certain maintenance jobs seemed to include handling of unexpected findings. We collected examples of the working practices and aspects of the working culture which may have significance for resilience of maintenance activities in a sense that they able or unable the fulfilment of the core task working practice demand. Table 3 shows examples of working practices and aspects of culture at the three Nordic nuclear power plants. Examples of this kind are expected to be beneficial when the impact on culture to the resilience of the system is inspected more in detail in 2012.

Table 3. Some examples working practices and aspects of culture in the case organisations.

Working practice demands	Examples of the solution taken in the observed jobs
1. Co-ordinating timetables and resources within maintenance	The diesel service was more extensive than normally in outages. Thus, the mechanical maintenance of that unit didn't have enough experienced resources to work in two shifts. *They borrowed diesel expert from another unit.* The diesel team had detected a crack in a pipe which requires the pipe to be removed, taken to the workshop and welded. Thus, the team leader - whose group was working in the diesel room - *expected delays* since they have to wait for the pipe. However, at the same time the researchers were told by an engineer that the pipe is already fixed and is to be installed soon. *The team leader of the diesel work wasn't informed* about the status of the pipe but the planning engineer was. The workers of a contractor were filling up a pipeline with water in order to do a pressure test. The pump didn't work properly; it was unable to raise the pressure to sufficient level. The head of the team called a colleague from another subcontractor company and asked them to bring a pump of different type for tomorrow. *One contractor company helped another by providing the necessary equipment.*
2. Co-ordinating work between maintenance and operations	The pressure test of the turbine re-heater indicates small leakage somewhere. The team leader (a contractor) has *a clear picture how to proceed*; he calls operations and asks the field operators to come down to detect where the leakage actually is. Operations is responsible for isolating and verifying the tightness of the valves and flanges. Soon two fairly new field operators are sent to the field to scout out the most probable leaking points – which takes more than an hour. The maintenance team leader calls to the field operators couple of times during their task since he starts to get worried of the delay. The maintenance workers sneer that they would have found the valves quicker than the field operators but they *don't try to assist the field operators.* The diesel work starts with a delay since the *operations wasn't able to drain the system on time.* Later a maintenance manager expresses his worry about crowding maintenance jobs due to the operations inability to issue work permits. He doesn't know why this is taking place. A representative from operations tells that their newly implemented control room has at least 200 small, detected, functional bugs which make the isolation work much more resource consuming for the operators this year.

3. Co-ordinating work between technical support and maintenance	The person *responsible for the turbine re-heater outage work is "borrowed" from the technical group* for this outage. He has maintenance background. Ata charge pump room a planning engineer comes to check how the tasks are proceeding. The researchers ask him to clarify the safety functions of that pump. When the *engineer explains it one of the maintenance workers listens with interest* and comments: "Really? I didn't know that!"
4. Defining responsibility areas	The schedule for the re-heater pressure tests is tight and delayed due to the leakage found. The team leader wishes that the container can be filled in tonight. Another company has left one of the manholes open after their work and the company responsible of the pressure test *can't intervene with others' work scope and close the manhole themselves.* Filling of the tank is postponed to the next day. The main contractor company holds a clear leading role in executing the turbine bearing change. The team is specialised in turbine works and many of them has worked together around the world. Members of other organisations such as a contractor taking care of sensor cables and crane service *are in the background and patiently wait for their turn* and role to come in the bearing change job.
5. Keeping up with the maintenance program for the specific work scope	A system undergo a full pressure test every eight year. The outage 2011 was so called *short outage which put challenges to the execution of the full scope pressure test.* Some of the workers consider that a clear planning mistake. The diesels had suffered from technical problems during the previous operating periods. The manufacturer had informed the company about quality deficiencies in certain components already a couple of years ago. *This information had, however, received little attention* until the unit started to recognise deviances in those components.
6. Prioritizing the work tasks	The contractor company has men working with multiple work scopes. *The team leader flexibly takes working pairs to tasks which are most urgent.* At a charge pump room the maintenance *engineer informed the workers that they are not going to do a thorough inspection of the gear boxes today* even though the gear boxes had partially been opened already. The decision was due to a milling work at the same room and consequently a risk of debris in the gear boxes. The milling work was seen more urgent.

7. Co-operation between different technical disciplines within maintenance	The generic schedule table of the diesel service includes both mechanical and electrical maintenance work permits. However, common perception in the organisation seemed to be that there are only *two "diesel teams" i.e. the two mechanical groups working with the diesels. The electricians are not perceived to be integral for the work.* The mechanics report that they need to interrupt their work when "electricians pop in to do their work".
8. Adhering to procedures and instructions	The diesel team placed *an inspection plan on the wall* as a generic outline of the course of activities during dismantling and installing of the cylinder heads. When asked about detailed work instructions concerning the installation they laugh and say "*It is obvious* how the parts need to go there. We have disassembled these ourselves." Technicians are installing jacking oil piping in the turbine bearings. A set of pipes (originally installed in the bearing a year ago) doesn't seem to match the lead-ins. The technicians do trouble shooting by blowing into the pipes and sensing if the air comes out, thus figuring out if there is a pipe without a connection. They conclude that one of the pipes is in a wrong position. This finding indicates a year old latent error in the piping. The supervisor says he is rather sure that the piping was done according to the drawings the last time but there is *an error in the drawings*. He doesn't have the drawings with him, however.
9. Transparency of actions and documentation of the work and its outcomes	The contractors are filling up a system with water to carry out a pressure test. The supervisor comes to check the work. He pays attention to the fact that the pressure is fluctuating according to the impacts of the pump – even passing the level of the test pressure from time to time. He is worried that may put unnecessary stress to the system. The contractor explains that hammering effect of the pump *was known from previous outages. The information had not led to any conclusions.* The results of the pressure tests are verified by QC and regulator (testing company). The supervisor calls them just before the pressure in the systems is on a test level. In the observed case *same person conducted both the QC and regulator inspections.* He couldn't tell what – if any – differences these inspections should have.
10. (safety/risk) Information management	*No observations concerning near miss reporting* or any recorded reporting of the small setbacks in the observed tasks. The contractors at the turbine works seem to feel strong ownership of the components. In those cases information was reported orally to the power company in dedicated formal meetings.

11. Managing/ supervising/ collaborating with the contractors	A foreman of turbine works spends a lot of time in the turbine hall in order to be able *to take care of the spare parts* needed. Every morning there is a *meeting with the contractor's site manager.* A manager is doing *a safety walk* at the turbine hall when he hears a loud bang from the turbine. He asks the group of contractors who is in charge here, what is happening. A representative of the main contractor then explains where the sound came from and that is nothing to worry about. The manager is happy with the explanation.
12. Knowledge of the safety significance of the systems one is working with	The functions of the turbine re-heater are *not perfectly clear* to the working group although there are good descriptions on that available. The plant has a campaign against foreign objects in the systems this year. The *risk of foreign objects is not considered big.* The main contractor group is specialised in turbine works and knows the system and its components well. The bearings now installed are new designs, however. *The safety significance of turbine works is generally considered to be low.* Possible turbine shut down is considered an operational loss not a nuclear safety matter.
13. Mentoring/on the job training of the newcomers	A newcomer *worked based on oral instructions and illustration done by an experienced group member.* He didn't recognise anyone to be his mentor but one of the *experienced workers felt he is responsible* for keeping an eye on the doings of the newcomer.

4. CONCLUSIONS

In 2011 the MoReMO project focused on applying and testing four different approaches or methods suitable for the identification and analysis of resilience. In particular, 2011 work has been dedicated to data collection and analysis, and to build a preliminary understanding of the parameters regulating, guiding and supporting maintenance work during outages.

The application of the four methods has provided relevant insight about their respective potential for:

- describing and understanding how activities are carried out in practice,
- understanding what is the local rationale of the practices and their effects on safety, and
- supporting the development of flexible and adaptive work practices.

From a general point of view, the 2011 work highlighted how current theoretical and methodological development in resilience engineering provided good foundations for grasping certain challenges of safety management of maintenance and outage. For example the notion of goal conflicts is important in understanding why local, sometimes risky adaptations are made. Goal conflicts or at least conscious trade-offs between efficiency and thoroughness of work may be impossible to grasp by surveys or interviews. Thus observations and close discussion with the workers are in an important role (Axelsson et al., 2011).

The Organisational Core Task modelling aims to identify contextual criteria for evaluating the acceptability or risks of the working practices identified in the maintenance organisations. While it seems reasonable to say that the four abilities (i.e. anticipating, responding, monitoring and learning) of resilient system by Hollnagel (2009) are all relevant for safe activities during outages, they don't outline the specific nature of the context of the work and the requirements it sets to the personnel. By the application of the OCT model it has been possible to pinpoint, for example, the continual need to coordinate and collaborate with diverse working groups and disciplines. In 2012 we aim to bring the core task model to a more tool like format in order for it to be applicable for the maintenance organisations in the nuclear industry.

Modelling the actual activities with FRAM certainly proved maintenance to be a complex activity. The FRAM model provided insight about how the successful accomplishment of maintenance work relies on complex interaction between multiple actors operating in the system. The inter-couplings are so complex that it is nearly impossible to perceive them all. Thus the cultural mechanisms that regulate the connections between the functions are important. These may be informal, human mechanisms or concrete tools such as instructions and schedules. The FRAM modelling of the Emergency Diesel Generator overhaul indicated that some of the functions that could be considered relevant for executing the activity smoothly were not explicitly included into the work descriptions by the plants (e.g. taking in advance care of spare parts needed in the work). Fulfilment of those functions is based more on the tacit knowledge and thus may be subjected to greater extent of variability. In 2012 we aim at representing with the FRAM the performance variability, its potential propagation within the system and the way in which it may combines and resonate.

The main goals of the ETTO study were defined based on the assumption that the interviewees would experience ETTO's in their work. Since only a few instances of ETTO's were reported, the study did not succeed in answering these research questions. However, it succeeded in identifying a range of factors that may contribute to promote safety performance at nuclear power plants – and thus performance, which implies that safety goals are adequately prioritized. Several examples of positive work practices, in particular related to teamwork and team decision making, were identified. Regarding the usefulness of the ETTO concept, the study is inconclusive, except that it supports the assumption that ETTO's are rarely used consciously. Thus, from the perspective of the plant, follow-up studies may emphasis the question of how to become more efficient at being thorough, and thereby reduce the probability of situations in which an individual has to prioritize between efficiency and safety.

A cultural perspective led the conduction of most of the working practice observations and of the interviews conducted in 2011. The approach constituted a valuable reference framework for collecting and analysing data. The observations done at the three different power plants' outages in 2011 provided numerous examples of the need for adjusting original schedules and plans to unanticipated findings in the technology or requests from other working groups. By mean of the application of this reference framework it has been possible to reveal how certain steps of maintenance activities are not carefully specified, for example no specific work instruction exists for dismantling of certain components. The knowledge base for doing these local adjustments becomes a relevant research question to study further in 2012. The preliminary findings from 2011 data suggest that the knowledge of the work scope, its functions and safety relevance is really diverse.

In 2012 MoReMO completes the data collection and integrates the results to present insight in to the questions on how resilience can be operationalized and built in a safety critical and socio-technical context.

5. ACKNOWLEDGEMENT

NKS conveys its gratitude to all organisations and persons who by means of financial support or contributions in kind have made the work presented in this report possible.

6. REFERENCES

Axelsson, C., Hildebrandt, M., & Skjerve, A. B. (2011). *An Interview Study Investigating Efficiency-Thoroughness Trade-Offs in Maintenance Work at a Nordic Nuclear Power Plant.* (IFE-HR-2011/1516).

Baker, J., 2007*. The report of the BP U.S. refineries independent safety review panel. Available from:www.bp.com/liveassets/bp_internet/globalbp/STAGING/ [Accessed 23 March 2010].*

Dekker S. Drift into failure. From hunting broken components to under- standing complex systems. Farnham: Ashgate; 2011.

Hale, A.R., et al., 1998. Evaluating safety in the management of maintenance activities in the chemical process industry. Safety Science, 28, 21–44.

Halin, M., Oedewald, P. & Pietikäinen, R. (2010). Safety culture challenges when working with small contractor companies – a case study. A presentation at the International nuclear energy development forum, November, 3-5, Barcelona, Spain .

Hildebrandt, M. & Koskinen, H. (2011). *Success factors for Organizing Outage Control Centers - Preliminary Results* (HWR-972). Halden, Norway: OECD Halden Reactor Project.

Hoffman, R.R., Woods, D.D., 2011. Simon's Slice: Five Fundamental Tradeoffs that Bound the Performance of Human Work Systems. *Proceedings of the 10th International Conference on Naturalistic Decision Making (pp. 18-23).*

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

Hollnagel, E., 2006*. Resilience – the challenge of the unstable. In: E. Hollnagel, D.D. Woods, and N. Leveson, eds. Resilience engineering. Concepts and precepts. Aldershot: Ashgate, 55–65.*

Hollnagel, E. (2009). *The ETTO principle: Efficiency-Thoroughness Trade-Off*. Farnham, UK: Ashgate.

Gustavsson, P., Johansson, B. & Hildebrandt, M. (2011). *Resilience and Procedure Use in the Training of Nuclear Power Plant Operating Crews – An Interview Study and Literature Review* (HWR-1026). Halden, Norway: OECD Halden Reactor Project.

Kletz, T., 2003. Still going wrong! Case histories of process plant disasters and how they could have been avoided. Oxford: Butterworth-Heinemann.

Macchi, L. (2010). *A Resilience Engineering approach to the evaluation of performance variability: Development and application of the Functional Resonance Analysis Method for Air Traffic Management safety assessment*. PhD Thesis, MINES ParisTech, France.

Oedewald, P. & Reiman, T. (2003). Core task modelling in cultural assessment: A case study in nuclear power plant maintenance. *Cognition, Technology & Work* 5 (4), 283 – 293.

Oedewald, P. and Reiman. T. (2007). Measuring conceptual knowledge among NPP maintenance personnel – a tool for knowledge management. The proceedings of the joint 8th conference on human factors and power plants and 13th annual meeting of the HPRCT organization, 26–31 August 2007 Monterey, CA. doi:10.1109/HFPP.2007.4413235.

Oedewald, P., Pietikäinen, E. & Reiman, T. (2011). 3. 2011:20 A Guidebook for Evaluating Organizations in the Nuclear Industry - an example of safety culture evaluation. Swedish Radiation Safety Authority, Research Report 2011:20.

Orr, J.E., 1996. Talking about machines: an ethnography of a modern job. Ithaca, NY: ILR Press.

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

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

Reason, J. and Hobbs, A., 2003. Managing maintenance error. A practical guide. Hampshire: Ashgate.

Reiman , T., 2011 Understanding maintenance work in safety-critical organisations – managing the performance variability, Theoretical Issues in Ergonomics Science, 12:4, 339-366

Reiman, T. & Oedewald, P. (2006). Assessing the maintenance unit of a nuclear power plant – identifying the cultural conceptions concerning the maintenance work and the maintenance organization. Safety Science 44 (9), 821-850.

Reiman, T. & Oedewald, P. (2007). Assessment of Complex Sociotechnical Systems – Theoretical issues concerning the use of organizational culture and organizational core task concepts. Safety Science 45 (7), 745-768.

Reiman, T. & Oedewald, P. (2009). *Evaluating safety critical organizations. Focus on the nuclear industry*. Swedish Radiation Safety Authority, Research Report 2009:12.

Reiman, T., Pietikäinen, E. & Oedewald, P. (2010). Multilayered approach to patient safety culture. Quality and Safety in Health Care. 19, 1-5 doi:10.1136/qshc.2008.029793.

Sanne, J.M., 2008a. Framing risks in a safety-critical and hazardous job: risk taking as responsibility in railway maintenance. Journal of Risk Research, 11, 645–657

Skjerve, A.B. (2009). A Goal-Conflict Typology to Support Adequate Prioritization of Safety Goals in Decision-Processes Mediated Via Co-operation Rooms – A Psychological Perspective. In: A.B. Skjerve, M. Kaarstad (Eds.), *Building Safety. Literature Surveys of Work Packages 2 and 3: Decision Making, Goal Conflicts, Cooperation, IO Teamwork Training, Decision Support, and the impact on Resilience of New Technology* (IFE/HR/F-2009/1388), Halden, Institute for Energy Technology, pp. 29-68.

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

Trist, E. L. (1978). On socio-technical systems. In, Pasmore, W. A. & Sherwood, J. J. (Eds), *Sociotechnical systems: A sourcebook*. San Diego, CA.: University Associates.

Woods, D., Decker, S., Cook, R., Johannesen, K. & Sarter, N. (2010). *Behind Human Error*. Farnham, UK: Ashgate.

7. APPENDIXES

APPENDIX 1: OCT MODELING interview scheme

1) Could you briefly describe your tasks normally and during this outage?

2) How would you define the core task of the *maintenance organisation*? What is it that they need to achieve, why are they needed?

3) What is the core task of maintenance *during the outage*? Why is that organisation there? What are they aiming for?

   (Pay attention whether the respondent sees that the maintenance core task is to improve, or to maintain the functioning of the equipment. In the Swedish case there is lots of clear improving due to the previous maintenance backlog and now big refurbishments => how does that affect maintenance core task during the outage and their conceptions concerning OCT in general?

   Pay attention to possible control principles of outage planning: How much does refuelling guide the schedule etc of the outages? How are tasks of each outage decided, is condition monitoring used to determine interval…)

4) Does everyone (at the power company + contractors) have a shared view on the core task? If not, what are the different viewpoints?

5) How has the core task changed during the years of the operation?

6) What characterizes the plant? How it differs from other plants maintenance organisations could work with?

   (Pay attention to whether respondent talks about the plant or the components. This relates to the questions 2 and 3; is the core task to maintain the plant or to fix the components.

   Expect answers such as radioactivity, personnel safety, good quality of the work; long life time expectation, old plants; fatigue and ageing effects of technical systems; security procedures; the mixture of new and old technology, digitalized control room; some parts are in a bad shape; large, redundancy, safety systems, lots of couplings between systems.

   Consider asking if safety class of the system determine the maintenance practises a lot.

   Consider asking what kinds of practical constraints one has when working with this plant if not obvious from the answer so far)

7) What is specific for the outage activity compared to other stages of NPP maintenance activities?

(Expect answers such as reactor is on cool shut down, fuel reloading => specific tasks due to this, access to many systems; many safety critical tasks; lot of people around, also new people; time pressure is evident, prescheduled activities; coordination need between different teams and units; need to adjust and accommodate one's work according to other's progress; major opportunity to see the real condition of the plant, unexpected problems are detected.

Consider if the interviewee answers to these: is the detection of weak signals considered a task of all during the outage? Why are workers so specialised, even the contractors. Is time pressure concrete?)

8) What specific demands/constrains comes outside the plant they need to take into account (regulations, societal issues, owner's needs…)?

   (Expect answers such as modifications receive regulatory attention, time pressure for keeping outages short; demand for transparency towards media, change of worker generation, succession planning; Fukushima)

9) You named XXXXX as the constraints and pressures – how does the outage organisation take these into account? How do you cope with these?

   (Consider asking about:

   a. *needed knowledge and understanding, tacit knowledge*
   b. *adjustments*
   c. *his own role as providing information on the plant condition to the management and to the engineers*
   d. *how does the organisation balance with competing goals, trade -offs)*

10) Generally speaking what were the positive aspects of the last outage? What were the aspects that made the things manageable? What makes the outage work run smoothly?

APPENDIX 2: FRAM-model of the diesel engine overhaul – Functions description

Function	Input	Output	Control	Preconditions	Resources	Time
Isolate System (OP)	Long term planning	Isolated system	OP's procedures	System made available (stand by DG910, an outage or LER)	1-2 Field operators	
	Preventive maintenance schedule					
Drain system	Preventive maintenance schedule	Drained system	Tested water	Isolated system	1-2 technicians	4-5 hours
			Work permit issued			
Remove cylinder head	Identified need for exhaust valve replacement	Removed cylinder head	Manufacturer procedure	Isolated syst*em*	5 technicians	12-16 hours
			Knowledge & experience	Drained system		
			Work permit issued	System made available (stand by DG910, an outage or LER)		
Inspect cylinder liner & cleaning	Removed cylinder head	Inspected and cleaned cylinder liner	Preventive maintenance schedule	Isolated system	2 QC inspectors	5-6 hours
			Maintenance diesel procedure	Drained system	1-4 technicians	
Assemble cylinder head	New/refurbished cylinder heads	Assembled cylinder heads	Manufacturer procedure	Inspected and cleaned cylinder liner	5 technicians	20-24 hours
			Knowledge & experience	Isolated syst*em*		

Function	Input	Output	Control	Preconditions	Resources	Time
			Work permit issued	Drained system		
Replace fuel injection pumps	New fuel injection pumps	Replaced fuel injection pumps	Preventive maintenance schedule	Isolated syst*em*	2 technicians	8-12 hours
			Maintenance diesel procedure	Drained system		
			Work permit issued	Assembled cylinder heads		
Replace hoses	New hoses	Replaced hoses	Manufacturer procedure	Isolated syst*em*	1-2 technicians	
			Work permit issued	Drained system		
Fix identified problems	Identified problems	Fixed identified problems	Evaluated urgency of problems	Isolated syst*em*	1-2 technicians	
			Work permit issued	Drained system		
			Knowledge & experience			
Inspect auxiliary equipment	Preventive maintenance schedule	Inspected auxiliary equipment	Maintenance diesel procedure	Isolated syst*em*	1-2 technicians	
		Identified issues	Evaluated urgency of problems	Drained system	1 QC inspector	
			Work permit issued			
Overhaul auxiliary equipment	Inspected auxiliary equipment	Overhauled auxiliary equipment	Manufacturer procedure	Isolated syst*em*	1-2 technicians	8-16 hours

Function	**Input**	**Output**	**Control**	**Preconditions**	**Resources**	**Time**
	Identified issues		Knowledge & experience	Drained system		
			Work permit issued			
Grease auxiliary equipment	Preventive maintenance schedule	Greased auxiliary equipment	Maintenance diesel procedure	Isolated system	1 technician	0,5 hours
			Work permit issued	Running engine		
Lubricate DC alternator supply	Preventive maintenance schedule	Lubricated DC alternator supply	Maintenance diesel procedure	Running engine	1 technician	0,5 hours
			Work permit issued			
Lubricate control rod to injection system	Preventive maintenance schedule	Lubricated control rod	Maintenance diesel procedure	Running engine	1 technician	0,5 hours
			Work permit issued			
Align system (OP)		Aligned system	Operations diesel procedure	Work permits completed & signed off	2 field operators	8 hour
		Running engine				
Test system (MA & OP)	Aligned system	Engine declared operational	Maintenance diesel procedure	Work permits completed & signed off	9-10 field operators	4-5 hours
	Preventive maintenance schedule					

Function	Input	Output	Control	Preconditions	Resources	Time
Monitor for problems		Identified problems				
Evaluate urgency of problems		Evaluated urgency of problems				
Spare parts management		New hoses				
		New/refurbished cylinder heads				
		New fuel injection pumps				
Experience/ Knowledge management		Knowledge & experience				
Issue work permits		Work permit issued				
Outage planning & control		System made available (stand by DG910, an outage or LER)				
		Preventive maintenance schedule				
Test water		Tested water				

Function	Input	Output	Control	Preconditions	Resources	Time
Procedures management		OP's procedures				
		Manufacturer procedure				
		Maintenance diesel procedure				
		Operations diesel procedure				
Assign personnel to functions		Technicians				
		Field operators				
		QC inspectors				
Complete & sign off work permit	Drained system	Work permit completed and signed off				
	Removed cylinder head					
	Assembled cylinder heads					
	Replaced fuel injection pumps					
	Replaced hoses					
	Fixed identified problems					
	Inspected auxiliary equipment					

Function	**Input**	**Output**	**Control**	**Preconditions**	**Resources**	**Time**
	Overhauled auxiliary equipment					
	Greased auxiliary equipment					
	Lubricated DC alternator supply					
	Lubricated control rod					