

Research

---

# Operational Readiness Verification, Phase 3

A Field Study at a Swedish NPP during a  
Productive Outage (Safety-train Outage)

Erik Hollnagel  
Vincent Gauthereau  
Bodil Persson

January 2004



# **SKI Perspective**

## **Background**

During the last five years of the 20<sup>th</sup> century the Swedish nuclear power plants reported a number of incidents related to safety systems not operable after outage and maintenance. As a result of these reported incidents the Swedish Nuclear Power Inspectorate (SKI) required that the licensees of the Swedish nuclear power plants should review and analyse the safety of their management, routines and strength and weaknesses of these verification activities of safety systems. These safety reviews and analyses should be done, in the light of the reported incidents, to improve the process of operation readiness verification accomplished before the facility will be taken into operation. The licensees have completed their safety reviews and have made improvements in the area of operational readiness verification based on their analyses.

After these analyses and improvements of operational readiness verification SKI started a research project in the area.

Phase I of the research project was concluded in July 2001. Phase I is documented in SKI report series number 01:47. The results of phase I was: a literature survey of relevant research and conclusions, a proposal on a description of important steps in the process of operational readiness verification and barriers based on e.g., earlier research, and a description and analysis of the current situation at Swedish Nuclear power plants. Also, phase I resulted in proposals on further research issues in the area.

Phase II of the research project was concluded in November 2002. Phase II is documented in SKI report series number 2003:09. Phase II resulted in: a field study on operational readiness verification at a Swedish nuclear power plant, and the selection and application of a number of analysis concepts/tools from other scientific disciplines. These concepts/tools were:

- Community of Practice, defined as small groups of people who through extensive communication developed a common sense of purpose, work-related knowledge and experience;
- (2) Embedding, which means that all tasks and activities take place in an environment or context that may be physical, social or historical (cultural); and
- (3) The Efficiency-Thoroughness Trade-Off (ETTO) principle, which characterises how people try to adjust what they do to the local conditions of work (temporal, physical and organisational).

These tools showed to be useful to better describe the practise in operational readiness verification. Also, the study resulted in proposals on further research issues.

## **SKI's Purpose**

This research assignment concerns Phase III of the project. The purpose of this study was, based on the results of phase II, to further study in a field study (a safety train outage at a Swedish NPP):

- how tasks are adapted relatively to the different types of embedding and the degree of correspondence between nominal and actual Operational Readiness Verification (ORV),
- the coordination and communication within and between Communities of Practice.

## **Results**

One result of phase III is a deeper understanding of how different Communities of Practice communicate and coordinate. For example the study discusses and gives examples from observations on how social rules affect participation. Other aspects discussed are how “division of labour” affects the way people interact and communicate, especially within the control-room teams. The interactions within and between Communities of Practice may on the one hand serve as redundant checks, hence enhance safety, and on the other as a way of adjusting to current demands, hence potentially degrade safety. The organisations coping with the complexity of ORV was also discussed by the relation between expectations and surprises, how planning was used as control, attention to details, and the practices of shift changes.

Another result was a proposal of a revised model of ORV. The studies have shown that ORV, rather than a simple sequence of tasks as originally assumed, comprises multiple activities of different scope and duration, where several of them are carried out simultaneously.

Also, the study resulted in suggestions for improving ORV.

## **Continued Works**

The research project will be concluded by a seminar on Operational Readiness Verification (ORV) to present the results of the research to the licensees of the Swedish nuclear power plants.

## **Effects on SKI's Work**

The research (phase I, II and III) has given SKI a knowledge and a model which can be used as a tool in preparing for inspections in the area of operational readiness verification. Two of the studies (Phase II and III) have been carried out at a Swedish nuclear power plant which gives SKI the opportunity to be enforcing in the work of safety.

## **Project Information**

SKI Project Manager: Per-Olof Sandén  
SKI Identification Number: 14.3-00114/2272

## Research

---

# Operational Readiness Verification, Phase 3

A Field Study at a Swedish NPP during a  
Productive Outage (Safety-train Outage)

Erik Hollnagel<sup>1</sup>  
Vincent Gauthereau<sup>2</sup>  
Bodil Persson<sup>2</sup>

<sup>1</sup>CSELAB  
Department of Computer and Information Science  
Linköpings Universitet  
SE-581 83 Linköping, Sweden

<sup>2</sup> Quality Management  
Department of Industrial Engineering  
Linköpings Universitet  
SE-581 83 Linköping, Sweden

January 2004

This report concerns a study which has been conducted for the Swedish Nuclear Power Inspectorate (SKI). The conclusions and viewpoints presented in the report are those of the author/authors and do not necessarily coincide with those of the SKI.



# Table of Contents

|       |  |    |
|-------|--|----|
| 1.    | <u>INTRODUCTION</u> .....  | 1  |
| 1.1   | <u>Operational Readiness Verification – Previous Research</u> .....      | 1  |
| 1.2   | <u>Aim Of the present study</u> .....                                    | 3  |
| 2.    | <u>THE RESEARCH SETTINGS &amp; METHODOLOGICAL CONSIDERATIONS</u> .....   | 4  |
| 2.1   | <u>Productive Outages (Safety-Train Outages)</u> .....                   | 4  |
| 2.2   | <u>Data Collection</u> .....   | 4  |
| 2.3   | <u>Data Analysis</u> .....   | 5  |
| 3.    | <u>ANALYSIS AND FINDINGS</u> .....                                       | 6  |
| 3.1   | <u>How Social Rules Affect Participation</u> .....                       | 9  |
| 3.1.1 | <u><i>The Identity of Expert Practitioners</i></u> .....                 | 9  |
| 3.1.2 | <u><i>Role vs. Person: What is most important?</i></u> .....             | 10 |
| 3.1.3 | <u><i>Language Games</i></u> .....                                       | 10 |
| 3.1.4 | <u><i>Echoing and feedback</i></u> .....                                 | 11 |
| 3.2   | <u>Division of Labour</u> .....  | 12 |
| 3.2.1 | <u><i>Sticking to the roles</i></u> .....                                | 13 |
| 3.2.2 | <u><i>Turning to an expert</i></u> .....                                 | 14 |
| 3.2.3 | <u><i>Relations Within and Between Communities of Practice</i></u> ..... | 15 |
| 3.3   | <u>The Evolution of Practice Over Time</u> .....                         | 16 |
| 3.3.1 | <u><i>Procedures versus Common Practice</i></u> .....                    | 16 |
| 3.3.2 | <u><i>Acceptance of failure</i></u> .....                                | 18 |
| 3.3.3 | <u><i>Practice of story telling</i></u> .....                            | 18 |
| 4.    | <u>MANAGING THE COMPLEXITY OF ORV</u> .....                              | 19 |
| 4.1   | <u>Expectations and Surprises</u> .....                                  | 19 |
| 4.1.1 | <u><i>Situational surprises</i></u> .....                                | 20 |
| 4.1.2 | <u><i>Coping with Surprises</i></u> .....                                | 22 |
| 4.2   | <u>Planning as Control</u> .....   | 23 |
| 4.2.1 | <u><i>Targeting</i></u> .....  | 24 |
| 4.2.2 | <u><i>Monitoring</i></u> .....   | 24 |
| 4.2.3 | <u><i>Regulating</i></u> .....   | 25 |
| 4.3   | <u>Attention to details</u> .....  | 25 |
| 4.4   | <u>Shift Changes</u> .....   | 26 |
| 5.    | <u>IMPROVING ORV</u> .....   | 27 |
| 5.1   | <u>ORV as a Communication Tool</u> .....                                 | 28 |
| 5.2   | <u>The Practice of ORV</u> .....   | 29 |
| 5.3   | <u>A revised model of ORV</u> .....                                      | 29 |
| 5.3.1 | <u><i>ORV as a barrier</i></u> .....                                     | 31 |
| 5.4   | <u>Suggestions for the industry</u> .....                                | 32 |
| 6.    | <u>GLOSSARY</u> .....  | 33 |
| 7.    | <u>REFERENCES</u> .....  | 33 |





## Summary in English

This report describes the results from Phase III of a study on Operational Readiness Verification (ORV) that was carried out from December 2002 to November 2003. The work comprised a field study of ORV activities at a Swedish NPP during a planned productive outage [*subavställning*], which allowed empirical work to be conducted in an appropriate environment with good accessibility to technical staff.

One conclusion from Phase I of this project was the need to look more closely at the differences between three levels or types of tests that occur in ORV: object (component) test, system level test and (safety) function test, and to analyse the different steps of testing in order to understand the non-trivial relations between tests and safety. A second conclusion was the need to take a closer look at the organisation's ability to improvise in the sense of adjusting pre-defined plans to the actual conditions under which they are to be carried out.

Phase II of the project found that although all three types of test occurred, they were rather used according to need rather than to a predefined arrangement or procedure. The complexity of ORV could be understood and described by using the concepts of Community of Practice, embedding, and Efficiency-Thoroughness Trade-Off. In addition, organisation and the different communities of practice improvise by adjusting pre-defined plans or work orders to the existing conditions. Such improvisations take place both on the levels of individual actions, on the level of communities of practice, and on the organisational level. The ability to improvise is practically a necessity for work to be carried out, but is also a potential risk.

Phase III of the project studied how tasks are adapted relative to the different types of embedding and the degree of correspondence between nominal and actual ORV. It also looked further at the different Communities of Practice that are part of maintenance and ORV, focusing on the coordination and communication between communities. These interactions may on the one hand serve as redundant checks, hence enhance safety, and on the other as a way of adjusting work to current demands, hence potentially degrade safety. The organisation's coping with the complexity of ORV was discussed by the relation between expectations and surprises, how planning was used as control, attention to details, and the practices of shift changes. The study concluded by two suggestions for improving ORV. The first is that ORV should be complemented by a reflection about ORV on both the individual and the group or organisational levels. This would mean that a job is not completed when the last step of the work permit has been carried out, but only when it has been reported and acknowledged. The second is that the issue of organisational learning should be considered more directly, since people learn not only from their own experience but also from that of others, across the professional community. This practice could possibly be made a little more systematic and supported as an explicit contribution to system safety.

## Svensk sammanfattning

Denna rapport redovisar resultatet från del III av ett projekt om driftklarhetsverifiering (DKV). Arbetet ägde rum mellan december 2002 och november 2003 och omfattade en studie av DKV-aktiviteter på ett svenskt kärnkraftverk under en subavställning. Detta gav goda möjligheter för att utföra observationsstudier under realistiska förhållanden, samtidigt med att det fanns möjlighet för att få tillgång till teknisk personal.

En slutsats från fas I av detta projekt var att det fanns ett behov av att närmare studera skillnaden mellan tre olika provningar som ingår i DKV: objekt eller komponent test, system test, och säkerhetsfunktionstest. Detta skulle omfatta en analys av hur olika test används för att bättre förstå det komplexa sambandet mellan provning och säkerhet. En ytterligare slutsats från fas I var nödvändigheten av att studera organisationens möjligheter till improvisation, dvs. det sätt på vilket tidigare förberedda planer anpassas till de förhållanden som existerar när dom skall förverkligas.

Fas II fann att det inte var möjligt att konstatera någon tydlig skillnad mellan det sätt de tre olika typerna av provning blev utförda, och att de användes enligt behov snarare än enligt en intern logik eller struktur. Vid analysen av resultaten togs ett antal begrepp från andra vetenskapliga disciplin i användning, speciellt följande: (1) Community of Practice (verksamhetsgemenskap), dvs. att ett antal mindre grupper genom omfattande kommunikation och samarbete utvecklar en gemensam uppfattning av mål, kunskapar och erfarenhet; (2) embedding (inkapsling), dvs. allt arbete och alla aktiviteter sker i en kontext som kan beskrivas med bl.a. en fysisk, en social och en historisk (kulturell) dimension; och (3) Efficiency-Thoroughness Trade-Off principen (dvs. avvägning mellan effektivitet och noggrannhet), som beskriver hur människor försöker att anpassa sina arbetssätt till de rådande arbetsförhållandena (tidsmässigt, fysiskt och organisatoriskt). Dessa begrepp visade sig nyttiga för att bättre kunna beskriva praxis under DKV, och till att förstå varför handlingar då och då kan avvika från vad som var tänkt och planerat. Resultaten från studien visar att organisationen och de olika verksamhetsgemenskaperna hade förmågan att improvisera och anpassa sina planer till de aktuella förhållandena. Dessa improvisationer skedde på olika nivåer: individuell-, verksamhetsgemenskaps-, och organisationsnivå. Improvisationsförmågan är å ena sidan nödvändig för att arbetet ska kunna utföras effektivt, men å andra sidan utgör den en potentiell risk. Denna risk kan inte reduceras genom att införa en strängare praxis och ställa krav på mera rigida beteende. I stället bör man sträva efter att förstå orsaken till att arbetet måste anpassas i enskilda situationer, och använda denna kunskap till att förbättra den totala arbetssituationen.

I fas III undersöktes hur anpassningen av arbetet (improvisationen) beror på inkapsling (embedding) och vilken betydelse det har för hur väl den nominella och reella DKV stämmer överens. Fas III såg också på hur verksamhetsgemenskapen praktiskt kommunicerar och interagerar. Å den ena sidan kan detta fungera som en redundant uppsikt som främjar säkerheten; å den andra kan en ömsesidig anpassning också leda till en

försämring av säkerheten. Organisationens förmåga att ta hand om komplexiteten i en DKV diskuteras i rapporten i relation till hur man förhåller sig till överraskningar, hur planering fungerar som kontroll, hur personalen lägger märke till detaljer, och hur skiftbyten hanteras. Rapporten innehåller två förslag till hur DKV kan förbättras i praxis. Det ena är att man explicit reflekterar över DKV på individuellt såväl som organisatoriskt nivå, t.ex. genom att ett arbete inte anses avslutat förrän det har säkrats att alla är medvetna om det. Det andra är att främja möjligheterna för organisatoriskt lärande; erfarenheten visar att personalen drar nytta av båda egen och andras erfarenhet, även utanför den egna organisationen. Det borde övervägas om denna praxis kunde förbättras för på detta sätt att ge ett bidrag till ökat säkerhet.



# 1. Introduction

## 1.1 Operational Readiness Verification – Previous Research

This report presents the results from “Phase III – A field study at a Swedish NPP during a productive outage” (Best nr. 02272), which was carried out from December 2002 to November 2003. This work was a continuation of two earlier phases in an overall project called “Operational Readiness Verification: A study on safety during outage and restart of nuclear power plants”.

The first phase of the study, concluded in July 2001, comprised a literature survey of research relevant for ORV issues, and an assessment of the present situation with respect to ORV practices. The literature survey was primarily aimed at research related to NPPs, but also looked at other domains with comparable problems.

- The survey focused on MTO aspects relevant to the present situation in Swedish NPPs. One finding was that ORV should be seen as an integral part of maintenance, rather than as a separate activity coming after maintenance. Another, that while there is a characteristic distribution of failure modes for maintenance and ORV, with many sequence errors and omissions, none of them are unique to ORV. Several sources also suggested that ORV could usefully be described as a set of barrier functions in relation to the flow of work.
- The assessment of the present situation with respect to ORV practices made use of interviews with technical staff at most of the Swedish NPPs. It focused on the solutions developed by the various NPPs to cope with the problem, and the steps taken specifically to improve the efficiency of ORV. It was found that ORV could not be separated from the rest of the work done in a NPP during outages since many of the proposed solutions were quite a general nature, hence had consequences that reach beyond an ORV focus. This finding reinforced the conclusions from the literature survey.

One outcome from the first phase was the need to look more closely at the differences between three levels or types of tests that occur in ORV: object (component) test, system level test and (safety) function test, and to analyse the different steps of testing in order to understand the non-trivial relations between tests and safety. Following the advice of the project reference group this was done during a partial or productive outage (*subavställning*) at an NPP, which allowed empirical work to be conducted with better accessibility to technical staff than during a full outage period. Phase II of the project, concluded in September 2002, found that although all three types of test occurred, there was no simple relation among them in the sense of a clear procedure for their order of occurrence. The different tests were rather used according to need rather than to a predefined arrangement or procedure. This means that the relation between them may vary, that they sometimes are carried out in order but at other times that either the order is changed or a test is omitted for reasons that seem perfectly reasonable at the time of action.

In order fully to understand the complexity of ORV, it was therefore found useful to introduce four concepts, namely: (1) **Community of Practice (CoP)**, (2) **embedding**, (3) the **Efficiency-Thoroughness Trade-Off (ETTO)** principle, and (4) **improvisation** and re-planning.

A Community of Practice (CoP) is defined as a small group of people who through extensive communication develop a common sense of purpose, work-related knowledge, and experience. Three Communities of Practice turned out to be of particular interest during ORV: (1) control room operators, (2) the maintenance personnel, and (3) Work Permit Management (ABH). Each CoP has established a mode of working (an institutionalised practice) which is effective under normal working conditions, although it sometimes may differ from formal work descriptions. The concept of CoP was useful to understand how practices emerge from the general conditions of work, and especially how communication customs are established. Understanding the details of specific tasks and actions was greatly helped by describing the various environments in which the activities were embedded.

The concept of embedding means that all tasks and activities take place in an environment or context that may be physical, social, or historical (cultural). It refers to the detailed assumptions that people make when an activity is carried out, both as pre-conditions for doing something and as the background for interpreting the outcomes. The essence of embedding is that every task and activity takes place in an environment or context that may be physical, social, or historical (cultural), i.e., no task or activity can be understood in isolation. This means that tasks and activities that are related to each other, for instance because they are part of the same procedure or have a common objective, or because they are carried out at a specific place and time, also have a common context.

The ETTO principle characterises how people adjust their work to match local conditions (temporal, physical and organisational) and conflicting demands. Since it in most situations is impossible to be both thorough and efficient – because thoroughness takes time, hence reduces efficiency – the usual solution is to trade-off thoroughness for efficiency. The way in which this is done depends on the established Communities of Practice, and on the embedding of tasks in the technical, social, and historical environments. One consequence is that what people do, even if it turns out to have unwanted consequences, should be understood from the perspective of the adaptiveness of normal performance rather than from the perspective of performance failures and errors.

ORV practices must finally be seen in relation to the conditions of the socio-technical environment, and the organisation's ability to improvise, i.e., to react appropriately in the face of unexpected events and developments, is therefore central. Improvisation as a phenomenon on the organisational level corresponds to how people, either as individuals or as groups, adjust their performance to the local conditions trying to achieve their objectives in an efficient manner.

Phase II also found a potential overlap between work done by maintenance staff and by plant operators, formally as well as in practice. Maintenance and operation are, in terms of the terminology introduced in Phase II, two different Communities of Practice although with a considerable overlap, not least because they in many ways are embedded in the same context. There is no absolute boundary where the responsibilities

of one community ends and those of the other begin. There may, for instance, in actual situations be insufficient information about the status of work as well as the plans and tasks of other groups. In consequence of that the transition of responsibility between communities can vary from case to case. How this overlap is managed may have consequences for the safety of an ORV, and it is therefore important to better understand how this takes place in practice.

## **1.2 Aim of the present study**

Based on the findings from the two previous phases of the project, Phase III was planned to achieve the following specific objectives.

- A further study of how tasks are adapted relatively to the different types of embedding, specifically but not exclusively the physical embedding (i.e., how the physical environment determines the task sequence). This should provide an indication of the degree of correspondence between the nominal ORV, that is the ORV assumed by the rules and regulations, and the actual ORV.
- A further identification of the different Communities of Practice that are part of maintenance and ORV, where a specific focus is the study of the coordination and communication between the communities. Each community has unspoken rules for how one behaves, and how and when interaction with other communities takes place. Such interactions are rarely explicitly prescribed or provided for. The interactions may on the one hand serve as redundant checks, hence enhance safety, and on the other as a way of adjusting work to current demands, hence potentially degrade safety.

In agreement with the MTO point of view, unwanted events – ranging from near-misses over incidents to accidents – should be explained as the result of unforeseen combination of conditions such as multiple embeddings and differences between Communities of Practice, rather than as the result specific, isolated causes. This defines a need to understand when such conditions can arise, how they can be detected, and how they possibly can be counteracted. Such knowledge may become part of training or operational rules.

The work comprised a preparatory phase, followed by an empirical phase with an in-depth study of a productive outage. The focus was on the communication among Communities of Practice (and how it can be facilitated), ETTO, planning and improvisation. The results can be used to identify possible shortcomings of the current approach to ORV and to indicate how they can be remedied. The results from Phase II pointed to the risks that may arise from different meanings of the term. It was therefore important to see which practices the different communities subsumed under the term, and to understand how these practices were coupled to each other.

## **2. The Research Settings & Methodological considerations**

### **2.1 Productive Outages (Safety-Train Outages)**

The NPP where the studies took place undergoes a so-called productive or safety train outage four times a year. In this NPP the safety systems of each unit are divided into four independent groups or trains. Since the regulations allow the NPP to be operated with three out of four safety systems in place, it is possible to carry out maintenance on the fourth without shutting down the NPP and bringing it off-line (hence the name productive outage). The productive outages also make it possible to reduce the duration of non-productive outages (NPO). However, for safety reasons, the number of productive outage days is restricted to 60 per year.

The productive outage offered the research team a better opportunity to follow the verification procedures than a full outage would, since the latter requires much more attention from the plant personnel. This limits the possibility for field studies, which must necessarily involve some level of interaction with plant personnel. During a non-productive outage, the staff of the unit is also mixed with external contractors and personnel from other units. This “unusual” situation requires more effort and attention from the staff of the unit and therefore limits their availability to answer the researchers questions.

A productive outage is also considerably simpler than a non-productive outage, hence much easier to grasp by the researchers (who by no means are experts on NPP operation). After a few weeks at the plant under normal conditions or during a productive outage the researchers usually have of fairly good idea of “who is who” at the plant. There is no practical possibility of achieving the same degree of familiarity during a non-productive outage.

There are, however, also some limitations from studying productive outages, of which two must be mentioned. One is that productive outages because of their “simplicity” may not reveal certain behaviours / processes that can occur in the more complex situations encountered during non-productive outages. Conversely, there may be some “short-cuts” / simplifications in the work process that only appear during productive outages. The other is that productive outages are not subject to the same production pressure as non-productive outages. This makes them different from non-productive outages where there often is a strong desire to restart the plant (i.e., to formally end the productive outage) as soon as possible. Most of the control room operators seem quite aware of the day-to-day developments of the electricity market and are thus quite attentive to the economical impacts of their work.

### **2.2 Data Collection**

The data collection for this study mainly took place in March 2003. Two observers followed the activities of ORV at the Nuclear Power Plant during two weeks, except for 1.5 days when only one observer was present.



The most important observation site was the Main Control Room and the data collection focused on the tasks of the operations personnel. This required one of the observers attended meetings, both daily and weekly, involving this staff group. Additional time was spent with work permit management (ABH) in order to get their view of the course of events. While the previous study specifically focused on ORV for a few selected systems, the present study, in accordance with the conclusions from phase 2, focused on further understanding “work as participation in Communities of Practice”. Instead of focusing on the more practical side of ORV, we paid attention to the communication processes within members of the CoP formed by control room personnel and between this community and other communities that took part in the ORV, not least the maintenance community. We studied how information from the plant came to the control room personnel and ultimately to the shift-supervisor, how the supervisor treated this information, and how it was further spread. Since it was found that discrepancies between the reality of “work as practiced” in the field and work as described to others might lead to local problems, we tried to understand further the rules (both formal and informal) that guide the management of information.

While one of the observers tried to follow the operations from the control room, the other focused more on what went on in the plant outside. In the beginning of the observation period most observations were made with the two observers working together, or at least at the same location. This was done in order to create a common framework and to synchronise the observation method to some extent. Later on some events were studied separately, with one observer in the Main Control Room and one in the plant focusing on the same issue. This enabled us to look at a particular event from two different points of view.

Most observations were made without any interference from the observers. In some cases, however, the observers asked question in order to understand the situation. In addition to this, some short unstructured interviews were carried out spontaneously when an observer felt that there was need for it. The occasions were chosen so they did not add to the workload of the personnel, e.g., when people seemed unoccupied. Because of the circumstances in which the interviews took place, none of them were tape-recorded.

Each day during the observation period a substantial amount of hand-written field-notes were taken. These notes were then transcribed and entered into a computerised observation log during evenings. In cases where it was not possible to complete the daily transcription due to lack of time, the remaining field-notes were transcribed as soon as possible afterwards. The average daily transcription rate was about 80 percent. The advantage of transcribing the notes as soon as possible is the possibility of completing with details not necessarily written down during the observation but still fresh in the observers’ memory. Another advantage is the possibility to start reflecting on the material and develop strategies for the following observation periods.

## **2.3 Data Analysis**

The first step of the analysis was to transcribe the field notes. In doing so, the observations were rendered anonymous. As a consequence, all the individuals will be referred to as male, i.e., by the pronoun “he”. This should not be considered as gender

discriminating, but rather as a practical choice since most of the observed individuals were male.

The analysis of the data followed an iterative procedure. After transcribing the field notes the observers started to code the notes using the simple set of concept proposed at the conclusion of Phase 2. As coding progressed, the set of concepts evolved. Some concepts seemed more interesting than others, while others seemed more complex in their nature than previously appreciated. Although the analysis was based on concepts originally developed outside the nuclear power generation domain, the analysis of the work practices was not constrained by that. Indeed, the concepts allowed the particularities of the work setting to be easily recognised and expressed.

### 3. Analysis and Findings

In report from Phase II, we introduced several concepts that were useful to understand work as participation in a CoP. As described above (Section 1.1) they were Community of Practice, embedding, Efficiency-Thoroughness Trade-Off, and improvisation / re-planning.

In order to structure the discussion of work as being part of a CoP we will use a model that is central to **activity theory** (Cole & Engeström, 1993; Engeström, 1990 & 1993). The very concept of an activity requires that there is someone or something that acts (the subject) and that the activity is directed against something (the object). The subject could, for instance, be the *station technician* and the object the *emergency diesel*. The activity clearly also has a purpose, for instance to make sure that the emergency diesel has been *verified as ready for operation*. This direct subject-object relation can be represented as in Figure 1.

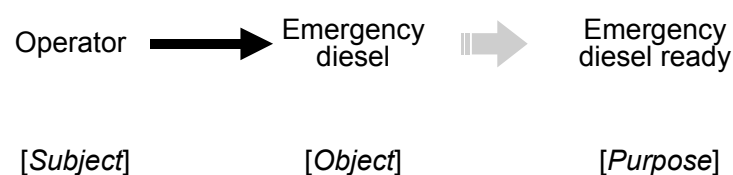


Figure 1: Direct subject-object activity.

Activity theory is based on the premise that an activity always is mediated and never works directly on the object, i.e., that something intervenes or goes between the subject and the object. That which mediates or goes between is called a tool – or more formally, a mediating artefact. Tools can be either physical (technical) such as a hammer or a specialised instrument or non-physical such as a procedure, a plan, general knowledge, etc. Language is also a tool, and one that often is very important. Activity theory shows this as in Figure 2, where the activity is carried out by means of something. The normal form is that of a triangle, which is a traditional way of showing indirect relations among objects or concepts (Ogden & Richards, 1923).

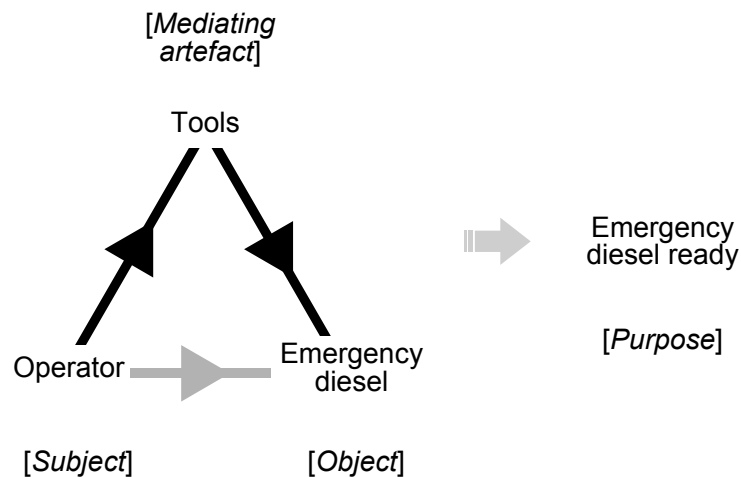


Figure 2: Mediated subject-object activity.

The principle of mediation is important for several reasons.

- Tools shape or affect the way in which people interact with objects. This is easily illustrated by thinking of the many situations where the right tool for some reason is not available, or where the available tool is unnecessarily complex. (This obviously goes for both technical and non-physical tools such as instructions!) The “tool” affects both how the person sees the object and what the person thinks he is able to do – and more importantly what he is not able to do.
- Tools represent the accumulated experience of others who have tried to do the same thing. This experience can be formalised in a design or simply be seen as the result of evolution – or trial-and-error. Good examples of that are procedures, or even ORV rules, which capture the established “wisdom” about how to do something. Tools are furthermore gradually transformed by the activity itself and therefore carry with them a particular culture. They represent not just the factual knowledge, but also the social knowledge and are therefore non-physical or psychological tools in a very real sense.
- Tools always exist in a context and the users’ understanding of the tool is shaped by that context. Psychological tools may especially develop to meet the demands of a specific CoP. However, that which makes a tool more suitable for one CoP may also make it less suitable for another. Indeed, two Communities of Practice may have a different view of the same tool, for instance with respect to when and how it should be used.

One advantage of using the triangle to show the mediating tool or artefact is that this representation can be extended to cover other relations as well. One obvious extension is that the subject’s activity towards the object is mediated by the CoP as well as by the tools. Instead of showing this in the same way as in Figure 2, activity theory has adopted the practice of showing the second triangle as a mirror image of the first, as seen in the left part of Figure 3, and furthermore to combine the two triangles as shown in the right part (cf. Cole & Engeström, 1993; Engeström, 1999). In the present case the community can be extended to include the various levels of embedding as described later.

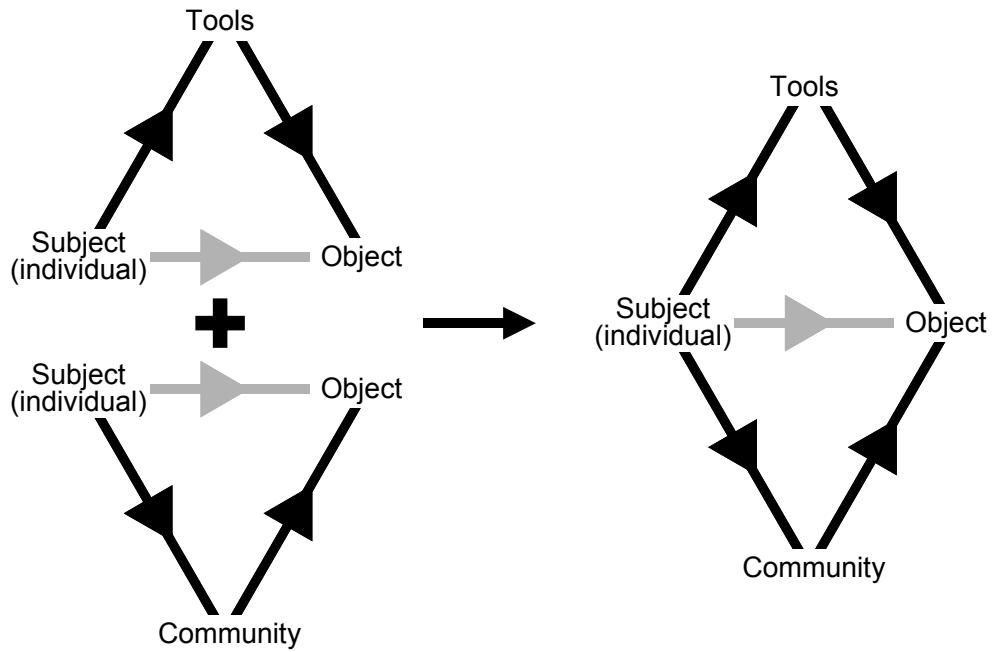


Figure 3: Tools and community as mediating artefacts.

Two other important relations are those between the subject and the community, and between the community and the object. In the present context that means the operators' activities vis-à-vis the community, both the "local" CoP and the larger organisation, and the activities taken by the organisation and Communities of Practice vis-à-vis the object, e.g., the safety train that is being maintained. As shown by Figure 4 this can be expressed by one triangle showing how the subjects' activities vis-à-vis the community are mediated by social rules, and a second triangle showing how the communities' activities vis-à-vis the object are mediated by the ways in which labour is organised or divided. (Notice that the base of the triangle no longer is the bottom line. The base is rather defined by the positions of subject and object, while the apex is defined by the position of the mediating artefact (social rules and division of labour, respectively)).

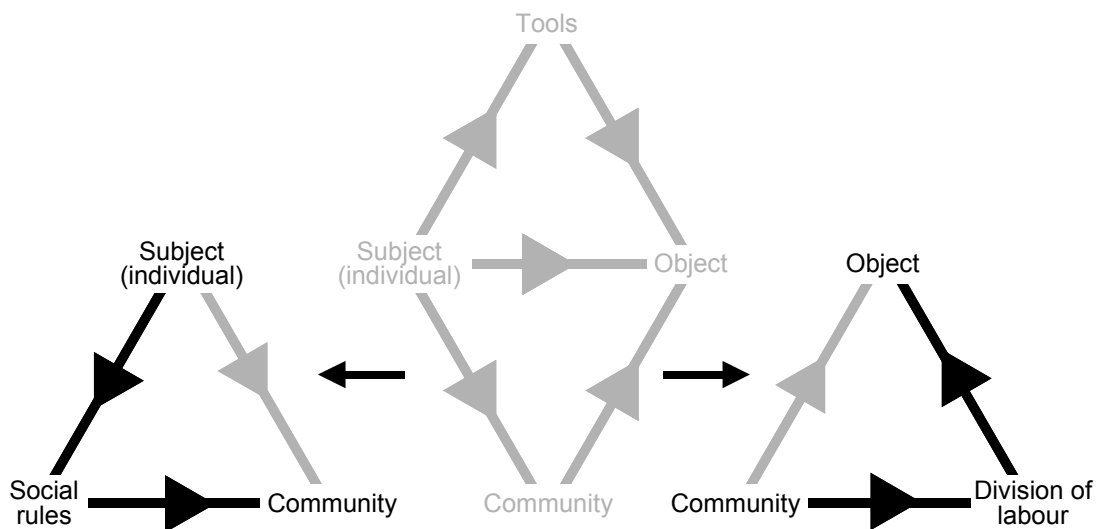


Figure 4: Social rules and division of labour as mediating artefacts.

With reference to the concepts identified as essential in Figure 4, the observation data will be discussed in terms of how rules affect participation and the division of labour. In addition we will also discuss how ORV practices develop or evolve over time.

### 3.1 How Social Rules Affect Participation

Even though many tasks during ORV are carried out by people working alone or in pairs, nothing is done without extensive interaction with other people in one way or the other. This interaction is subject to social rules that have evolved over time, although they are rarely written down or formalised. Such rules help people to decide whom they should turn to and how they should behave in different situations. The rules provide guidelines for how people should express themselves when interacting with others as well as how to act in relation to the larger community at the NPP.

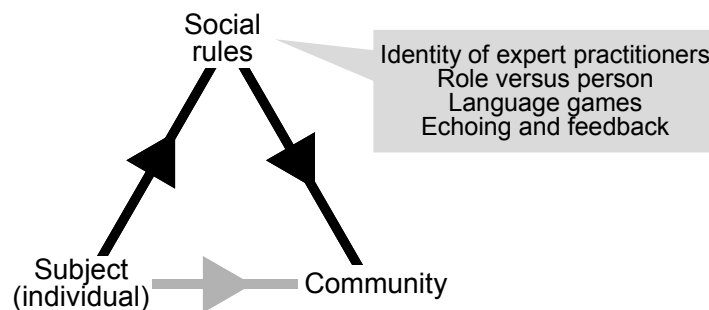


Figure 5: Social rules as a mediating artefact.

#### 3.1.1 The Identity of Expert Practitioners

Everything takes place in a social environment that in some way affects all behaviour. One example is that an activity in itself may require coordination and collaboration with other individuals. Another example is that even if a single individual performs an activity, there are often others who in one way or another depend on the outcome. Activities moreover often take place in a social context where other individuals may be present and therefore potentially may pass judgment on the outcome. Indeed, individuals are always influenced by the presence of others, whether it is actual, imagined, or implied (Weick, 1995, p. 39). The social context is, however, not only important when individuals need to cooperate. For instance, in a study of photocopier maintenance operators, Orr (1996) shows how story telling is an integral part of the operators' work activity. Operators do not directly cooperate when troubleshooting photocopiers – as this primarily is an individual activity. However, Orr highlights the importance of the relationships between operators for the successful completion of the activity and shows how “talking about machines” is a central component of the operators' work (cf. Section 3.3.3 below).

In order fully to appreciate the influence of the social context, it is important to understand how social identity is constructed. In the eyes of others “what we do” often determine “who we are”. As shown by Lave & Wenger (1991, p. 110), learning is not just about mastering new skills or increasing one's responsibility in a community, but also includes constructing the identity of a “master practitioner”. Becoming an

experienced practitioner requires acting like one in the eyes of others and being acknowledged by them. This ongoing construction of identity cannot be separated from the study of work practice.

### **3.1.2 Role vs. Person: What is most important?**

The characteristics of an expert differ depending on the area of expertise and the organisation in question. In the case NPP operations, the level of expertise is closely related to a person's experience in that particular field. Since the level of expertise usually is congruous with the role or position of the person, a person's knowledge can often be inferred from that. Thus, someone in need of help can in most cases settle for someone holding the appropriate position, instead of searching for a specific person. In other organisations, where expertise is not linked to the hierarchy, knowledge is first and foremost associated with a particular individual.

A person's knowledge may, however, become outdated and it is therefore only the present role that counts. For instance, even though a shift supervisor has worked as a station technician at one point in his career, and thus knows of the reality of the ST's work, the many changes in a plant that take place over time mean that past experience does not necessarily make a person an expert in the present. The relation between role and expertise is, however, not always this simple. In some cases extraordinary knowledge is associated with particular person. For instance, one ST said: "*Our SS is like a computer machine. He remembers everything – even what happened back in 1984*". Although very useful, this is not a quality that one can expect any SS to have. If therefore features like good memory and a long track record are required, this particular SS, rather than just any SS, would be the one to consult.

Another example of how the focus is on roles instead on people, especially for the operations personnel, came up during a meeting:

*The leader asked everyone around the table if they had anything to add. However, when getting to one person he left him out. That person seemed a little bit surprised, but made no comment. Another person, who came from a totally different department, who also seemed very surprised, asked "You didn't have anything either?"*

At this meeting two people represented the same department. The leader only asked questions to one of them, presumably because they were seen as having the same role, hence that they would pass on the same information.

### **3.1.3 Language Games**

For an outsider, the language used at the plant is filled with nearly unintelligible terminology. Yet most people involved in conversations understand this language when it is used. For example, when referring to technical systems, numeric codes are used instead of names. One advantage is that it is quite effective, especially in short conversations. Another advantage is that numbers are more precise than names so that there most likely will be fewer misunderstandings. Still, only certain categories of staff are fully capable of understanding this linguistic code, and during meetings it may cause

some trouble. In the following situation, one of the participants obviously lacked this knowledge.

*The person in question took notes during the meeting. It was clear that the person could not fully follow the conversation (neither could the observer). At the end of the meeting, when the conversation was less formal, the person started asking questions to individual participants about what was said. The first participant wrote something for her in her notes. When the others were leaving she asked a second participant about another issue. He answered that it could wait and that it was not very important. He gave no further information or explanation.*

This situation apparently made the person feel insecure and slightly ignored. After that first attempt, the person therefore made no further effort to understand what had happened, at least not at this meeting.

The extent to which people are expected to understand the terminology depends on how long they have been working at the plant, what position they have, and which division they belong to. These differences sometimes caused confusion among the personnel regarding what they were expected to know. They sometimes felt as if they were expected to understand more than they did, especially in meetings including members from different divisions.

In addition to the terminology, the language used is often very concise and summarised. During morning meetings, when all divisions are represented, the observers could often sense that one or two issues were not entirely understood by some of the participants. However, questions seldom came up during the actual meeting. It seemed as if most people felt uncomfortable about admitting a lack of understanding in this forum. The morning meetings were also traditionally kept very short. They were considered to be informative meetings and there was therefore no time set aside for discussions. Furthermore, since different divisions were present, detailed information would not necessarily concern every participant. This could also explain the restrained attitude towards asking questions at the meetings. After the meeting we often observed more private groups discussing an issue or clarifying information.

Most of the time this works quite effectively but there are potential pitfalls. For example, if an individual worker did not understand something he might disregard it as not being important to him, even though the opposite might turn out to be the case. Misunderstandings could also happen with a larger group. If information were presented with an attitude that indirectly told people that they should understand or recognise the information, they would quite naturally feel that it was not acceptable to interrupt with questions. Or rather, that an interruption would have an unfavourable influence on their image. Many individuals would avoid confrontations in such cases, because they believed that everyone else understood. Cases where most of the people do not understand the situation will then result in a state of mutual ignorance, where few understand and nobody wants to be the first to ask.

### **3.1.4 Echoing and feedback**

A common social communication rule is the use of repetitions (echoing, call-back). This way of communicating is an important factor when it comes to avoiding

misunderstandings and thereby preventing faults. Echoing / repetitions usually take the shape of short but informative conversations, like the following:

*ST: "It is full"*  
*RO: "It is full, okay"*  
*ST: "Tell the planners"*  
*RO: "Tell the planners"*

The participants in this conversation most likely do not use this tactic deliberately and actively to prevent misunderstandings. It is rather a natural and intuitive style which has evolved gradually and which is part of how we communicate with others, at work and at leisure. In most cases the conversation ends without any further clarifications. However, sometimes misunderstandings were actually discovered.

*The RO tells the observer that a particular device shall be changed. He refers to it as only one device.*

*RO: "Which device should I change"*  
*SS: "AX and AY"*  
*RO mumbles: "Okay AX"*  
*SS raises his voice: "AND AY"*

In this case, the RO obviously did not expect that he could be wrong. Still, by repeating the answer he got from the SS he saved the situation from any repercussions.

In another, the exchanges were extremely brief and illustrated both the use of specific terminology (linguistic codes) and the role of echoing.

*SS (to another person): "A-ha?"*  
*Respondent: "712"*  
*SS: "712?"*  
*Respondent: "OK!"*  
*SS: "OK."*

The use of repetitions may, however, also be quite deliberate. For instance, control room operators clearly asked for more details from inexperienced personnel than from experienced staff. Thus after a first general question about how a specific task was performed ("how did it go?"), the operators would not satisfy themselves with general answers ("nothing special"), especially if the person in the operators' view was inexperienced. In such a case further details are usually asked.

## **3.2 Division of Labour**

The division of labour is important in any environment as complex as a NPP. People who carry out the work are trained for specific duties and functions, and are in most cases fully aware of which tasks they are responsible for. Sometimes, however, individuals find that their own skills and expertise are insufficient for what they do, and that they need assistance from others in order to manage. This can happen for many reasons, for example that the actual situation is different from what was expected or assumed.



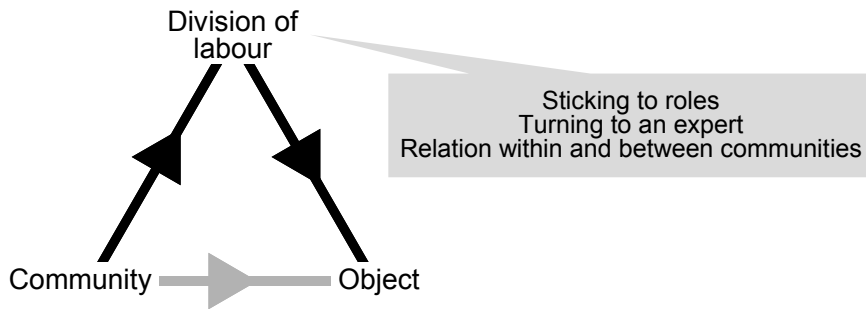


Figure 6: Division of labour as a mediating artefact.

### 3.2.1 Sticking to the roles

Roles are important, regardless of whether they are the assigned duties (formal roles) or the expected social behaviour (informal roles). This is especially so within the operations organisation, as seen by the many different ways in which people relate to each other.

In the central control room we found that everyone knew their responsibilities and that it was only with noticeable hesitation that someone diverted from their roles. For example:

*While an RO was on the phone an alarm went off several times. The RO was out of sight and the TO was clearly considering whether or not to cancel the alarm sound signal. Finally, he did so. The RO returned, still on the phone, and the alarm went off again. This time the TO had the chance to say “I can take care of that” before he turned it off.*

Although this behaviour sometimes seem a bit exaggerated it is nevertheless important to avoid making mistakes about who takes responsibility. In the example above the TO’s action was accepted without any comments. However, it is also clear that deviating from a role can cause annoyance.

People can also ask others to take over a role for a certain reason. One sequence involved a RO that needed a short break:

*Just when the RO wanted to leave someone called on the loudspeaker.  
RO: “SS can you take that? I have to go to the toilet.”  
The SS took care of the matter, which in practice implied a simple action.  
When the RO returned the SS was busy.  
Since the TO was present during the call, the RO asked the TO what happened.  
The TO gave an (as it seemed to the observer) adequate description of the situation.  
However, as soon as the SS was free, the RO asked him the very same thing.*

This is an example of how important it is for the operations staff to stick to their roles. The SS had taken over the RO’s task and should therefore have been the one that reported on the situation, regardless of whether the RO already knew the answer. In this

case it is also important also to remember that the SS is higher in rank than the TO, since this probably contributed to the behaviour.

Even though the SS has a coordinating role and manages most activities it does not mean that he does so in all cases. For example, when it comes to water and sewage, the station technicians handle the control panel and the incoming alarms without interference from control room operators. In this case the roles and responsibilities are also clearly defined.

### **3.2.2 Turning to an expert**

Since no one can know everything for every situation, there will sooner or later be a need to rely on others – on experts. It is important for the quality of the work to know something about when this happens, i.e., what the triggering conditions are. There basically seems to be three different situations where an expert is needed:

- If the person facing a particular situation does not know what to do and has no other way of getting that knowledge.

In this case the person does not really have a choice when it comes to choosing a course of action. He needs further information or knowledge, and the only reasonable way to get that is by turning to an expert. This will therefore be the next step except in cases where the action can be postponed or suspended.

- If the person realises that it is possible to find a solution alone, but that it would take a considerable amount of time.

Here the person probably turns to expertise because he believes that this will be the simplest and most effective way to get the required information. However, in such cases the course of action can also depend on other considerations. For example, if knowledge regarding the task to be performed is associated with a high sense of prestige, the person might choose a less effective way to get the information thereby concealing his lack of knowledge. Although this kind of behaviour should be expected in any organisation, no instances of that were found in the current study.

- If the person wants to confirm knowledge that he may already have.

Here a person seeks expertise in order to confirm something that is already known, although with some uncertainty. In relation to safety this approach certainly contributes to a higher level of reliability. It can happen if the procedure states that a particular expert or organisational role should take responsibility, or because the person finds this arrangement more convenient.

The situations where this need may arise are difficult to define precisely. It is also uncertain whether an expert is available when needed or can become available in time. The decision to seek an expert may also reflect concerns about responsibility for safety and how confident a person feels there and then. If the stakes are very high, most people are usually willing to consider a second opinion, even in a non-punishing environment.

The following example gives an idea of how a situation can evolve:

*During a complex situation, with many people involved and where many problems came up, a person from maintenance became uncertain. He said “Maybe I should go check with department X. That lamp is blinking. As far as I recall, it shouldn’t”.*

*He came back after a while and said: “It is supposed to blink out there ... I just wanted to confirm what I believed, so I know instead of just believing”.*

In this case the person sought expertise to confirm an already established belief. As it turned out, the assumption was actually wrong and the confrontation with the expert provided an opportunity to learn. This situation was not critical, but in other cases it might have been. In such cases what would happen if the person chooses not to consult anyone or if an expert is not available? These possibilities suggest that it would be useful to have clear rules for what to do and to ensure that asking for help is not seen as a loss of prestige.

Expertise may also play a role in more informal collaborations, even though it clashes with the formal roles. This became very clear in the following situation:

*Two station technicians were sent on a task also involving maintenance personnel.*

*A novice ST was assigned the task and the other more experienced person accompanied him to support with experience and expertise.*

*When communicating with the maintenance personnel it was clear that the novice ST was responsible, and he was the person the others turned to.*

*However, no decisions or actions were really carried out unless the expert ST had been consulted.*

In this situation the novice ST had more responsibility than he wanted to handle by himself and that he felt confident about. However, by using the advice of the expert ST he could informally transfer some of the responsibility to him.

### **3.2.3 Relations Within and Between Communities of Practice**

Even though people in their individual roles play an important part in how work is structured, it is certainly not the only thing that matters. People also belong to different divisions or groups depending on their tasks. Some of these are defined by the organisation, such as operations and maintenance, while others are established through the practice of work, such as the various Communities of Practice. This division has clear consequences for the interaction and communication for people both within a community and between communities.

For shifts belonging to the same CoP we noted a kind of friendly competition. During an ORV a number of tasks have to be completed within a specific time frame. The shifts seemed to try to do their best and work as fast as possible, though less for their own sake than to prepare tasks for the following shift. This obviously clearly a positive thing since it increases the carefulness with which tasks are carried out. Furthermore, there does not seem to be any prestige lost in making a mistake. For instance, a major leak was discovered during our presence at the plant and for a few days people tried to find out exactly where the leak was. During this period of time many individuals proposed possible answers and trouble-shooting strategies, most of them being erroneous. However, we never heard any comment about something being a “bad” idea.

Yet the attitude is quite different when it comes to prestige **between** different Communities of Practice. The operations personnel clearly saw themselves as being one CoP, different from the others. This was evident, for instance, from comments and jokes made about other groups. Similarly, while mistakes and errors were accepted within one's own CoP, they were often quite severely sanctioned (socially) when they came from somebody on the "outside". This dimension of work practice is further discussed in Section 3.3.2.

### 3.3 The Evolution of Practice Over Time

In addition to the specific relations characterised above, cf. Figure 4, it is also necessary to consider the changes that take place over time as the development or evolution of practice. In the present study we found three typical instances of that. One was the way procedure and practice was aligned. A second was the acceptance of failure, as an instance of performance variability. And finally, there was the practice of story telling as a pervasive learning mechanism.

#### 3.3.1 Procedures *versus* Common Practice

Doing things the right way is generally considered as extremely important by the personnel. But in order to be able to do things the right way it is necessary to know what the "right way" is. From a formalistic point of view it might be assumed that doing things the right way means following procedures and instructions to the letter with no exceptions whatsoever. This is, however, neither possible nor advisable in practice. It is impossible because a procedure cannot cover every detail of what needs to be done. Something is always taken for granted, for instance that people have specific knowledge and skills. It is inadvisable because the situation assumed by the procedure never exactly matches the actual situation. Following a procedure blindly amounts to total feedforward control and that is only possible for trivially simple systems.

The need to interpret and fill-in procedures and instructions obviously leaves room for some variability in implementing them. Quite often a practice of interpretation develops and becomes the established norm, even to the extent that it overrides the official procedure or instruction. One example concerns safety equipment:

*Helmets should, according to the rules, be worn when inside the plant. However, one ST explained that he wore his helmet only when doing jobs, not during regular rounds. Two other STs explicitly stated that they only wore helmets because the (female?) observer was present. Later, one of them hung the helmet on a fire-extinguisher.*

The practice of when to wear a helmet also illustrates an efficiency-thoroughness trade-off (ETTO), since putting on a helmet requires an additional effort. People know by experience when it is safe not to wear a helmet – at least as long as conditions are normal. That is the strength of following the ETTO principle, but also the weakness. (The example is also interesting in because a fire-extinguisher was seen as something convenient for hanging a helmet. This also represents an example of ETTO, since it apparently was easier to use the near-by fire extinguisher than go to the cloakroom.)

A widespread common practice may sometimes lead to a change in written procedures. When this happens, everyone involved should obviously be carefully informed about the change. However, changes that come up against already established behaviour might not get much attention. We found several cases where the STs seemed more or less unaware of the formal change in instructions. The reason was that they had established a common practice for the task a long time ago and therefore no longer consulted the written procedure; the change therefore did not matter. An example shows this:

*When refilling filter pulp the ST explained that there were two ways to do it, but that he preferred one of them. The ST was not using instructions so the observer asked if there were no instructions for this task. The St replied that of course there were instructions, but he knew them by heart. He only had to look out for changes. To prove that he took out a binder, but it was the wrong one. He then took out the right binder to show the observer the instruction. In doing so he noticed that the instructions only included one course of action, namely the one he had just used. Slightly embarrassed he said that new instructions were supposed to be announced.*

The impression given by the STs was that diverting from the instructions in some cases is nothing to be ashamed of. Indeed, in several cases the STs described the situation as if they did something slightly different from what the instructions stated. However, when asked, they admitted that they in fact followed the procedures to the letter.

*In one situation the ST told the observer that while waiting for a temperature to drop to an acceptable level, the ST would “take the opportunity to do the other things first”, giving the impression that this was the ST’s own initiative. When the observer double-checked it turned out to be in accordance with the instructions.*

This illustrates how people may develop an understanding of the nature of the work that differs from the formal descriptions. Under normal conditions this matters little, as the outcome will be as intended, and probably achieved more efficiently – an illustration of ETTO again. But the difference between formal procedures and common practice may be important in unusual situations, in the sense that differences in the way of reasoning may lead to unexpected and unwanted results.

Common practice is not just about saving effort. We also found cases where people actually chose to do more than was needed according to the rules.

*One ST explains that he in addition to the regular instructions also brought along the emergency procedures (“störningsinstruktioner”) for some tasks. This meant that he had these instructions ready if something did not go according to the plan. “Not everybody brings them. They call instead.” He then added that he would call too if something really happened, but that it still felt better to bring the procedures along.*

It is difficult for an observer to understand when it is acceptable to deviate from instructions and when it is not. There are clearly also limits for when a deviation is no longer tolerable. The plant personnel were keenly aware of this, and the differences between procedures and common practice served to reduce superfluous actions without affecting in the least the safety of the plant.

### 3.3.2 Acceptance of failure

The general attitude at the plant includes a level of acceptance of problems and that things can go wrong. No one expects that everything will always go according to plans. For instance, a situation where a problem had occurred elicited the following comment:

*“It’s good that things happen, that’s how you learn. This plant runs way too well ... (But) it doesn’t have to be things that make us lose power, or that cost us money.”*

On the other hand, some faults are less well accepted than others. Problems that are due to ignorance or misinterpretations are usually not appreciated and the persons involved may therefore become the target of negative comments to varying degrees, depending on the situation. Usually these situations involve personnel from more than one department.

*During some work on the diesel engine a number of problems came up. Some of them were due to actual faults; some were due to misunderstandings between people working for different divisions. It was clear that the misunderstandings occurred because the workers had different knowledge about the system and the things that had to be measured. Still the situation caused quite a lot irritation among them.*

This can also be seen as a further example of the relations within and between Communities of Practice, cf. Section 3.2.3 above.

In this example people found an explanation for why things turned out the way they did. In other situations this may be difficult or even impossible to do. For example, when the file structure of the computer system was re-organised, people ended up being unable to get the documents that they were authorised to reach. Their attitude was that *“this would take a week or more to fix”*, i.e., a general pessimistic assumption about the efficiency of the IT-department. Such situations may cause considerable annoyance and be detrimental to the overall organisational climate. While the general acceptance of failures within a CoP does not extend to include other Communities of Practice, it is nevertheless important that everyone should be allowed to make mistakes, since this is the essential basis for learning.

### 3.3.3 Practice of story telling

Story telling is a general way of disseminating knowledge and experience found in all domains and type of work, and this NPP was certainly no exception. In addition to serving the purpose of bringing knowledge to the attention of other people, the stories also often represent the overall values of the plant. One observer was told a story about a former manager of a unit who one night had pushed a button which disconnected the unit from the grid. The point was that the manager in question apparently had not fully understood the fact that the plant was actually run from the main control room. The final comment was: *“Where the \*\*\* did he think the plant was run from!”*

Another story was about a ST that said that he was *“in the right safety train”* when asked by the SS. To an outsider this might seem like a reasonable answer, and nothing to tell a story about. However, what the ST should have done was saying *which* safety

train he was in by using the established identification code (A, B, C or D), and then let the SS decide whether this was the right safety train or not.

The reason for telling stories like these is to make clear that “this behaviour/attitude is not acceptable. He (they) did not know that, but I do, and if you want to be a part of this community you should remember it too.” The message thus goes well beyond the actual story since people are supposed to generalise from it. Once they have been told the story, they are normally expected not to make the same mistakes.

## 4. Managing the Complexity of ORV

To avoid getting lost in the many details in the observations, it is useful to take a step back and look at what happens during a productive outage as a whole. This can conveniently be done using the triangular relation advocated by activity theory, where the subject is the plant (or the NPP unit), the object is the outage (and the outcome is a successful conclusion of the outage), and the mediating artefact is the ORV as a general concept (Figure 7).

Throughout this report, as well as in the report from Phase II, we have emphasised the importance of seeing work as the participation in Communities of Practice. This has proved to be helpful to clarify how relations within and between Communities of Practice affect work at the plant and therefore also the quality of ORV. We have looked in more detail at three important issues, namely social rules, the division of labour, and the evolution of practice over time. This section will refocus the discussion on ORV as a whole, keeping in mind what has been learned from the preceding analyses. In doing so it is relevant to consider three aspects, namely how surprises are managed, how activities are planned, and how control can be described as taking place at several layers simultaneously.

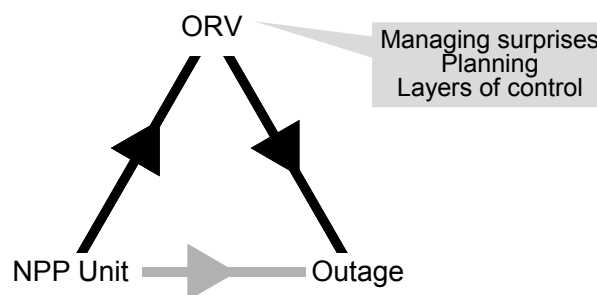


Figure 7: ORV as a mediating artefact.

### 4.1 Expectations and Surprises

A main purpose of planning and preparing the work during an outage – as well as during normal situations – is to avoid surprises. Surprises must be seen in relation to expectations and a surprise is usually defined as something that goes against

expectations. A surprise is therefore an indication that the expectations were wrong, which may signify a need of further investigation.

Surprises can be either situational or fundamental (Woods, 1990). **Situational surprises** happen when there is a functional failure in gathering information, i.e., when the assessment of the situation somehow has been imprecise or incomplete. **Fundamental surprises** happen when there is a conceptual failure in understanding the information, i.e., a fundamental incompatibility between reality and how it is generally perceived. Examples of fundamental surprises are, for instance, the launch of Sputnik for the US or Prime Minister Olof Palme's murder for Sweden. Another well-known example is the TMI accident, which surprised the nuclear power industry by showing that failures could come from socio-technical systems as well as from technical failures or pure "human error" (Woods, 1990).

Fundamental surprises put serious burdens on individuals and organisations and often force them to reconsider their view of the world. While such crises can lead to fundamental learning, there is also the risk that the view of the surprise may change, so that it is considered situational rather than fundamental. This can happen because it is much easier to respond to a situational surprise than to a fundamental one. People also generally have a strong tendency to change their views with the help of hindsight.

#### 4.1.1 Situational surprises

Weick & Sutcliffe (2001) have proposed the following four types of situational surprises.

- When something expected happens but where the *direction of the expectation* is wrong. For instance, when going for a run one usually expects the heartbeat to increase as fatigue sets in. One would therefore be surprised if the heartbeat was lower than usual, although this may happen when running while tired.
- When something expected happens *too early*. For instance, one usually expects to be tired at the end of a day's work. A person might therefore be surprised if tiredness appeared around 3 o'clock instead.
- When something expected is of the wrong *duration*. For instance, a problem that was expected to be transient might turn out to be long lasting (Weick & Sutcliffe, 2001). A shift supervisor, for instance, showed his discontentment by telling someone who walked into the MCR: "*we're still onto the XX system... instead of working with the diesel*". Apparently he was annoyed by the fact that the other system required much more time than he had anticipated.
- When the *amplitude* of the expected problem differs from what was expected. One example is that a leakage may be much larger than expected, hence lead to a revision of the diagnosis – from being a small leakage to being a problem with the flow measurement.

Surprises can obviously not be separated from expectations, and it is therefore important to understand expectations as both an individual and group phenomenon, embedded in the physical, social and historical (cultural) context of behaviour. We have already discussed how practice evolves over time (Section 3.3) where storytelling was an



important component. According to Olson, Roese & Zanna (1996) expectations are “beliefs about a future state of affairs” based on direct personal experience, communication from other people (indirect experience, storytelling) and other beliefs (arrived at by logical inference). And as we saw in Section 3.3.1, beliefs and expectations will guide the perception of events as well as how people respond or behave.

Expectations are strongly linked to actions. Indeed, actions are usually planned and carried out in order to achieve a specific effect, e.g., to bring about a change in the system in one way or another. The main basis for the expectation is the individual’s understanding of the situation, which provides the rationale for the action. This understanding can, however, not be separated from the CoP and the socially shared knowledge. This shared knowledge includes what each person – and the community as such – does now, what the state of the plant is, the past experience as it is made available to members of the community, and the common expectations about what will happen in the near future.

The level or number of surprises during an activity can be seen as a good indicator of the quality of work. It is obviously desirable to keep the number of surprises as low as possible. One reason is that surprises often are associated with unwanted consequences that may lead to (local) uncontrollable developments. Another is that the occurrence of surprises means that it is necessary to revise the expectations and the underlying understanding as well as taking remedial action. Both of these take time, and although time may not be as scarce a resource during a productive outage as during a disturbance, it is never unlimited.

The social complexity of expectations – and therefore also of surprises – can be illustrated by the example shown in Figure 8. It begins when the station technician ST is given a task to do. The ST starts planning what to do, making use of the history of the outage, the history of the plant, as well as his own experience. During this planning the ST needs additional information, and therefore asks the SS as an expert practitioner. In giving his answer, the SS considers the plant’s history, the outage history, possibly also the task history and definitely his own history. The answer is given to the ST, who then presumably goes on with his planning of the task.

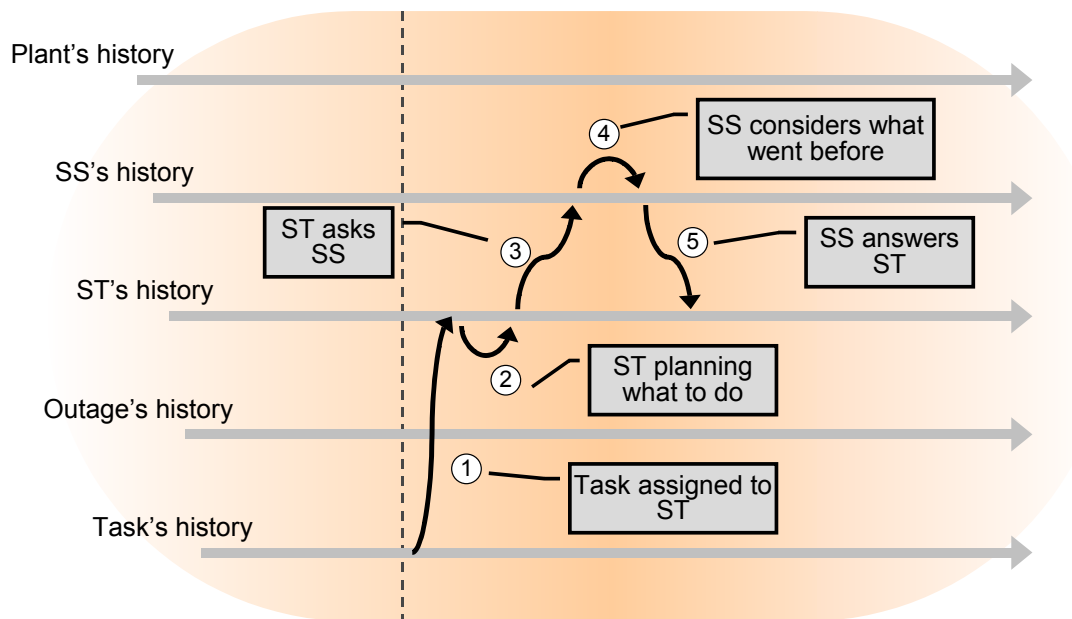


Figure 8: How activities are embedded in multiple contexts.

This small example illustrates both how a task is embedded in different contexts, where each context can be seen as a source of knowledge, and how the expectation is built up within the system. The ST's expectation of what should happen – and consequently his surprise if it does not – is based on many things. It is not just a function of what the ST happens to know, nor is it confined to the ST. In this case the SS will also have a – possibly vague – expectation of what may happen, as will others who may have been witnesses to the events.

#### 4.1.2 Coping with Surprises

There may occasionally be problematic situations that have not been experienced before. These situations are different from the ones discussed in the previous section. Whenever they occur, the process of trying to *explain* the situation begins. This is also the first step towards solving the problem and getting back on track. It is common that many people are involved in this task. The process can be described as collective reasoning, starting with a spontaneous brainstorming session. This results in an explanation, a solution or at least the next course of action, which evolves over time. Solutions are tried out, new informal sessions are held, and new suggestions are made, until the problem is finally solved.

During this process, where hypothesis are created and discarded, personnel that are not directly involved in the problem solving activities are continuously informed about the current assumptions. It is interesting to see what happens with the discarded solutions. Apparently they are not evaluated in any way when the problem has been solved. Instead, people seem simply to forget them and the fact that they were wrong. This is positive in some sense since it makes it less likely that the brainstorming process becomes limited by fears of being wrong or of asking “stupid” solutions. The question nevertheless is whether something useful could come out of a systematic evaluation of the problem solving process once the situation again has come under control.

## 4.2 Planning as Control

The report from the previous part of the study (Hollnagel & Gauthereau, 2003) made a link between the reliability of ORV and the ability first to plan the outage and then to adapt the plan to local contingencies. But rather than differentiating between “planning” and “adapting the plan”, we propose to look at how the plant as such “control” the outage. This implies a differentiation between planning and control – or between the practice of planning and the activity of control. Following the principles of the Extended Control Model (ECOM, cf. Hollnagel et al., 2003), the activities that are part of an outage can be described as comprising multiple, simultaneous layers of control of which the layers of targeting, monitoring, and regulating are especially important (see Table 1). While the formal activities of planning are mostly related to higher layer of control (mainly targeting), lower layers of control are managed through work-order and work permit management.

*Table 1: The four layers of the ECOM model*

|            | Type of control involved                      | Demands to attention                                   | Frequency of occurrence                           | Typical duration                |
|------------|---|--|---|---------------------------------|
| Targeting  | Goal setting (feedforward)                    | High, concentrated                                     | Low (preparations, re-planning)                   | Short (minutes)                 |
| Monitoring | Condition monitoring (feedback + feedforward) | High (disturbed conditions) / Low (normal conditions). | Intermittent but regular, depending on conditions | 10 minutes to duration of event |
| Regulating | Anticipatory (feedback + feedforward)         | High (irregular actions), / Low (common actions)       | Medium to very high (depending on conditions)     | 1 second – 1 minute             |
| Tracking   | Compensatory (feedback)                       | None (pre-attentive)                                   | Continuous  | <1 second                       |

The reason for proposing several layers of control is that all complex processes involve multiple events with different time characteristics. All complex systems furthermore comprise several layers of subsystems, which may be coupled in a non-trivial manner. One subsystem may require inputs (or commands) from a subsystem higher up, while another may depend on what happens in a subsystem lower down. In order to control the overall system it is therefore necessary to keep track of multiple processes with different dynamics. The four layers shown in Table 1 obviously simplify the real situation, but nevertheless capture some of the essential aspects such as the type of control involved, the demands to attention, the frequency of occurrence (i.e., how often it is necessary to do something), and the typical duration (temporal dynamics).

In relation to ORV this means that the sequential model proposed in earlier reports (see Figure 9 below), should be replaced by a multi-layered control model. The first analogy was that of jazz improvisation, the point being that a good improvisation is one where the different actors are free to adapt their play but still have to follow the overall structure of the melody. Though this analogy provided a useful and interesting alternative view on ORV, it was nevertheless too simple. In the following we will explore how the model of multi-layered control can be used to improve the understanding of ORV.

### **4.2.1 Targeting**

The highest layer of control in the model is targeting or goal setting, which primarily relies on anticipatory control. At the plant, targeting is about defining the frames or conditions for the productive outage. The time frame is defined first, since both the start and the end of the outage are decided in advance. The regulatory frame is also considered and documents are written to specify which actions have to be performed at the beginning and before the end of the outage. On the whole, the targeting of productive outages does not have to take into account very many constraints. Whereas non-productive outages need to take into account the demands of the electricity market, productive outages are only constrained by a maximum of sixty days per year. Sometimes, however, resource constraints affect the definition of the frame. Certain maintenance operations can only be performed by a limited number of employees who may not be available during the period originally planned. In such cases, additional productive outages can be planned for a later date. In other words, targeting is not only about taking higher level goals into account, it is also about being aware of the resources that are needed to achieve the goals.

### **4.2.2 Monitoring**

Once the frame for the productive outage is defined, the required maintenance tasks are identified and work permits are created. Monitoring consists mainly of these two tasks. The aim of monitoring is both to create a picture of the current situation and of what will happen in the nearest future, and to make sure that everyone has the same representation of this picture.

The identification of the tasks to be performed is a routine operation since productive outages are quite similar from one year to another. Moreover, “surprises” from previous outages are naturally taken into account as well. This does not just apply to surprise from the plant where the outage is to take place. NPP staff also tries to keep themselves informed of unexpected events at other plants. People further know from experience that approximately one third of the activities during an outage cannot be anticipated, and that new maintenance needs may be discovered during the outage. People are thus prepared to create new work permits during the outage itself. During this planning situations may sometimes arise that are not straightforward or easy to understand, and finding solutions or explanations to unexpected problems is therefore a part of this process. These unknown elements create the need of frequent communication in order to keep everyone updated of what is going on.

Monitoring at the plant is very much a question of ensuring that everyone has a good understanding of what goes on during the outage. The problem here is the level of detail that should be provided. For instance, informing everyone that the plant is currently going through a productive outage is a simple item of information that may be sufficient for most of the persons involved in the operation of the plant. Each individual can then in turn determine what to expect in relation to his own work, or for the local CoP. Based on previous experience people are able to develop expectations from this simple piece of information. The solution is less obvious when the situation is not “as usual”, e.g., when there are multiple surprises during the outage. In such cases it is very important to inform everyone as well as possible, but it may be more difficult to decide which level of detail is appropriate, and whether different groups in the organisation need different types of information.

### 4.2.3 Regulating

Regulating implies following-up everything that is happening. This is achieved formally through strict work permit control. No activity is performed in the plant without a work permit being issued and control room operators are informed of all work permits delivered. Moreover, when it comes to maintenance operations on the control systems (i.e., operations that directly affect what operators can see in the control room), operators request to be informed right before the activity. So not only do maintenance technicians need a valid work permit, they also need to inform the control room operators personally.

One fundamental strategy developed at the plant is not to rely on the plans. The operators say: “*it is reality that controls us*” (i.e., it is what happens rather than what is in the plans). During the outage the overall plan has little influence on the work in the control room and operators instead focus on the reality, i.e., on what goes on in the plant. While they check whether work goes as planned, they are not actively seeking to follow the plan.

In order to succeed in this, main control room (MCR) operators must be correctly informed of what goes on in the plant. Although they can see the control panels that represent the state of the plant, control room operators are only indirectly connected to the plant itself. Information coming from station technicians provides essential details that cannot be obtained from the control panels. The abilities of the operators to show *attention to details* and *extract cues* are therefore crucial. In addition to this specific communicational “tricks” are used to ensure that conversations are effective and free of misunderstandings.

## 4.3 Attention to details

It is commonly understood by the plant staff that paying *attention to details* is central, and that even small details should be reported to the MCR (Weick & Sutcliffe, 2001). One example was two persons from the work permit management group who during lunchtime went for a short walk in the forest along the shore. There they saw that the buoy marking the position of the water inlet had been moved by ice formations. As soon as they came back into the plant they reported this to the MCR operators. Another example was when a female station technician signalled to the operators the lack of ventilation in the women’s locker room.

*One morning there was a cardboard box placed near the wall close to the entrance of the main control room. The observer did not notice the box when entering the room, but everyone that came after made some kind of comment about it. The box was addressed to a particular person and when he arrived someone said “We are curious!” He opened the box and it contained slippers for the personnel to wear at the plant.*

The interesting thing is not so much the tendency to report small deviations as the sensitivity to notice deviations. The people who went for a walk knew the normal position of the buoy, even though their work was unrelated to it. In fact, every employee seems to know what the normal state of the plant is supposed to be, and everyone seems to recognise the importance of noticing the smallest deviations from this normal state.

One ST explained to the observer that he always checks all the leaks when doing the round. He says: *“There are always leaks, but I check to see that nothing increases or changes in any way”*.

Control room operators also pay attention to details and constantly try to find out what goes on in the plant. For instance, operators can notice the activity of an emergency diesel engine close to the control room without looking at the control panels because they can hear / feel the engine vibrating (while the observer failed to notice anything). Operators constantly try to find out who is where in the plant, and they usually succeed. For instance, the communication between the station technicians and the operators usually takes place via intercoms, which are fixed in the corridors / rooms of the plant. It was regularly noticed that control room operators could guess where the station technicians were in the plant and therefore could call them on the right intercom. Further, even during a period when a massive amount of insignificant alarms came in, the RO was attentive enough to notice that one real alarm suddenly appeared among them.

## **4.4 Shift Changes**

We previously saw that people continuously try to make sense of what goes on by extracting cues from the context. Sense making is about interpreting cues, but is first of all about selecting cues. Different persons will naturally focus on different cues in their environments. Relating to the previous section, different members of the operating team will pay attention to different details.

To avoid the problems with tunnel vision, the organisation should encourage a multiplicity of opinions. At the same time it is also important for the team to have a common understanding of the plant's state. One way this is achieved is by means of the changeovers from shift to shift. Each of these changeover meeting has three phases. First the departing team gathers in order to summarise what has happened in the past shift. Then each operator meets his counterpart from the incoming team. Finally the incoming team gathers to discuss what has happened since the last time they were in charge and what is going to happen during their upcoming shift.

The first and third phases look quite different from one shift team to another. For some teams, the shift supervisor starts by telling his side of the story, and then asks each member of the team to complete his report. For other teams, station technicians might first be asked to report, then operators will supplement their report, and finally the shift operator completes and summarises what the team members have said. These two strategies have important implications for the participation of the members in the practice. While the first approach leaves some participants with a peripheral role, the second approach allows peripheral participants equal participation. While the first approach emphasises a single perspective of the plant state, the second allows different perspectives to be shared. The second approach therefore appears to support learning better than the first, and also seems to contribute to safety by extending the operators' awareness of what actually goes on in the plant.

## 5. Improving ORV

While the tasks that make up ORV have existed from plant operations began, “Operational Readiness Verification” as a distinct set of tasks was a consequence of the incidents in the late 1990s. These incidents therefore in a sense created the concept, which in turn called for a formalisation of the activity.

Phase I of this study concluded that ORV could be described as consisting of six steps that came between the completion of maintenance and the designation of the system as operationally ready, cf. Figure 9. Of these six, the four middle ones are described in the official ORV instructions.

- First, components are tested, for instance, when the operator tests that a rotor in a pump can rotate freely.
- This is followed by “reinstating control” (*återställning*). This phase is basically an administrative check that all ordered maintenance activities have been completed.
- The next step is to reset the basic configuration of the systems (*basläggning*), for instance, ensuring that valves that had been closed before maintenance are reopened.
- Following that the systems are setup for operation (*driftsättning*).
- After that a system level function testing is carried out (*provning*).
- The last step is safety function testing. Only when this step is completed can the system regarded as operationally ready.

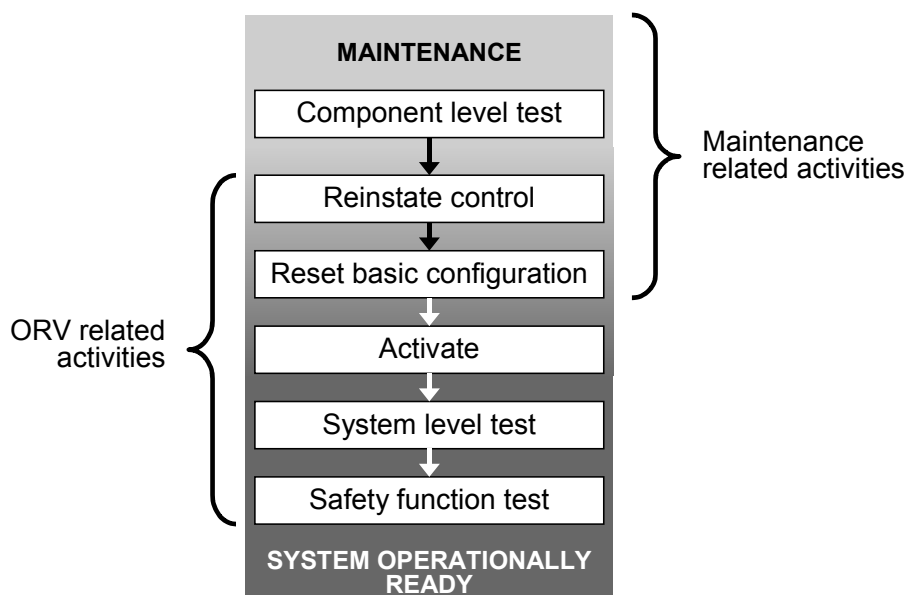


Figure 9: The six steps of ORV.

In this description ORV is a clearly defined set of activities, which has the specific goal of ensuring that the system is ready for operation. ORV involves specific staff members whose actions are coordinated via work permits. However, when looking closer at the practice of ORV (i.e., of how operational readiness verification is carried out in real settings) there may be reason to doubt the notion of ORV as a distinct set of tasks, not least because the formalisation of the six steps only approximately reflects actual working conditions.

The results from Phase II showed that while the first steps were the duty of the maintenance department, the subsequent steps were the responsibility of the operation department. These are two Communities of Practice with somewhat different goals although the goals are neither far removed from each other nor incompatible with the overall goals of ORV. Yet the maintenance department's interest in taking care of systems before they break down may sometimes be at odds with the operation department's preference to minimise maintenance on a well functioning system. While these conflicts are never serious, they may nevertheless lead to arguments between members of the different Communities of Practice.

Phase II also concluded that the tasks and the constituent activities often were interlaced rather than clearly separated from each other. Furthermore, since each system has its own technical characteristics, the test sequence may vary among systems. The verification procedure also depends strongly on the distinctiveness of the outage, even for the same system. The formal ORV procedure finally leaves out the period of time-out (so-called *oberoende DKV*) taken before restart and aiming to assure that the systems' operational readiness verification went correctly.

## 5.1 ORV as a Communication Tool

In agreement with the above, our task of studying ORV was thus not just a matter of understanding its constituent tasks and how they relate to each other. It was also important to understand how the concept itself, the term ORV, was used by the staff and whether different categories of personnel understood the concept in different ways.

When individuals were directly asked to define the term they usually adopted a definition that reflected their CoP. Maintenance operators would focus on the component tests, while control room operators would focus on system and function testing and on the time-out period. Only work permit management personnel seemed to use a definition that embraced all the tasks constituting ORV, due to their position as intermediaries between the maintenance community and operation personnel.

We also looked at how the staff used the term spontaneously, i.e., without being prompted by the observer and looked at differences between the use of the term to another person and to a group (as in a meeting). There was a clear distinction between the use of the word as a description of the activity and as a buzzword or "catch phrase". It was found that the word was used as a buzzword about as often as a description of the activity. The different uses of the term seemed evenly balanced between meetings and one-to-one conversations.



## 5.2 The Practice of ORV

While the content of ORV has not changed much over time, its formality increased considerably after the nine incidents in the late 1990s. It came as no surprise that some employees felt that this increase in formalisation went beyond what was strictly necessary. In practice, the formalisation has over time been adapted to achieve a viable balance between on the one side a stringent adherence to the rules and on the other a recognition of the constraints and opportunities that the work environment affords.

The adaptation – and part relaxation – of the formalism is due both to a lack of further incidents and to the understanding of ORV as a “catch phrase”. The lack of incidents clearly diminishes the need and motivation further to strengthen the formalisation process. In addition, some employees may find it difficult to think of ORV as something unique since the constituent tasks preceded the introduction of the term as such. This lack of uniqueness reinforces the employees’ view of ORV as a “catch phrase”, which in turn affects the importance given to ORV.

While some relaxation of the formalism certainly can be positive, it should not be allowed to go too far. This is probably not a risk on the level of each specific CoP, since the people involved are keenly aware of what they do and of the safety implications (cf. Section 3.2.3). It is, however, less easy to maintain the overview of the ORV activity as such, i.e., hence to anticipate the consequences of relaxing the formalism that governs the conduct **between** Communities of Practice. The existing ORV procedure implies that tasks take place on a single level of control, as shown by the sequence in Figure 9. This contrasts with the findings from these studies that ORV comprises multiple, simultaneous activities of different scope and duration. It therefore appears as if the proposed formalism does not completely cover ORV as it is carried out in practice, i.e., there is some discrepancy between the formalism and reality.

The experience from other fields of practice strongly suggests that the importance of a concept will diminish in the long term if it does not have a firm foundation in practice. An excessive formalism with little practical value in the eyes of the users will not be adhered to for long. If practitioners have difficulties linking the formal description of ORV to safety as practiced, the value of ORV as a formalised activity is compromised.

## 5.3 A revised model of ORV

The studies have shown that ORV, rather than being a simple sequence of tasks as originally assumed, comprises multiple activities of different scope and duration, where several of them often are carried out simultaneously. It is therefore more appropriate to describe ORV in terms of multi-layered control, i.e., simultaneous and mutually dependent activities. This is also consistent with the current view of human performance as coping with the complexity of the work environment rather than responding to events in a skill-based, rule-based or knowledge-based manner. The current view can be found, for instance, in descriptions of naturalistic decision making (Klein et al., 1993) and macro cognition (Cacciabue & Hollnagel, 1995).

One example of how to model multi-layered control is provided by the Extended Control Model (ECOM; Hollnagel, et al. 2003). Without going into technical details of the model, the useful feature for a description of ORV is that actions are characterised in

terms of four different layers of control, which from the top down are called targeting, monitoring, regulating, and tracking. The **targeting** or goal setting layer is where the objectives and performance criteria are generated. The **monitoring** layer keeps track of the performance relative to the objectives, and may also generate more specific subgoals that are necessary to overcome temporary problems, for instance if the completion of a specific activity is delayed. The **regulating** layer directly controls how specific activities and tasks are carried out, i.e., the actual manipulation of the plant components. Finally, the **tracking** layer is used to describe the minute details of actions, such as the execution of skills and single actions. The tracking layer is, however, not important for the modelling of ORV.

When this description is applied to how the ORV is carried out, the targeting layer corresponds to the overall planning of the outage and specifically to the work permit management (ABH). The regulating layer corresponds to the work that is carried out within the Communities of Practice, i.e., the actual activities that constitute the ORV on the level of physical equipment. The monitoring layer is partly found within each CoP and partly in the MCR. It is, however, less clearly located than the layers above and below. A rendering of the ECOM as it may look for ORV is shown in Figure 10. The figure shows how the six phases of an ORV can be found on each level, but also how they are “shared” among levels. For instance, resetting the basic configuration (*basläggning*) is described both as a target, as a goal for monitoring, and as a set of specific activities on the regulating layer. The multi-layered description thereby represents not only the progression of the ORV as a whole, but also the couplings and dependencies among the different Communities of Practice as they carry out their work. The representation in Figure 10 is by no means complete, but can be used as a basis for looking at how the ORV can achieve its purpose – and also some of the ways in which it may possibly go wrong.

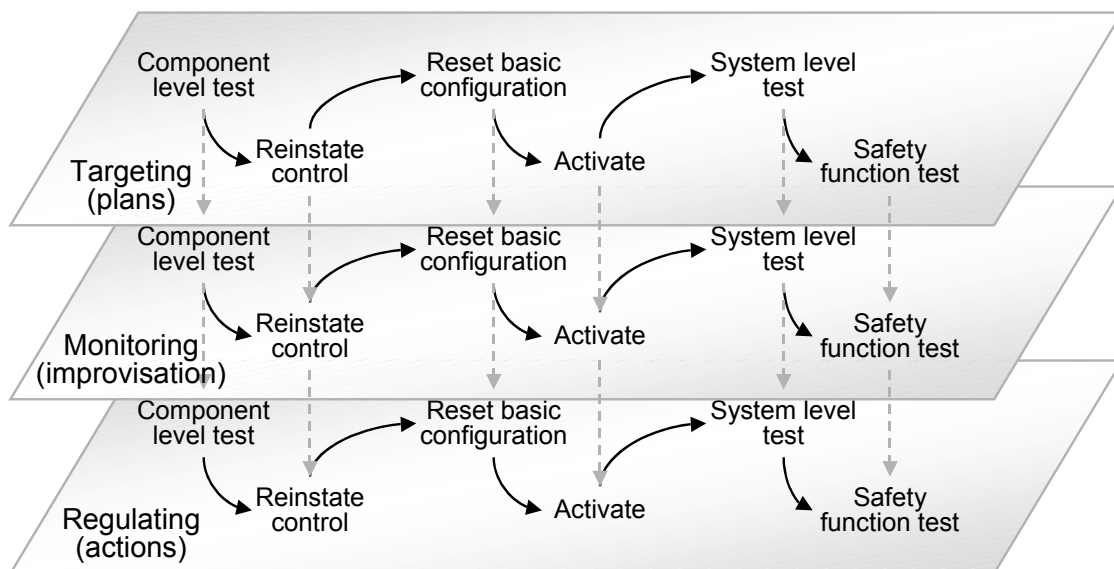


Figure 10: A revised ORV model

### 5.3.1 ORV as a barrier

The report from Phase I of this study described the ORV as a set of barriers designed to prevent a breach of safety during the start up after an outage. The six main functions described in Figure 9 represent a mixture of functional and symbolic barrier systems, where the general barrier function is to **prevent** something from happening. (A more detailed characterisation of each functions requires that they are analysed step by step.)

From an overall point of view, the main ORV functions look as if they provide a defence in depth (INSAG, 1995). The similarity is, however, only superficial. Whereas defence in depth consists in a hierarchical deployment of different levels of independent barriers (equipment as well as procedures) that provide a graded protection against a wide variety of transients, incidents and accidents, the ORV only has a loose structure. The various activities that constitute ORV are organized primarily by means of pre-conditions, in the sense that activity A must be completed before activity B can be started. Yet these preconditions are only effective if the formal ORV procedure is implemented rigidly and without variations. Since the complexity and variability of the work environment renders this impossible, the conclusion is that the ORV cannot be effective in terms of its formal structure alone.

The reports from Phase II and Phase III of this study have shown how ORV can be described as an ongoing adjustment of procedures and practice to the actual conditions. This adjustment is necessary because there are multiple goals on different time-scales and a lack of complete certainty about what may happen next. It is therefore essential that the organisation is able to improvise in the sense of adjusting existing plans, or even re-plan, in done to meet the existing demands.

While the improvisation is a necessary condition for the efficiency of work on the organisational level, in the same way as the Efficiency-Thoroughness Trade-Off is on the individual level, it can also be a source of risk. The mutual adjustments that organisations and people make (“drifting”) are only effective as long as the underlying assumptions hold, i.e., as long as the variability is not too large. This requires effective monitoring. It is therefore worthwhile considering how the variability can be kept under control.

The traditional solution is to provide more procedures under the assumption that if everyone works according to prescriptions, nothing can go wrong. This solution is, however, not useful in practice since the very nature of practice is to apply procedures judiciously rather than literally (cf. Section 3.3.1). Indeed, this flexibility is necessary in order for the system to work, since procedures always are under-specified and therefore cannot provide the minute details that are needed to cope with the actual conditions of work. To insist on compliance and to discipline deviations is therefore not likely to produce the desired outcome.

Perrow (1984) describe the problems of complex systems in terms of tight couplings and non-linear interactions. According to this view a possible solution is to reduce the degree of coupling in the system, i.e., to decouple partly subsystems and functions from one another. In that sense the effects of the inevitable performance variability will be reduced and possibly also made more predictable. At least the couplings can be brought closer to the level where people are actually able to imagine them, hence to be prepared for their effects.

While this solution may be useful in general, it is not well suited to ORV, because ORV is not a loosely coupled set of activities. Indeed, ORV is very much an issue of coordination a considerable number of activities, which can only be decoupled if the organisation is willing to accept a significant cost in terms of additional monitoring and communication. Effective ORV requires continuous targeting (re-targeting) and monitoring, in parallel with and closely linked to the actual activities (regulating).

An alternative to reducing the degree of coupling in the system is to make the couplings more conspicuous. This can be achieved by providing better status indications and communication, particularly whenever an activity starts and ends. This is tantamount to paying even more attention to details, and to provide the information that is necessary to know about the details. On the individual level each person knows what he or she is doing, but it cannot be taken for granted that others know it as well. It is therefore important for everyone clearly to communicate what is going on, when it will be completed, and what is going to happen next – and also to make sure that the opposite is the case, i.e., to be aware of what others are doing.

On the organisational level this is addressed by the procedures for handover. This procedure is used in the transfer from one shift to another, but something similar might be considered in the transfer between major segments of the ORV, for instance something corresponding to the six tasks shown in Figure 9, or even for the details of each major task. Providing more information may also be an efficient way of coping with situational surprises, cf. Section 4.1.1.

## **5.4 Suggestions for the industry**

The impression that remains after these studies is that possible problems ascribed to ORV do not lie with the detail of ORV – as a procedure or a technical solution – but rather with the use of ORV, i.e., the social and organisational issues. The analysis of the observations from Phase III has in particular pointed to a number of interesting and important “mechanisms” that are used in practice, such as story telling, the acceptance of failures, attention to details, and the extraction of cues. On the basis of this, two suggestions for ORV improvement are possible.

Firstly that ORV is complemented by a reflection about ORV in two different ways. One is on the individual level (individual operator or technician) and the other on the group or organisational level. The first means that when a segment of the ORV has been completed, e.g., as defined by the ABH, then there should be a short phase of reflection on the individual level. In essence, the people who have done the job know that it has been done, and also know (hopefully) what to do next. The reflection is in relation to the other people around. Do they know that the job has been done? Or even that it was being done? Also, do others know what will happen next? The reflection amounts to putting oneself in the position of others, and reflect on whether that which each person takes for granted is also known – or taken for granted – by others. This might conceivably be formulated as some rule, or defined as an additional activity in the existing procedures so that a job is not completed when the last step of the work permit has been carried out, but only when it has been reported and acknowledged.

Secondly, that the issue of organisational learning is considered more directly. People clearly learn not only from their own experience but also from that of others, as shown

by the phenomenon of story telling. It is quite likely that this learning could be made more effective by formally recognising it and assigning resources to it, primarily time. In this way the rule that applies to the individual, cf. above, also applies to the organisation. In other words, when an ORV has been completed, or even when a major segment of the ORV has been completed, an evaluation phase should be introduced before going on to the next step. Story telling has proved to be an efficient way for people and organisations to learn within and across domains. It might be considered whether this useful practice could be made a little more systematic, and supported as an explicit contribution to system safety.

## 6. Glossary

|      | English                            | Swedish                             |
|------|------------------------------------|-------------------------------------|
| ABH  | Work Permit Management             | Arbetsbesked Hantering              |
| CoP  | Community of Practice              | Verksamhetsgemenskap                |
| DKV  | ORV                                | Driftklarhetsverifiering            |
| ETTO | Efficiency-Thoroughness Trade-Off  |                                     |
| MCR  | Main Control Room                  | Central Kontroll Rummet             |
| MTO  | Man-Technique-Organisation         | Människa – Teknologi - Organisation |
| NPO  | Non-Productive Outage              | Kortstopp                           |
| NPP  | Nuclear Power Plant                | Kärnkraftverk                       |
| ORV  | Operational Readiness Verification | DKV                                 |
| RO   | Reactor Operator                   | Reaktor operatör                    |
| SS   | Shift Supervisor                   | Skiftchef                           |
| ST   | Station Technician                 | Stationstekniker                    |
| TO   | Turbine Operator                   | Turbin operatör                     |

## 7. References

Cacciabue, P. C. & Hollnagel, E. (1995). Simulation of cognition: Applications. In J.-M. Hoc, P. C. Cacciabue & E. Hollnagel (Eds.), *Expertise and technology: Cognition and human-computer cooperation*. New York: Lawrence Erlbaum Associates.

Cole, M. & Engeström, Y. (1993). A cultural-historical approach to distributed cognition. In G. Salomon (Ed.), *Distributed cognitions - Psychological and educational considerations*. Cambridge, UK: Cambridge University Press.

Engeström, Y. (1990). *Learning, working and imaging: Twelve studies in activity theory*. Helsinki, Finland: Orienta-konsultit.

Engeström, Y. (1993). Developmental studies of work as a testbench of activity theory: The case of primary care medical practice. In S. Chaiklin & J. Lave (Eds.), *Understanding practice: Perspectives on activity and context* (p. 64-103). Cambridge, UK: Cambridge University Press.

Hollnagel, E. & Gauthereau, V. (2003). *Operational readiness verification, Phase 2: A field study at a Swedish NPP during a productive outage* (SKI Report No. 2003:09). Stockholm: Statens Kärnkraft Inspektion (SKI).

Hollnagel, E., Nåbo, A. & Lau, I. (2003). A systemic model for Driver-in-Control. Proceedings of 2<sup>nd</sup> International Driving Symposium on *Human Factors in Driver Assessment, Training and Vehicle Design*. July 21-24, 2003, Park City, Utah, USA.

INSAG (1995). *Defence in depth in nuclear safety*. Vienna: International Atomic Energy Agency.

Klein, G. A., Oramasu, J., Calderwood, R. & Zsombok, C. E. (Eds.) (1993). *Decision making in action: Models and methods*. Norwood, NJ: Ablex.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Ogden, C. K. & Richards, I. A. (1921). *The meaning of meaning*. (10th edition, 1972.) London: Routledge & Kegan Paul Ltd.

Olson, J. M., Roese, N. J. & Zanna, M. P. (1996). Expectancies. In E. T. Higgins & A. W. Kruglanski (Eds.), *Social psychology handbook of basic principles* (pp. 211-238). New-York: Guilford.

Orr, J. E. (1996). *Talking about machines: An ethnography of a modern job*. Ithaca and London: IRL Press - Cornell University Press.

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

Weick, K. E. (1995). *Sensemaking in organizations*. Thousand Oaks, CA: SAGE Publications, Inc.

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

Woods, D. D. (1990). Risk and human performance: Measuring the potential for disaster. *Reliability Engineering & System Safety*, 29, 387-405.



[www.ski.se](http://www.ski.se)

**STATENS KÄRNKRAFTINSPEKTION**  
Swedish Nuclear Power Inspectorate

**POST/POSTAL ADDRESS** SE-106 58 Stockholm

**BESÖK/OFFICE** Klarabergsviadukten 90

**TELEFON/TELEPHONE** +46 (0)8 698 84 00

**TELEFAX** +46 (0)8 661 90 86

**E-POST/E-MAIL** [ski@ski.se](mailto:ski@ski.se)

**WEBBPLATS/WEB SITE** [www.ski.se](http://www.ski.se)