SKI Report 2003:09

Research

Operational Readiness Verification, Phase 2:

A Field Study at a Swedish NPP during a Productive-Outage

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SKI Perspective

Background

During the last five years of the 20th 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.

SKI´s Purpose

This research assignment concerns phase II of the project. The purpose of this study was, based on the identified issues in phase I, to study and analyse the different steps in testing as a part of operational readiness verification to understand the relation between testing and safety.

Another purpose of phase II of the research project was to further improve the research methods and concepts for the third and last phase of the project.

Results

Phase II of the research project 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.

Continued Works

The research assignment will continue in phase III and contain following major activities:

- a more detailed study based on the results from phase II;
- the development of a proposal of a method to identify vulnerable functions, as either single or multiple barriers, which can be used to assess the overall quality and safety of formal and/or established operational readiness verification practices; and
- to develop concrete suggestions for ways in which the safety of operational readiness verification can be improved.

Effects on SKI´s Work

The concluded phase I and II of the research assignment have 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. One of the studies (Phase II) has 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
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Abstract.

This report describes the results from Phase II of a study on Operational Readiness Verification (ORV), and was carried out from October 2001 to September 2002. 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.

One outcome of Phase II is that there is no clear distinction between the three types of tests in the way they are carried out, and that they are used according to need rather than according to an internal logic or structure. In order better to understand the complexity of ORV, it was found useful to introduce concepts such as: (1) Community of Practice, defined as a 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). By using these terms to understand the practice of ORV, it becomes easier to understand how actions at times can be carried out in such a manner that the outcomes differ significantly from what was desired. It was found that the organisation and the different communities of practice are able to improvise in the sense of adjusting the 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. But while the ability to improvise is practically a necessity for work to be carried out, it is also a potential risk. The solution to this is not to enforce more rigid practices of work, but instead to understand better the nature of the risk, i.e., to understand how work is shaped to meet demands.

Svensk sammanfattning

Denna rapport redovisar resultaten från fas II av en studie av driftklarhetsverifiering (DKV). Arbetet blev utfört under perioden oktober 2001 till September 2002, 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 1 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.

Ett resultat från fas II är 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 (ETTO) 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-, verksamhets-gemenskaps- 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.

1. Background – Introduction

1.1 Operational Readiness Verification – Previous Research

This report presents the results from “A Field Study At a Swedish NPP during a Productive-Outage” (Best nr. 01209), which was carried out from October 2001 to September 2002. This was a continuation of the study on “Operational Readiness Verification: A study on safety during outage and restart of nuclear power plants” (Best nr. 98157) that was concluded in July, 2001. Operational Readiness Verification (ORV) – in Swedish called *Driftklarhetsverifiering* (DKV) – refers to the test and verification activities that are needed to ensure that plant systems can function as required when the plant is restarted after an outage period. (Since this report is written in English, the abbreviation ORV will be used in the following.) The concrete background for the work was nine ORV-related incidents that were reported in Sweden between July 1995 and October 1998. The first phase of the study comprised two activities: (1) a literature survey of research relevant for ORV issues, and (2) 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 that follows 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 studies also suggested that ORV could usefully be described as a set of barrier functions in relation to the flow of work, using the following five-stage description, cf. Figure 1:

- preventive actions during maintenance/outage,
- post-test after completion of work,
- pre-test before start-up,
- the start-up sequence itself, and
- preventive actions during power operation – possibly including automatic safety systems.

The field survey consisted 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 soon 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 are of quite a general nature, hence have consequences that reach beyond an ORV focus. This finding reinforced the conclusions from the literature survey.

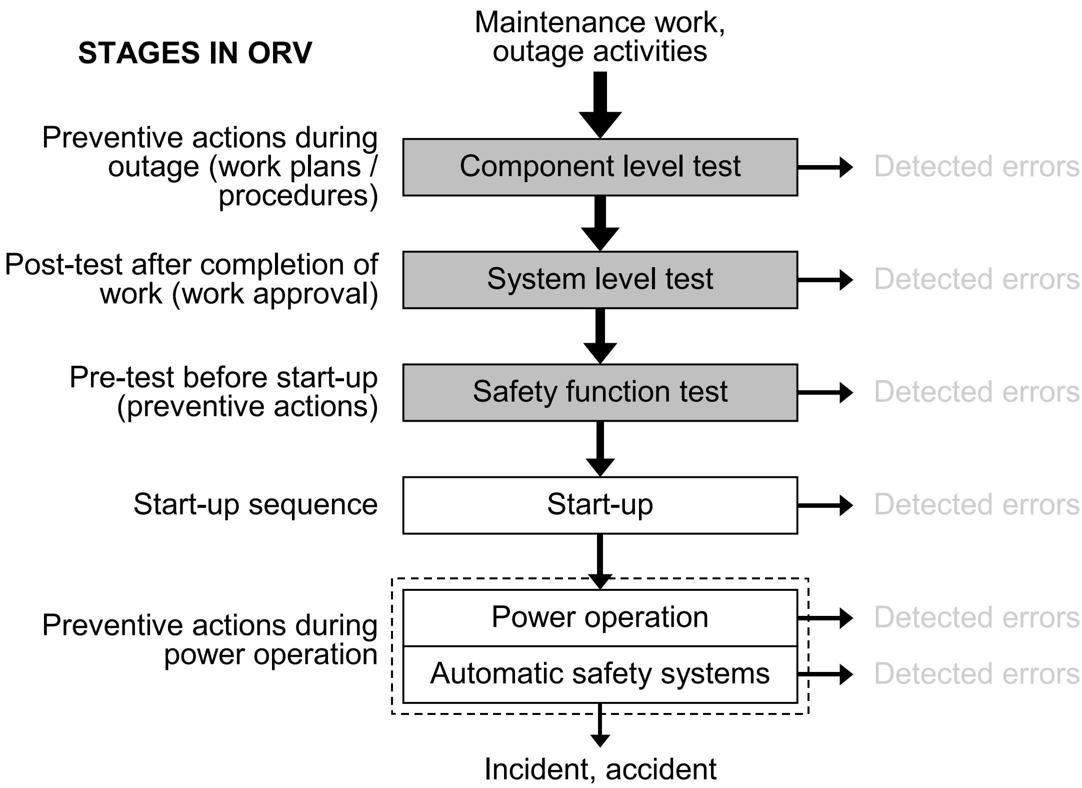

Figure 1: Types of testing and ORV work flow

An analysis of the nine Swedish ORV cases had found weaknesses in four main areas: (1) administration processes, (2) management, (3) human performance, and (4) control room layout. In response to these, the Swedish NPPs have implemented several technical and organisational solutions. The former include an overall re-qualification scheme, blocked safety functions, computerised operational position control, and central indications in the control room. The latter comprise operational readiness plans, systematic ways of working, new instructions, co-ordinated testing, and the use of redundant or independent controls. Special emphasis has been put on how the NPPs plan their outages, how the plans are implemented, and how deviations are handled. Issues related to learning from experience have also been investigated. It was found that all Swedish NPPs approached the ORV issues in a serious and efficient manner, but that the actual solutions inevitably reflected the characteristics of the organisation.

A conclusion from the first phase of the study was the need to look more closely at the differences between three levels or types of tests that occur in ORV: (1) object (component) test, (2) system test and (3) (safety) function test, and to analyse the different steps of testing in order to understand the non-trivial relations between tests and safety. The study should take place at a single NPP during a safety-train outage (*subavställning*), since these would allow empirical work to be conducted in an appropriate environment with better accessibility to technical staff than during a full outage period.

1.2 Aim of the present study

The work in the first phase of the ORV study identified a number of research questions of interest for the readiness verification issues, and more generally for NPP safety. Some of these are of general interest, such as safety culture issues or the influence of technical solutions on the operators' work, while others are more specifically linked to ORV problems.

One specific issue concerns 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. Outages are always carefully planned, including the specific collection of tasks that make up the ORV. However, due to the complexity of NPPs as socio-technical systems and of the work taking place during outages, unexpected conditions and events may arise which create a need to adjust existing plans or even to re-plan. The ability of the organisation to react appropriately in the face of such unexpected events depends on its ability to improvise and may be vital to ensure the plant's operational safety.

A second specific issue concerns the quality of testing. A distinction is usually made between three levels or types of tests (cf. the first three levels of Figure 1):

- Tests on the component/object level (*objektprov*),
- tests on the system level (ORV as post condition) (*systemprov*), and
- tests on the functional level or safety function test (ORV as pre-condition) (*säkerhetsfunktionsprov / samfunktionsprov*).

The complexity of the NPP directly affects these tests; although each seems to be quite distinct and in theory simple, they turn out to be quite complex to carry out in practice.

Since these research issues had resulted from the first phase, it was proposed that the second phase was used to study these issues further by means of a limited field investigation. This would also offer an opportunity to fine tune methods and concepts, and hence provide the best possible basis for a potential third phase.

1.3 The Present Study in the Research Process

In an attempt to redefine the role of research in psychology, Fishman (1999) distinguished between two models of professional practice. The first described professional activity as applied science, while the second described professional activity as disciplined inquiry.

According to the "Applied Science" model of professional activity (Figure 2), there is a linear chain of relationships from basic research to the development of technology, which help a client to solve a problem through professional application. In this model, basic knowledge is consequently context independent.

Figure 2: Professional Activity as Applied Science (Fishman, 1999)

This assumption runs counter to the current view, according to which knowledge is embedded in and depends upon a context, considering professional activity as applied science is not viable. The suggested alternative is based on the so-called "disciplined inquiry" model (as adapted from Peterson, 1991). This model (see Figure 3) starts with a problem to be solved (Step A, "Client"), followed by an assessment phase in which the different stakeholders (basically the client and the researcher) formulate the problem with previous research and experience as guidance. The formulation of the problem and of the plan of action leads to the carrying out of the action with outcomes that are evaluated and used as input for further action.

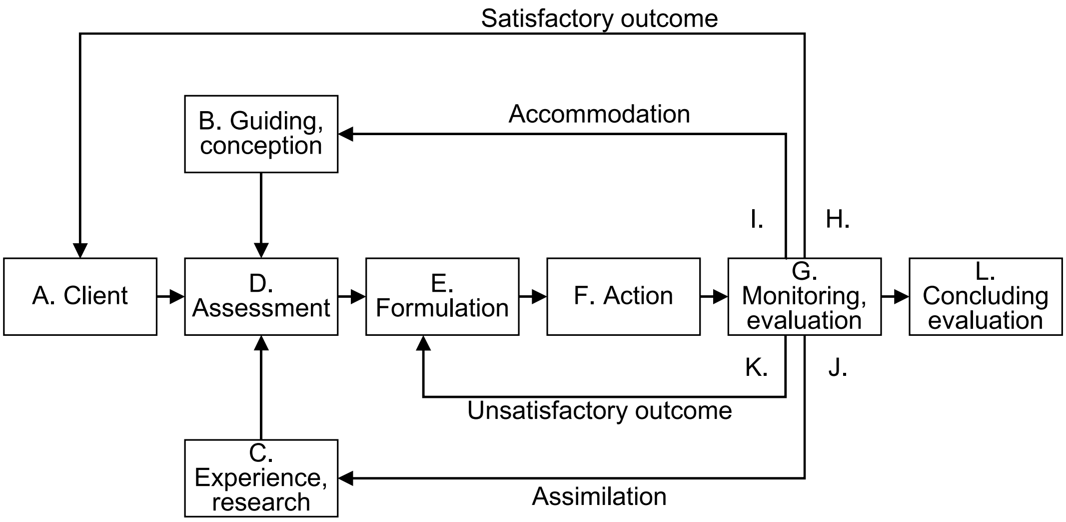

Figure 3: Professional Activity as Disciplined Inquiry (Fishman, 1999)

The present research project seems to fit this framework: starting with a need from the 'client', studies in phases 1 and 2 aimed at assessing the situation (Steps B, C and D), which led to a further specification of the "problem" (Step E). The next step (phase 3) will in due course conduct an 'action'/improvement and an evaluation of the outcome (steps F and G). In doing so it is necessary to take into account the complexity of the context and the risks associated with the setting. Further discussion of how an "improvement" can happen in the domain will take place during phase 3.

1.4 ORV And Testing

The starting point for the proposed work is the relation between the five stages in the flow of work (cf. Section 1.1 above) and the three different types of test. The various tests constitute the basis for ensuring the operational readiness of the NPP. The tests can therefore be seen as providing the substance of the several levels of barriers that guard against possible failures from outage and maintenance work, as outlined by Figure 1.

It is furthermore common to distinguish between two different test methods, which are called functional tests (*funktionsprov*) and performance tests (*prestandaprov*) respectively. Table 1 summarises the different tests types and test methods and indicate how they relate to Operational Readiness Verification.

Table 1: Test types, test methods, and resulting status.

Test type	Test method		ORV status
	Functional test (*funktionsprov*)	**Performance test (*prestandaprov*)**	
Component level test (*objektprov*)	Activation test, manoeuvring test, logic test (*startprov, manöverprov, logikprov*)	Capacity test (*kapacitetsprov*)	Object / component ready
System level test (*systemprov*)	Activation test, manoeuvring test, logic test (*startprov, manöverprov, logikprov*)	Capacity test (*kapacitetsprov*)	System ready
Safety function test (*säkerhets-funktionsprov*)	Activation test, manoeuvring test, logic test (*startprov, manöverprov, logikprov*)	Logic test (*logikprov*)	Safety function ready

The desired outcome of performing these tests is, of course, that the plant as such can be declared ready for operation, so that the start-up sequence can be initiated. The background for these tests is found in STF – Chapter 4, as well as in NPP safety analyses. From these documents, an evaluation of the required tests is realised during the planning phase of the outage (whether it is a productive or a non-productive outage). This means that the testing sequences are not created anew for every outage, but that they rather are developed from available standard operating procedures.

One of the responses to the ORV-related incidents mentioned above was the introduction of a systematic way of working which could be applied to any system, although in a more or less formalised manner. This defined four steps needed to achieve operational readiness:

- Reinstating control of subsystem/component.
- Resetting basic configuration of subsystem/component. This includes calibration.
- Activation of subsystem/component.
- Testing of subsystem/component.

The fourth step of this sequence, the test, corresponds to ORV as post-test or post-condition (system level test).

While the four steps clearly are essential for ORV, step 1 (reinstating control) and step 2 (resetting basic configuration) may also rightfully be considered as the final steps of maintenance. The four steps therefore suggest that there is an overlap between two different types of activities, something that in practice may be a source of problems. Indeed, it is known from studies of Licensee Event Reports (LERs) that maintenance failures often involve forgetting to reinstate control and/or resetting the basic configuration.

The value of introducing this kind of systematic, or logical, approach to testing is easy to appreciate. In practice, the use of this approach nevertheless leads to a number of questions, which often are discussed among practitioners, such as:

- **Test method**: Are we testing the right way? This refers to issues such as the sequence of steps in a test – or even the correctness of the test procedure itself, whether the proper pre-conditions have been established, etc.

- **Test object**: Are we testing the rights things? This may be a problem when there are many components of the same type, where the distinction can be quite obscure such as a coded label. There are a number of cases (internationally) where field operators have tested the wrong components, without anybody realising it when it happened.

- **Test criteria**: Are we testing too little / too much? This refers to the issue of the testing criteria, such as the outcomes that should be observed or the duration of a test condition, which frequently are incompletely specified or rely on common knowledge.

- **Test schedule or frequency**: How often should we run tests? It is known that the test itself may stress the system and therefore potentially be a source of failure. The issue is therefore what the optimal (or correct) interval for the test is.

These questions refer to the context of the ORV, rather than to the process of ORV as such, and the answers therefore cannot be provided by the systematic test approach itself. This confirms the finding from the first phase of the study that ORV should be seen as an integral part of maintenance and the safety culture of the plant, rather than as a separate activity. The need to consider ORV as a whole process, i.e., from completion of maintenance to a state of readiness before start-up, also reflects the fact that the steps used to achieve operational readiness (reinstate control, reset, active, test) can be part of maintenance as well as ORV post-testing. In practice it is not possible to assign these steps exclusively to one or the other type of activity. Neither is it possible to analyse them without taking the larger context of ORV into account. Although failures are usually associated with specific actions, the understanding of why they occurred cannot be confined to the action itself but must include the many facts of the context. This is described further in the following under the notion of embedding.

2. The Research Settings

2.1 The Expected Situation

The NPP that was studied undergoes a so-called safety train outage four times a year. From a technical point of view, the safety systems of the unit are divided into four independent trains, which separately can be made inoperative thereby allowing maintenance to take place while still producing with three trains intact (thus the name productive outage). These safety train outages make it possible to reduce the duration of non-productive outages (NPO). However, for safety reasons, the number of safety train outage days is restricted to 60 per year. The safety train outage under observation was the last to take place in 2001.

The productive outage under observation was planned to last 17 days. This outage was unusually long because it included maintenance of one of the diesel engines. Even though these are used very rarely during the lifetime of the plant, a major revision must be carried out at certain intervals. In the planned safety train outage, the diesel engine was to be dismantled, parts were to be sent away for non-destructive control and finally the engine was to be remounted, and tested. This was the first time such a revision was planned; the three other diesel engines were to undergo similar maintenance during the three following safety train outages.

Furthermore, 11 days after the planned end of the safety train outage, another reactor (Unit 1) of the same NPP was to be shut down for renovation work that would last more than a year. A reorganisation of the maintenance department had consequently been carried out a few months earlier, which put maintenance personnel from the three reactors in the same organisational unit.

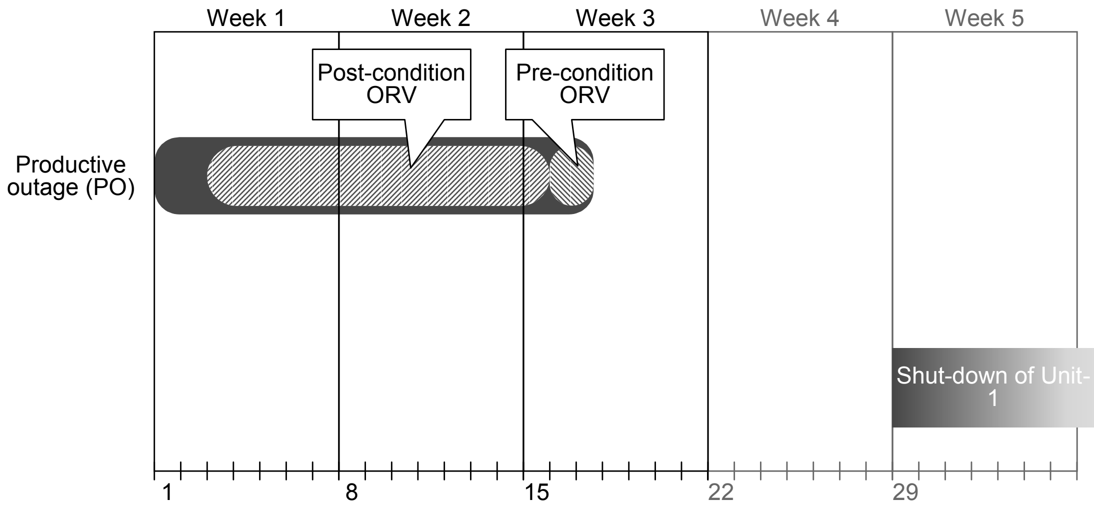

Figure 4: Expected Situation

2.2 The Actual Situation

During the summer 2001, not long before the study took place, traces of contamination had been found in the primary cooling system. This indicated that part of the fuel was leaking, and thus needed to be replaced. Based on the estimated size of the damage at the time, the experts envisaged a replacement of the leaking fuel during summer 2002 (that is during the next planned non-productive outage).

However, right after the beginning of the safety train outage, significant traces of contamination were discovered in the primary cooling system. This created an urgent need to replace the leaking fuel, and a short non-productive outage (NPO) was consequently planned. This will be the focus of a later section, and for the moment we will just see how this affected the study of ORV.

Basically, we planned to study ORV as post-condition (i.e., component and system level tests) during the first two weeks, and to focus on ORV as pre-condition (safety function test, so called “time-out”) right before start-up (see Figure 4). However the start of a non-productive short outage at day 12 enabled the observation of two additional sequences of ORV as pre-condition (see Figure 5). One was associated to the safety train outage and occurred since the plant was only allowed to shut-down for maintenance once all the systems, except the emergency diesel engine, had be declared ready for operation. The other extra sequence was associated to the short NPO.

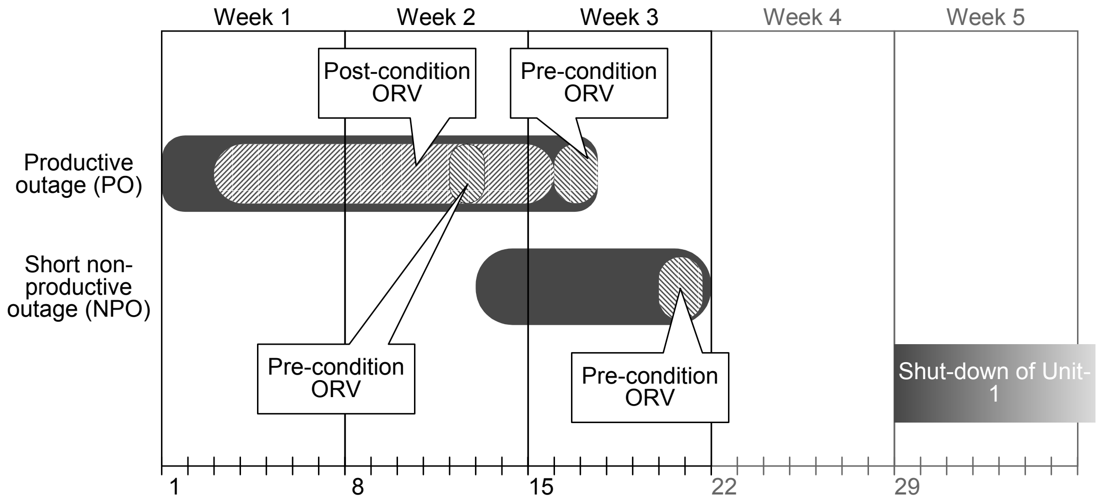

Figure 5: Actual Situation

2.3 ORV, Work-order Management (ABH), and Control Room Operators

2.3.1 The Organisation at the Unit

The basic principle is that the Unit is divided into two departments, the Operations Department and the Maintenance Department (U for *underhåll* in Swedish). The operations department is itself separated into two categories of employees. One category is the control room personnel, which comprises station technicians, and main control room (MCR) operators. In the control room associated to one Unit (i.e., one reactor) there are at least three operators: one Turbine Operator (TO) who deals with the turbine and the electric generation part of the unit; one Reactor Operator (RO) who deals with the reactor and the associated safety systems; and one Shift Supervisor (SS) who has the overall responsibility for the plant operation. All control room personnel work on shifts: seven shift teams work around the clock in 8-hour shifts during a period of seven weeks. The operation department also has a group of people that work only daytime. They provide a direct support for control-room personnel with functions such as planning, or Work-Order Management (ABH).

Of the maintenance department some resources are specifically dedicated to each Unit while others are common to the three reactors constituting the plant. Among the maintenance department staff some supervisors are specifically responsible for the maintenance of several systems at the Unit; maintenance planning, for instance, has a dedicated co-ordinator. All maintenance personnel work daytime only, i.e., there are no shifts.

In addition to these two departments, there are a number of supporting functions. One of them is the radiation-protection division. The staffs of this department work specifically with radiation-protection issues such as taking care of the dosimeter systems, decontamination of radioactive zones (for instance, before maintenance is performed), etc. People in the radiation-protection division work daytime. Yet another department is called technical calculations.

While the structure of the organisation is reasonably complex, an oversimplification, which also seems to corroborate the employees understanding of the organisation, is to see the daily work at the Unit as divided between two departments (Operation and Maintenance) with ABH sitting in between.

2.3.2 Definition of ABH Tasks

It was previously found that work permit management (Swedish: *Arbetsbeskedhantering* or ABH) is organised very differently among the NPPs, and it was therefore necessary to describe the organisation at the plant under study. Two persons are working with ABH all year around, but they get help during an outage from two additional individuals. However, during the time when the study was carried out, only two persons worked at ABH and the findings may therefore not reflect the normal outage conditions.

Work order management requires a close co-operation with both maintenance personnel and the control room operators. The flow of work is illustrated in Figure 6, which also shows by numbers the four main phases in work order management.

1. To gather information about the maintenance tasks which have to be performed (work-order). This is done with the use of a computerised information system; tasks are prepared by maintenance personnel and can be retrieved by ABH.

2. To prepare the so-called delimitations, protecting fences, or even “umbrellas”. In order to work on some components, the systems need to be prepared in the sense that pipes need to be emptied, electricity shut off, etc. When preparing protecting fences, ABH also prepares the instructions for setting-up the systems after maintenance. While the first phase is important for worker’s safety, the second is essential for plant safety. Each batch (protecting fence) usually includes a few work-orders.

3. Once the protecting fences are ready and reviewed by MCR operators, they are distributed to the concerned persons when appropriate. This phase therefore involves two steps. The work-permits first go to the MCR for the delimitation tasks to be performed, and then come back to ABH who deliver work-permits to maintenance staff.

4. Finally, once all work permits included in one batch (one protecting fence) are completed, ABH forwards the information to the MCR, which can set up the systems for operation. This final role can be understood as the reinstating control

step described earlier in this report. But since the responsibility for operational readiness verification lies with the shift supervisor, ABH's role in reinstating control is just one of support. Moreover, in case this task needs to be completed during night shifts when there are no people working in ABH, the MCR operators take over (as it happened in the case described in Section 4.2).

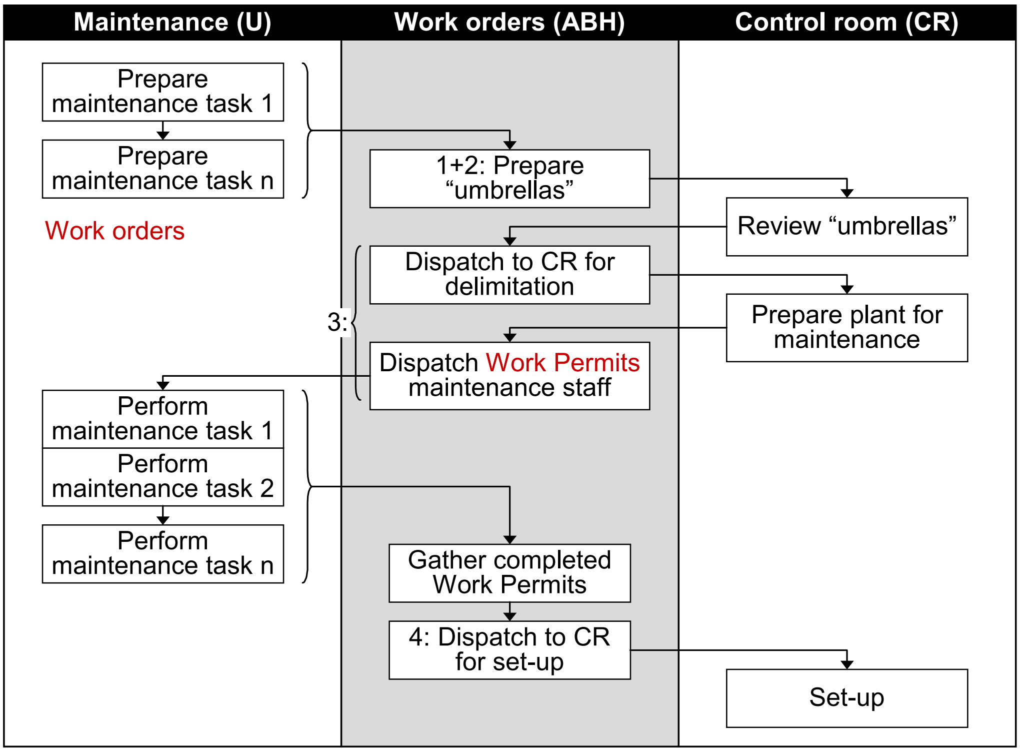

Figure 6: ABH Work-Flow.

2.3.3 Physical Location of ABH

The central role of ABH in co-ordinating the work of two separate departments is reflected in the physical arrangement of the plant, where the ABH office lies at the boundary between the main control room (MCR) and the plant (i.e. where maintenance is conducted). This physical location enables frequent contacts between ABH and the MCR personnel; even getting a cup of coffee entails walking through the control room. It also allows ABH to have consistent contact with the maintenance operators (ABH are the ones delivering the work permits!). The physical location of this office also provides the opportunity for contacts with the radiation protection office. However, although belonging to the daytime staff, ABH does not come into regular contact with maintenance-management staff since a few floors separate them, and thus ABH's physical centrality relative to the main control room does not allow them much contact with the maintenance coordinator and maintenance planning staff.

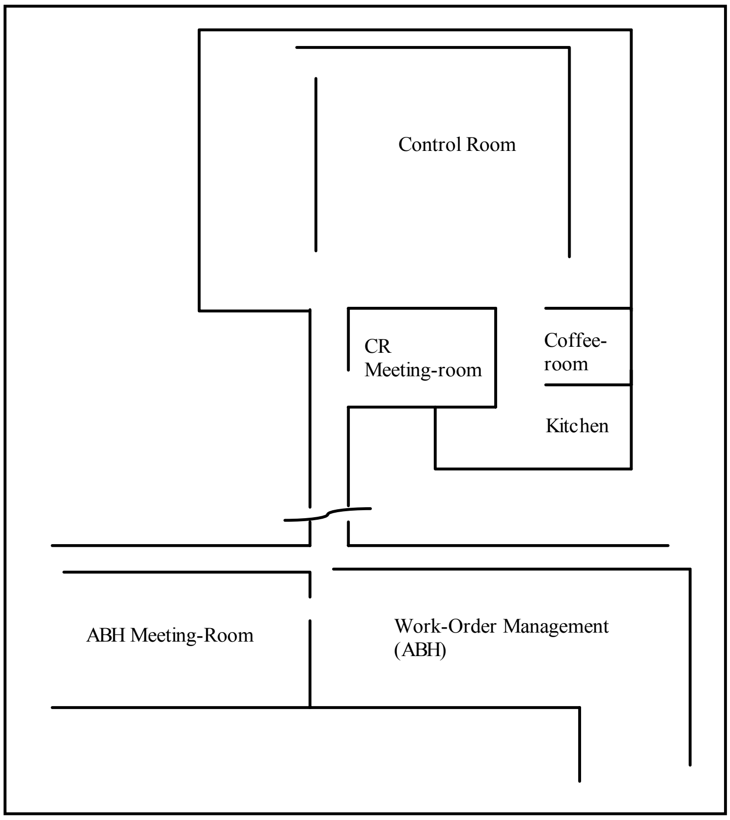

Figure 7: Physical location of ABH in plant.

3. Methodological considerations

3.1 Data Collection

The data collection was done according to the principles of an ethnographic field study. In practice this means that an observer (VG) spent an extended period of time at the plant during the weeks of the scheduled safety train outage (cf. Sections 2.1 and 2.2 above). This approach combined direct, reactive observations of selected NPP employees with several informal and a few formal interviews (e.g. Bernard, 1995, p. 311-331; Schwartzman, 1993).

At the end of each day, the observations were written into a computer. This transcription from paper to data served to complete the notes with details of the situations there had been no time to transcribe during the day, but which were remembered during the writing. When data were not put into a computer, notes were completed on paper. Since it is not possible to record on paper all the details of a situation, these notes were used as triggers for the observer's memory. Moreover, the observer wrote down his reflections about the observed situations. Especially during the first days, the observer wrote down his impressions and feelings about his being at the plant. This transcription was also a way for the observer to summarise what had been observed and to develop a strategy for the coming days.

After almost three weeks at the plant, the notes were left aside for a few weeks. During these weeks, the observer met fellow researchers in both informal and formal situations to discuss his experience. This partially enabled the observer to put apart the strong affective components associated to this experience.

Once the "heat" had subsided, data from observations was put into spreadsheets; sorting out the date, time, place, persons involved (department, function), tasks at hand, general situation (meeting, corridor talk, etc), the technical systems considered, etc. If the observation was directly related to the preliminary understanding of ORV, it was also specified to which step the observation referred.

3.2 Data Analysis

Due to the nature of the study, the data were qualitative rather than quantitative. One consequence of this is that the phases of data analysis and interpretation blend into each other. The separation between analysis and interpretation is really only possible if the data can be represented in quantitative terms, i.e., expressed by means of numbers. In that case numerous statistical techniques can be used to analyse the relationships between various quantities or set of numbers, and the results of the statistical analyses can then be interpreted in light of the purpose of the investigation, usually expressed in terms of a set of hypotheses.

For data of a qualitative nature, the analysis process is highly iterative. Coding, analysis and interpretation are not done in a sequential manner, but rather complement each other according to need. Rather than starting from a clear hypothesis or theory, the analysis-interpretation is part of the process whereby hypotheses and theories are developed and refined. In the case of this study, the analysis-interpretation led to a change in understanding of ORV as a concept and as a process. How this change came about is documented in the remaining part of the report.

During the data analysis process it became useful to introduce a number of concepts from other fields, such as organisational theory. The concepts are summarised below but will be explained in more detail in following sections:

- **Embedding**. This refers to the fact that each task and activity takes place in an environment or context, which may be physical, social, or cultural. Each step toward operational readiness is strongly embedded in the physical environment of the plant, in its social environment and in the history of the plant and the outage.

- **Communities of Practice**. The understanding of learning as a group characteristic is often constrained by the canonical definitions of groups, such as "bounded entities that lie within an organisation and that are organised, or at least sanctioned by that organisation and its view of the task" (Brown & Duguid, 1991, p. 70). Yet in other situations communities are also seen as emergent from a practice. This conflict is resolved by proposals that learning and practice go hand in hand in the development of so called Communities of Practice (CoP) that through collaboration generate a common, shared understanding of events and an action orientation for dealing with such events the next time they arise. Consequently, the study of learning, that is the study of the development of work practice, should be done through the studies of Communities of Practice (see also Lave and Wenger 1991).

- **Efficiency-thoroughness trade-off**. Human actions must always meet multiple, changing, and often conflicting criteria to performance. Humans cope with this complexity by adjusting what they do to match the current conditions. On the one hand people try to do what they are supposed to do and to be as thorough as they believe is necessary. On the other hand they try to do this as efficiently as possible, which means that they try to do it without spending unnecessary effort or wasting time. This is referred to as the Efficiency-Thoroughness Trade-Off (ETTO) principle (Hollnagel, 2002).

4. Operational Readiness Verification in Practice

4.1 ORV as Post-Condition: An Account of Three Systems

As described briefly in the beginning of this report, ORV as post condition can be described in four steps: (1) reinstating control, (2) resetting basic configuration, (3) activation and (4) testing (see Figure 8). Three systems were chosen in order to observe how these steps take place in practice.

4.2 Byte av elskåp för musselfiltern 712

Since this element was not only maintained but changed, the testing procedure was different from what was normal, at least for the maintenance department side of the work:

Phase	***(In Swedish)***	**Actor**
Assembly	*(montage)*	Maintenance
Assembly checklist	*(Gröning)*	Maintenance
Inspection	*(Besiktning)*	Maintenance
Testing	*(Provning)*	Maintenance
Resetting basic configuration, Activation	*(Driftsättning)*	Operation
Testing	*(Provning)*	Operation

An overview of the actual process is presented in Appendix A. Instead of describing the whole process, we will focus on a few points, which seem of interest. These are: (1) the distinction of the testing phase between maintenance and operation; (2) the indefinite time span of the reinstating control phase; and (3) the phase resetting the basic configuration / calibration.

- Maintenance / Operation. On the one hand the maintenance department encourages contacts between the different individuals: the technician who mounted the element talked with the supervisor prior to the *gröning* phase:

indicating the different zones where he had doubt. Similarly the person who performed the "*gröning*" told the person in charge of the testing phase about a few points which he thought were to be checked more thoroughly. However, despite clear uncertainties during the testing phase, nothing but "*we're done*" was said to the control room operators. Interviews with station technicians, who realised part of the tests for the MCR, showed a lack of interest for previous testing.

- Reinstating Control. When does it start? As soon as the maintenance-testing phase starts (because of the need of power)? When this testing phase is completed?

- Resetting Basic Configuration / Calibration. The fact that the calibrating phase was missed may actually be a consequence of the uncertainties in the reinstating control phase: the sequence of ORV had to be started for the component-tests but yet, not everything was ready for function-testing.

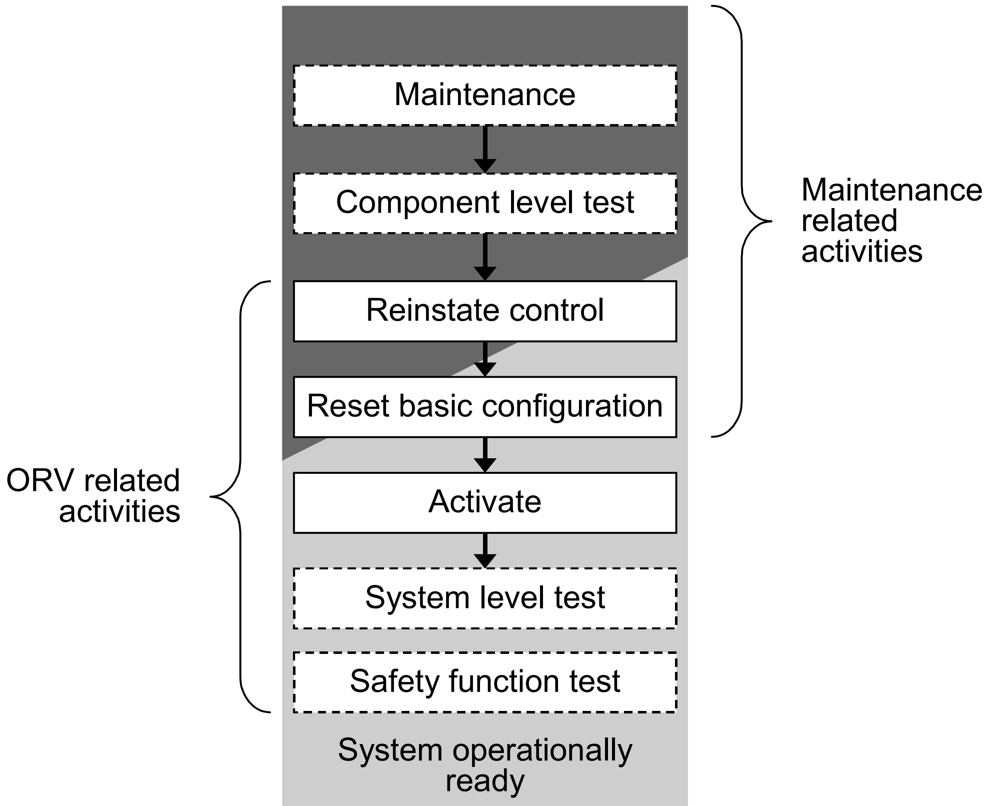

Figure 8 ORV as post-condition.

4.3 Pump 323

The ORV process for this component (shown in Appendix B) was actually quite similar to the theoretical description. Once maintenance was done, ABH started the reinstating control phase (checking that the different tasks part of the batch (*avgränsning*) were done). Then the SS took over the reinstating control task and handled the task of reinstating the basic configuration to a ST, who in cooperation with the control room completed his task out in the plant, before the SS took over to complete this reinstating task from the control room. Then different tests were run together with technicians from the maintenance department. Finally the system was declared operationally ready, right before a phase of precondition ORV started.

The task performed by the ST out in the plant is further described in a later section (section 4.6) in order to provide the reader with a more complete picture of the task.

4.4 Diesel Engine

The restarting / testing phase of the diesel engine seemed to be much more complex than the two systems previously described, mainly because of the number of persons involved.

The diagram presented on the next page does not show the whole discussion concerning ORV. During the maintenance phase, cracks were found which seem to question the operational readiness of the other diesel engines, since there is no reason to consider the other engines crack-free. The activities relating to that are not included in Appendix C.

In the case of the diesel engine, we once again observe a quite unclear definition of the reinstating control phase: when does it start, when does it end?

While the first tests involving maintenance also involved the operations department their results did not really matter. Many tests were performed, but at the end the operations department decided to have their own test, a so-called periodical test (run every two weeks during normal operation). During the whole process of testing, the operations department was there to operate the engine, but were not directly concerned with the tests themselves: each team (Mech., El, and Instrument) had their own interest in the various tests. The operations department only focused on knowing whether the different parties were satisfied with their own performance measurements. Once all these tests were conducted, the operations department did their own tests (as specified in STF chapter 4).

4.5 ORV as Pre-Condition

Theoretically three instances of ORV as pre-condition took place during the observation period, cf. Figure 5. The first, prior to the start of the short NPO (day 12), included all safety systems in the train under outage (with the exception of the emergency diesel engine that was still under maintenance at the time); the second, at the end of the productive outage (day 16), which basically was focused on the diesel engine; and the third, prior to restart at the end of the non-productive short outage (day 19).

These three verification phases varied in duration and formality, and in actual practice only the third corresponded to ORV activities during a normal outage.

While ORV as post-condition was an activity distributed among departments (Operations and Maintenance), ORV as pre-condition is the prerogative of the operations department, and more specifically of the control room operators (and station-technician), and is mainly composed of administrative checks.

4.6 ORV As A Set Of Embedded Tasks

As mentioned above, one important concept used to describe the activities during ORV is that of embedding (in the literature also called embeddedness). While certain tasks seem simple and describable by themselves, the reality is one of physical, social and cultural embedding. Each of the steps toward operational readiness is strongly embedded in the physical environment of the plant, in its social environment and in its history.

In order to illustrate this we reproduce part of the field notes describing the Reinstating Phase of the system 323, on day 11 (Table 2). This task illustrates clearly that even simple tasks (involving basically only one individual) are embedded in a complex manner in the physical and social environment of the plant. Moreover, this example is highly representative of what was observed during the field study. Though each task obviously is unique in a certain sense, we believe this series of events is a good demonstration of how tasks are performed at the plant.

Table 2: Excerpt of field notes from work on system 323.

Day 11, Basläggning / Driftsättning
The ST is in the control room, and is reading through reinstating instructions for systems 322, 323 and 327.
He reads as well different technical drawings.
Looking for a valve, he consults the SS who helps him to look for it:
ST: “Is it only on the out-side”?
SS: “We’ll do this one last…”
ST: “Every thing which is on the out-side will be done last”
The ST then goes “into” the station. On his way he reads further the instructions.
Arrived in the room (where the systems to be reinstated are), he puts the instructions on a shelf.
He reads the instructions aloud; goes to a valve, and takes away a tag (lapp)
Goes back to the instructions, and sign one of them.
He then goes to another valve (with the instruction in his hands), takes away a tag and signs the instruction.
He then reads through the different instructions.
Goes to throw away the tags.
Goes two stairs up (in the same room) via a ladder, with the instructions in his pocket (I can’t follow him there.. he comes back approx. 10 min later)
Reads one instruction, takes the two others in his hands, and goes and take away a tag. Signs the instruction.
Looks around the room, and take away yet another tag, signs one instruction.
Reads aloud, looks around the room, reads aloud one more time, Goes to a pump, and take away a tag
Talks aloud (to himself), and manoeuvre a valve (manually). Signs one instruction.
(etc.. this goes on for another 10-15 min)
He leaves the room, and goes to a room where the electrical equipment is.
Reads aloud
Puts the 3 instructions on the floor.
Reads the three instructions for another 3 minutes.
He goes and gets a “snabb-telefon”, and rings the control room:
“Can one do (these) before it is filled up?
Yes!”
He then takes away a tag and signs.
Takes away another tag, and signs.
He reads aloud: “Central position”
Check the time, reads in the instruction, takes away a tag
He reads aloud again: “central position…” takes the time.. and makes a comment to me: “It was a big valve!”
Signs down in the instruction, and leaves the room.
Before closing the door he wonders whether there is further work to be down in this room… “We’ll take it later”.
Goes back to the first room, where he reads aloud one instruction.
Looks around the room, and opens a valve.
Signs down in the instruction
(At this time there is a noise of water pouring into pipes)

45	"I am wondering.. " (says he) and closes the valve. Goes up some ladders to check ("in case…")
46	He comes back and talks aloud (to himself)…
47	
48	(etc: this reinstating sequence goes on for yet another 40-45 min, in yet 4 others rooms)

4.6.1 Physical Embedding

The strong influence of the physical environment was observed in almost every task, although with a special intensity for tasks performed in the plant (as the one described above). This physical influence acts on different levels:

- On how the task is planned. Right from the beginning control room operators separate tasks depending on the location, where three main zones are identified: the inside (*in-sidan*) where radiation-protection equipment has to be worn, the outside (*utsidan*) which comprises technical facilities outside of the radiation zone, and finally the Control Room itself. Lines 4-7 (in Table 2) illustrate this influence on the planning of the task.

- On more local planning: before going up two stairs the station technician gathers task to be performed "up there" (lines 14-17, 39-40 in Table 2)

- On the task itself: catching sight of the equipment to be activated is often the triggering factor. Many times we saw the station technician looking around the room, and at the same time reading the instruction aloud over and over until he detected the element in question (lines: 20, 21, 42 in Table 2).

We here observe two qualitatively different influences of the environment on how the task was performed. The first shows a readjustment of the task in order to obtain a certain level of efficiency. Following the steps of the task from top to bottom would not be the most efficient way to go about. Instead the station technician chose to alter the task so that efficiency was increased. However, efficiency was not the only concern that governed the readjustment of the task. Goals of thoroughness also need to be met, and too much restructuring of the task may lead to poorer performance – for instance because the overhead of keeping track of activities will grow. We saw the station technician enter and leave the main room several times even though this, for reasons of radiation safety, entailed extra efforts such as putting on / taking off footwear protections. Thus we see the physical environment as a factor influencing a certain Efficiency-Thoroughness Trade-Off, which shall be discussed in more detail later.

The other influence of the physical environment on task performance is of a qualitatively different nature. The execution of a procedure requires a certain level of interpretation. Verbal descriptions on paper (the physical document of the procedure) are transformed into a sequence of actions carried out by the operator in the following way (cf. Hutchins, 1995). First, the operator determines the meaning of the verbal description. Then the operator relates the meaning of the step to the task-world. It is important to note that this meaning depends strongly on both the world at hand and the operator. Finally, in order to take action, the operator realises the steps in the task world. In this way the physical environment plays a role in the interpretation of the step and in the formulation of the actions.

Similarly, when the operator remembers a procedure or a sequence of actions, it does not mean that they simply retrieve data from long-term memory, as a material object could be retrieved from a storehouse. Rather, remembering should be seen as "a constructive act of establishing coordination among a set of media that have the functional properties such that the state of some can constrain the state of others, or that the state of one at time *t* can constrain its own state at time *t+1*" (Hutchins 1995).

This understanding of the use of procedures turns our attention to the need for physically anchors and the importance of a good match between the procedure and the physical work environment. It also redirects our attention to the necessary trade-offs between efficiency and thoroughness that lead to local adjustments, which may easily be forgotten once the task has been completed.

4.6.2 Socially Embedded Adjustments

The concept of a community of practice (CoP) is useful to understand the activities during ORV. While the term community seems to refer to the sharing of cultural values, Lave & Wenger (1991), who after Brown & Duguid (1991) spread the use of the concept, define it slightly differently. In fact, "participation at multiple level is entailed in membership in a CoP". Moreover, a CoP cannot be defined by geographical or social boundaries. Members in a CoP participate in an activity system, with a shared understanding of the activity, and its meaning.

As described above, the instructions are often not performed from top to bottom in a linear fashion. The physical environment influences the adjustments to the order of the task, but the adjustments are not the result of something individuals do, but of a Community of Practice (CoP). These adjustments are in effect defined through the social interactions between the members of the CoP. As an example, line 6 (in Table 2), illustrates how the SS approves the station technician's choice.

Similarly, the socially established practice or rule also invites the station technician to ask the control room operator when he is unsure of something. Indeed, we rarely observe tasks performed in the station, which do not include some contact with the control room. This contact usually takes place via the intercom, which allows anyone in the vicinity of the telephone to hear the conversation. Rather than being a communication between two people only, this provides a way for all involved to maintain an understanding of the current situation and of what is going on.

Interviews with both station technicians and MCR operators showed openness to this kind of contacts with the control room, although with certain limitations. While station technicians are welcome to contact the MCR operator as soon as they judge it necessary, as a SS put it, "*it shouldn't get too often either!*". The right balance is usually learnt through the interaction with others. The Efficiency-Thoroughness Trade-Offs discussed earlier are thus not only individual trade-off. They are part of the social life of the plant; they are learnt from the interaction with others, and are constantly subject to re-negotiation. These trade-offs can therefore not be understood without introducing a time-dimension, and without placing the task performance in an historical context.

4.6.3 Historically embedded task

The tasks are also historically embedded in the sense that the influences from different time-lines or developments can be observed (see e.g. Cole and Engeström 1993 for similar analysis). Several types of development or embedding can be considered, cf Figure 9.

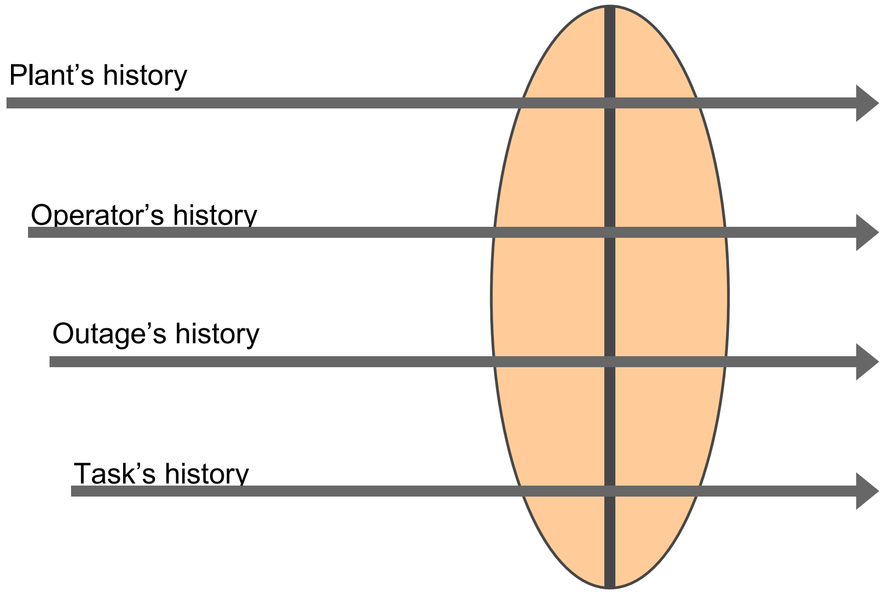

Figure 9: Types of embedding.

Plant's History: Influences of the plant history are best observed in the design of the instructions. Instructions evolve over time taking into account experience from previous use. The dialogue reported in lines 30-31 (in Table 2) highlights how the history of the plant influences the task at hand. In this case the station technician is unsure about the procedure to follow, but the SS assures him that the procedure he intended is physically possible.

Operator's history: the operators' past also influences the task at hand. A more inexperienced station technician would not have taken three instructions at the same time. Moreover, even though every component is clearly identified, good knowledge of the plant (and an understanding of the task) is necessary to perform the task. A concrete example is for instance on lines 36-37 (Table 2): the time it took for the valve to open was naturally interpreted by the station technician as a direct consequence of the valve's size. An inexperienced person, such as the observer, would not have noticed anything. As we saw previously, following a procedure or an instruction is largely a matter of interpretation. There seems to be little pressure towards strict compliance, which might also be impossible in practice due to the unavoidable imprecision of the instruction or procedure. Lack of precision is inherent in the nature of procedures, which present decontextualised knowledge; in contrast, the performance of the task itself is highly contextual.

Outage's history: The influence of task performed earlier during the outage is not clear in the chosen example. However, when it comes to pre-condition ORV, the knowledge of what has happened in the plant is crucial. In fact during the pre-condition ORV at the end of the short NPO, we often heard assertions such as: "*of course this system is ready for operation: we've never been near that room!*" Here we clearly observe yet another trade-off between efficiency, which means making an assumption based on the knowledge of the outage, and thoroughness, which would require additional gathering of information.

Task's history: The task history is also of importance. A few minutes after opening a valve, water could be heard running through in pipes (but not really close to the manoeuvred valve). The station technician then related this sound of running water to what he had just done, and acted on the valve again to check his assumptions (lines 42-46 in Table 2).

An important issue is the relation between the different time-lines and different persons. Let us take the example of the "simple" question shown in lines 29-31. First, the task puts the burden on the station technician (Step 1) who is looking ahead to what he his going to do next (Step 2). Not being able to decide by himself, the station technicians asks the SS (step 3), who based on his own knowledge of what has happened (step 4), answers the station technician (Step 5). In this case, from the station technician's point of view, thoroughness is achieved in an efficient way by delegating the responsibility to the SS. Yet in order for this to work it is an important assumption that the station technician and the SS have the same understanding of the task's history and of the present situation. This assumption is necessary for the communication to work properly. If the assumption is not correct, task performance may suffer. This may easily be the case when people are not sharing the same work environment, as in this case where the station technician moves around in the plant while the SS remains in the control room.

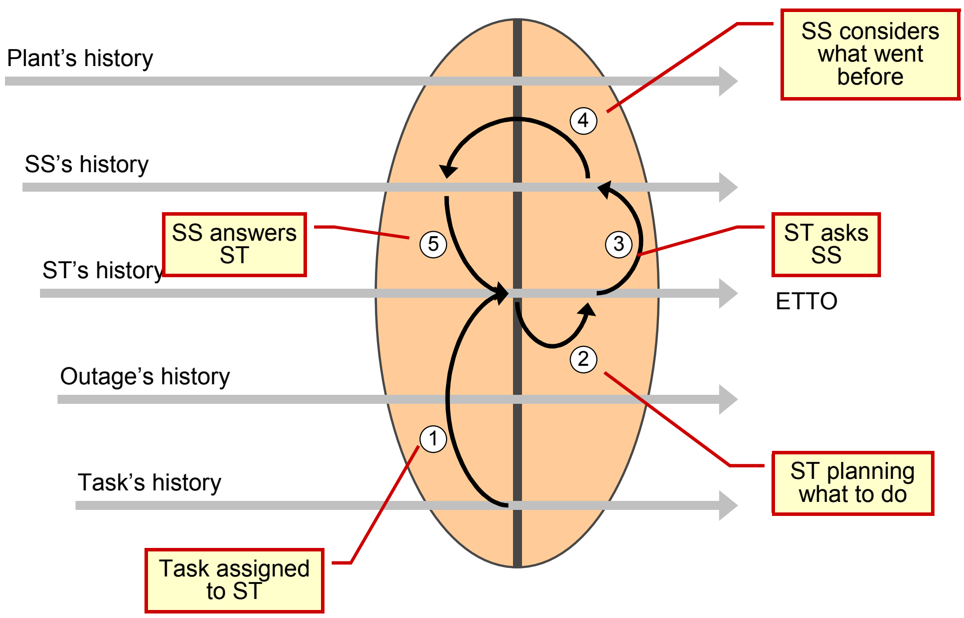

Figure 10: Illustration of embedding for a specific case.

This can be seen as another example of the ETTO principle, in the sense that it is generally more efficient for the station technicians to ask a MCR operator, than try to find out things for themselves. The station technicians thereby in a way voluntarily limit their own comprehension of the situation, or rather make it dependent on that of others (the MCR operators). The risk is that while MCR operators may reply to such requests, the fact that a reply is made does not guarantee that it is correct. MCR operators cannot in the long run maintain adequate awareness relative to all those who may ask (all station technicians, for instance). Indeed, MCR operators are not supposed to be able to do that. One may liken this to a game of simultaneous chess, where a grand master plays many opponents at the same time. The difference is that the grand master is expected, and able, to be aware of a set of parallel situations, so that s/he can respond appropriately regardless of whom the opponent is. MCR operators cannot in the same way keep aware of a set of parallel situations for the station technicians, hence may end up giving the wrong answer. Furthermore, we may assume that MCR operators themselves work according to the ETTO principle when they provide the answers, i.e., they try to be efficient, which involves making a number of assumptions about what the questions really are about.

This short analysis of the accomplishment of this re-instating task has highlighted the complexity of what could otherwise be understood as simple tasks. It has shown how simple tasks cannot be understood separate from the physical, social or historical contexts since these are what define major characteristics of a task.

This analysis also identifies two possible challenges to task performance. On the individual level, we saw the need for matching the procedure or instructions with the physical environment. This may involve trade-offs between efficiency and thoroughness, and a reasonable working practice is usually established after some time. On the inter-personal level, we also saw that intercom-mediated communications constitute potential problem areas in information exchange, because the two parts of the communication take place in different physical contexts. The need for such communication is to some extent reduced by the exchanges between the station technician and the MCR operator before the station technician goes out to the station. These exchanges serve to increase awareness of each other's contexts (both physical and historical). Here it is important that there is a one-to-one pairing between station technicians performing tasks in the plant and MCR operators. Structuring of the task to minimise communication can further reduce the need to establish a common understanding. However, limiting contacts is not an optimal solution, since it reduces the opportunity for mutual monitoring and failure detection. The structuring of the task affects the failure detection trade-off: widening the field of observation of individuals increases their opportunity to detect failure, while at the same time it increases the demands to each individual.

4.7 The Theory of Planning

ORV is an activity performed by an organisation, i.e., a collection of individuals working together toward a common goal. In order to coordinates the individuals' actions, an activity often referred to as planning is useful. In this section we see how planning (or coordination) is achieved at the plant. Studies of work practices have often highlighted the improvisational nature of actions at the sharp-end where physical and temporal constraints force individuals to depart from prescribed procedures by making local adjustments and improvisations. Regardless of how carefully an activity may be prepared, it is impossible in practice to describe a situation in every little detail (e.g. Suchman 1987; Leplat 1989). The original plan, such as it is, must therefore be adjusted to fit the action as it takes place (Keller and Keller 1993).

4.7.1 Organisational Theory

The focus is here often on the way in which an organisation structures and regulates work; indeed, the word *organisation* is itself often equated with structure. However, a more recent view focuses more on the dynamics inherent in organisations. This view emphasises the changing nature of organisations and the fact that routines are not only repeated over time, but in effect evolve and change. It insists on the mutual constitution of practice and learning (Lave and Wenger 1991), practice and cognition (Hutchins 1995; Orlikowski 2000), practice and knowledge (Orlikowski 2002). This focus on practice has changed the focus of organisational studies from nouns and structures (i.e., carrying static values) like **organisation**, **knowledge** to a focus on verbs and functions (i.e., carrying more active, lively values) like **organising**, **adjusting**, **learning**.

Theorists such as Karl Weick have insisted on changing the discourse of organisational studies from *organisation* to *organising* (e.g. Weick 1979), and later to focus the attention on the improvisational characters of organisations (Weick 1993; Weick 1998). Recently, several studies have tried to understand how organisations improvise (Crossan 1998; Moorman and Miner 1998; Pasmore 1998; Miner et al. 2001), especially in relation to product development activities. Improvisation in these contexts is often understood as a positive quality, although it does not directly correlate with concepts such as innovation or creativity (Moorman and Miner 1998).

4.7.2 Improvisation and Risk

When it comes to high hazard industries improvisation initially looks rather unattractive, since safety must be meticulously prepared rather than left to serendipitous actions! Improvisation is often caused by uncertainty, and uncertainty is clearly an unwelcome contribution to safety. On the other hand, resilience is a highly praised characteristic and a good organisation should be able to adapt to unexpected variability (Roberts 1993; Weick 1993; Carthey et al. 2001; Gauthereau et al. 2001). Theorists working with High Reliability Organisations (HRO) have emphasised that adaptation to a changing environment is a major quality of a HRO (e.g. Rochlin et al. 1987; Rochlin 1989; La Porte and Consolini 1991), and thus often point to slack as a main element of high reliability (Schulman 1993). However, these studies have too often focused on exceptional circumstances, on “cosmological events” as Karl Weick puts it, where a danger is identifiable (Weick 1993; Hutchins 1995, chap 8). Recent studies have highlighted the dynamic of practice over time as central to the understanding of safety. Snook’s “drift into failure” (Snook 2000), or Vaughan’s “normalisation of deviance” (Vaughan 1996) both show how the constant change of practice can lead to disaster. However, they also show that this drift, this evolution, is natural, and unavoidable.

4.7.3 Studies of Improvisation

Literature around the construct of improvisation is solid. While the concept of improvisation itself has been studied from different points of view and in different context, closely related concepts bring with them conceptual obscurity. Concepts such as adaptation, *bricolage* a term borrowed from the anthropologist Lévi-Strauss and defined as “making do with the material at hand” (Lévi-Strauss 1962), creativity, innovation, or even learning often get associated with improvisation (e.g. Crossan and Sorrenti 1997). In fact, part of the literature seems preoccupied with trying to differentiate these concepts from each other. For instance, Miner et al. (2001) propose that improvisation presents four different features: material convergence of design and execution, temporal convergence, novelty, and that finally the whole process should be deliberate. The different degrees of improvisation proposed by Weick (1998, p. 544-546) seem to confirm the rarity of improvisational acts: improvisation is seen on a continuum that ranges from simple "interpretation" to "improvisation" through "embellishment" and "variation".

It seems that the concept of improvisation has been over-specified, and although the definitions found in the literature might be relevant to the contexts in questions (e.g. product development), they do not seem relevant for the study at hand. Most of the common definitions would have restrained our focus to the third week at the Unit (that is, when the SO actually took place). In fact, the requirement of convergence of design and execution implies that if improvisation is to occur, it should be when execution takes place, i.e., during the third week. Since using such a focus would hide important parts of the process it is preferable not to be overly constrained by terminological dogmatism. Rather than trying to fit the observed events into a previously defined frame, we shall analyse them and explain why we understand the concepts related to improvisation as suitable for describing them.

The study of improvisation as practiced in organisations has also looked closely at what seems to support successful improvisation. From a study of the concept in different fields, Moorman & Miner (1998) propose that organisational memory "represents one of the key determinants of the nature of improvisational outcomes". Using a distinction borrowed from Anderson (1983), they further distinguish between procedural and declarative memory. Procedural memory entails skills and routines, while declarative memory can be more general. Pasmore's study of improvisation in jazz (Pasmore 1998) identifies three points to be considered for enhancing value added improvisation in organisations. First one should begin with knowledge and skills: a certain level of skill in playing the instrument is required, thus one should not be an amateur on the instrument. Then experimentation and learning should be encouraged. Pasmore specially draws attention to the need for experimenting and learning together, that is the "need to take time to reflect and learn collectively from the experiments" (Pasmore 1998: 563). His third point is that we should design organisation for change. His proposal to create such an organisation is a flexible organisation in which individuals' actions are guided by strong cultural values, which prevent anarchy. Mirvis's proposal from among others sports, comedy, military and psychotherapy (Mirvis 1998) also points out the need for skills and competence. Weick (1993) further argues that skills at *bricolage* at primordial. The need for a common goal is further put forth by (Crossan 1998).

4.7.4 Control Theory

Concepts from jazz improvisation were introduced in organisational theories in order to resolve conflicts assumed to originate from grammatical limitation: how can you talk about change using conceptual tools developed to describe structures? However, the definition of improvisation as the convergence of design and implementation still is based on the assumption that human cognition always design before implementing. More specifically design is often likened with the activity of planning, where no differences are made between different sorts of planning. It seems important here, to recount Lucy Suchman's introductory example of the differences between the Trukese and the European navigators.

> *"The European Navigator begins with a plan – a course – which he has charted according to certain universal principles, and he carries out his voyage by relating his every move to the plan. His effort throughout his voyage is directed toward to remaining "on course." If unexpected events occur, he must first alter the plan, then respond accordingly. The Trukese navigator begins with an objective rather than a plan. He sets off toward the objective and responds to conditions as they arise in an ad-hoc fashion. He utilizes information provided by the wind, the waves, the tide and current, the fauna, the stars, the clouds, the sound of the water on the side of the boat, and he steers accordingly. His effort is directed to doing whatever is necessary to reach the objective. If asked, he can point to his objective at any moment, but he cannot describe his course".*
> *(Berreman 1966, in Suchman 1987)*

She further gives three alternative explanations to these differences. First, that there are actually different ways of acting. Second, whether actions are *ad-hoc* or planned depends on the nature of the activity or degree of expertise. The third explanation is that however planned, purposeful actions are inevitable situated actions. (Suchman, 1987, viii). This third explanation is the one adopted by Suchman, and we will hereby adopt it also. In other words it means that "we all act like the Trukese, however much some of us talk like Europeans" (Ibid., ix).

This example enables us to separate two definitions of planning: the first definition is the understanding of planning as a detailed description of intended action, where each step is described in details. This is what could be called a popular understanding of a plan, and of the activity of planning! The second definition of planning is to see planning as a resource for action, actions are inevitably situated but a plan can be use as a support to situated, *ad hoc* action.

We can however still differentiate between several levels of planning. As a resource for action a plan can be more or less detailed, though even the most detailed plan will never be more than a resource for situated action. As shown by Schützenberger (1954), a distinction can be made between *strategy* and *tactics*. The difference is that tactics do not take into account the whole of the situation, but proceeds according to a criterion of local optimality. (Schützenberger also argued that the optimal strategy was the simple tactics of attempting to do as well as possible on a purely local basis.) Since strategy and tactics represent two different levels of planning, we may usefully distinguish between improvisation on the level of strategy, improvisation on the level of tactics, and improvisation on the level of execution instead of referring to a wholesale concept of organisational improvisation.

4.8 How planning / scheduling / coordination was performed at the plant

As observed earlier, Operational Readiness requires a good coordination between different Communities of Practice. In the context that was observed, this was the responsibility of the ABH. In this section we will describe some situations where the coordination is likely to take place and where information is being exchanged. Some of these settings are formal arrangements described in the plant organisation, others are informal meetings; moreover, the IT system distributing information around the plant is also considered as a potential **behaviour setting** (Schoggen, 1989).

4.8.1 Planeringsmöte

The planning-meeting is a weekly gathering of the different partners involved in the plant maintenance: the maintenance coordinator, the maintenance planner, ABH, radiation protection workers, and others. In this formal meeting the different partners go through the major events of the coming week.

4.8.2 Morgonbön

In D3D's meeting room, 7:35 AM. Every morning, the "morning prayer" (*morgonbön*) started and ended punctually. This was the opportunity for the different actors involved in the operation of the NPP to meet and briefly get information about the past 24 hours and to inform others about the coming 24 hours. This short (and effective) meeting regrouped employees from different departments: D3D (Drift-3-Drift), D3P (Drift-3-Planering), U (*Underhåll avd.*), MCR (*kontrollrum*), Radio-protection (*Strålskydd*), TR (*tekniska beräkningar*), etc. While between 15 and 20 persons were present every day, less than ten of them were active participants in this meetings; these included the active *Skift Chef*, ABH, D3D Chef, U, and *Skydd*. The physical positioning of the participants clearly indicated their engagement in the meeting: active participants sat at the table, the meeting leader was at the end of the table, and non-active participants sat on chairs along the wall (that is, not by the table).

The meeting procedure was also very stable and usually no discussions take place! This was an informative meeting where information was presented to others who received it. If discussion was needed, time was set for another meeting. Thus, after about 5 - 10 minutes, the meeting was ended and everybody could return to his/her work place!

However, while the formal meeting ended here, informal discussions usually went on until approximately 8:00. Right after the sanctioned end of the meeting, small groups formed spontaneously. Typically, 2-3 groups of 3-5 people formed every day. The first morning I was myself at the plant, my thoughts were: "*this is Monday: they haven't met since Friday, they are probably discussing their week-ends*", or since the situation at the plant was unusual (train-outage which started the night before, and a fuel damage discovered that night too), I went on speculating: "*these guys who are so devoted to carefully planned activities just need to exchange their points of view over the situation faced by the plant!*" And so my first day at the plant went!

Day 2: same scenario as the day before, and this continued on day 3, 4, 5, 6 … until my last day (day 14)! Everyday small groups were forming for discussions of 10 to 15 minutes! Together with my growing interest for these informal groups came two questions: Are these behaviour settings? If so, are these settings the same and only behaviour setting as the "morning prayer"?

4.8.3 Coffee breaks

ABH's staffs walk through the MCR in order to get their coffee. This often leads to a few words being exchanged between ABH and MCR operators. Moreover, ABH usually takes this opportunity to pick up the completed work-permits. These are lying on a table, and are picked up by ABH when the completeness of the work-order has been checked on paper, and always double-checked verbally with the shift supervisor.

Moreover, once a day (in the afternoon) one person from ABH workers sits down with the SS to discuss the completed orders and the one to be processed in the short future.

4.8.4 Delivering Work-Permits

Communication between ABH and the maintenance department is supposed to take place through the hatch (*lucka*) between the rooms, but it was often observed that maintenance technicians came into the room in order to get their work permits.

4.9 How plans are used

In the following an account is given of some observed events that illustrate how the organisation planned and performed a short non-productive outage (SO, *kortstopp* in Swedish), rather than a complete chronology of the observed events. Due to this there may therefore be days where there are no entries.

4.9.1 First week: "When should we start?"

Day 1

Monday morning, 07:35, the so-called "morning prayer" meeting regroups individuals from the main divisions of the plant: Operation, Maintenance, Operation Support, Quality, Chemistry, Planning, etc. Approximately 25 persons are normally present during these daily meetings. The participants were informed that the safety train outage was started the previous night, and that a major fuel leakage had been detected. This was to be discussed in a planning meeting at 10:00 on the same day. Right after the meeting was adjourned, small groups formed and started to discuss the situation: "*Additional work must be planned … - how, when …?*"; "*Will it be necessary to stop the safety train outage?*"; "*what type of signal are being sent?; if we have to interrupt the work, then it is time to think; etc.*".

Chemical analyses were conducted to determine whether a non-productive SO was needed. In the meantime, different alternatives were considered: a number of plans that had been developed since the discovery of the damage the previous summer were assessed on the basis of the actually available time, etc. Around 12 o'clock, the result of the analyses showed the need to take care of the fuel damage as soon as possible, and before Unit 1 was to shut down for renovation. A decision was to be taken the following morning (Day 2, Tuesday 08:00), the actual plan was to shut down the unit on Wednesday (Day 10) of the following week, so that restart would occur at the same time as the scheduled end of the safety train outage. Other factors influencing the decision were: the weather, the days of the week (week-ends), etc.

Day 3

The organisation (of the Unit) was informed that according to a probabilistic safety analysis, the plant was not allowed to do as originally planned and shut down the unit while carrying out a safety train outage. This information led to many discussions among the staff, which showed a lack of understanding for this decision.

A planning meeting was scheduled next. At that time, the SO seemed likely to be started after Friday of the second week (Day 12). Different concrete issues were thereafter discussed, e.g., experience feedback from previous SO, schedules for the reactor, planning of testing procedures, information exchange: "*how is it going to work?*" and organisation: "*how are we structuring the work?*".

Day 4

During the "morning-prayer", staff from technical computations informs that it is OK to shut down the unit even if the diesel engine is not ready for operation, provided that all the other systems are operationally ready. The shut down is now planned to take place after Friday the following week (Day 12), more precisely at 3 o'clock in the night between Saturday and Sunday.

Day 5

On the morning of Day 5, a meeting took place with daytime personnel and the supervisor of the morning shift. The discussion highlighted the fuzziness of the situation for part of the staff. The decision was taken to hold a decision meeting during the same afternoon. At 14:30 in the afternoon, the decision meeting took place; it was quite a short meeting with the purpose of "*making it clear for everyone*". As a way of achieving that, written schedules were presented with the help of the over-head projector.

Summary Of The First Week

Before continuing the presentation of the empirical material, it is useful to review and interpret what happened during this first week. It is noteworthy that the end of the first week also corresponded to the end of the first phase: an important decision was taken on Friday afternoon, a short while before most of the people go home for the weekend!

This first week brought forward important contrasts in the organisation. While the situation itself was full of uncertainty, people seemed to disregard this. Some employees were actively working on the planning of the SO: day-time personnel did their work preparing work-permits, work orders were being written. Yet it did not seem clear that a decision had been made. Of course, we could see this as a difference between *theories-in-use* and *espoused theories* (Argyris and Schön 1978), rather than as the improvisational side of the work. All the interviews conducted this first week point out the extreme confidence the employees have in their ability to plan the SO, while in practice there was a definitive worry. On the one hand the clarity of the upcoming situation was expressed, while on the other hand we noted repeated changes in the planned start of the SO.

During this week, we clearly saw an organisation trying to simplify the complexity of the work by trying to align the SO and the safety train outage (Figure 11). There were, of course, actual constraints: the work had to be completed before the reactor at Unit 1 was shut down for renovation, a constraint that finally prevailed over the need to simplify. Instead of waiting for the safety train outage to be fully completed, the decision was taken to start with the SO as soon as allowed.

Staff behaviour also showed a strong tendency to focus on the certain instead of the uncertain. Meetings focused on the concrete elements of the SO: what the organisation is going to look like, who is responsible for what, etc. Yet the starting date, which was still unclear, was not discussed. The use of written schedules could also be interpreted as a way for the organisation to escape discussing the uncertainty and focus on the concrete. Writing down a schedule can be seen as a way for members of the organisation to reassure themselves about the certainty of the situation. Schedules were normally not used for the safety train outage, which is a more common situation for the employees of the plant. Another indication was the use of the overhead-projector during the decision meeting; in practice this equipment was almost never used in information meetings. This can be interpreted as sending yet another signal of certainty to the organisation (Alvesson 1996). Moreover, the schedule for the SO did not show relations to the safety train outage, which can be seen as a way for the staff to confirm their own understanding of these two events as independent of each other. Not showing the dependencies was a way for the members of the organisation to reassure themselves about the simplicity of the situation.

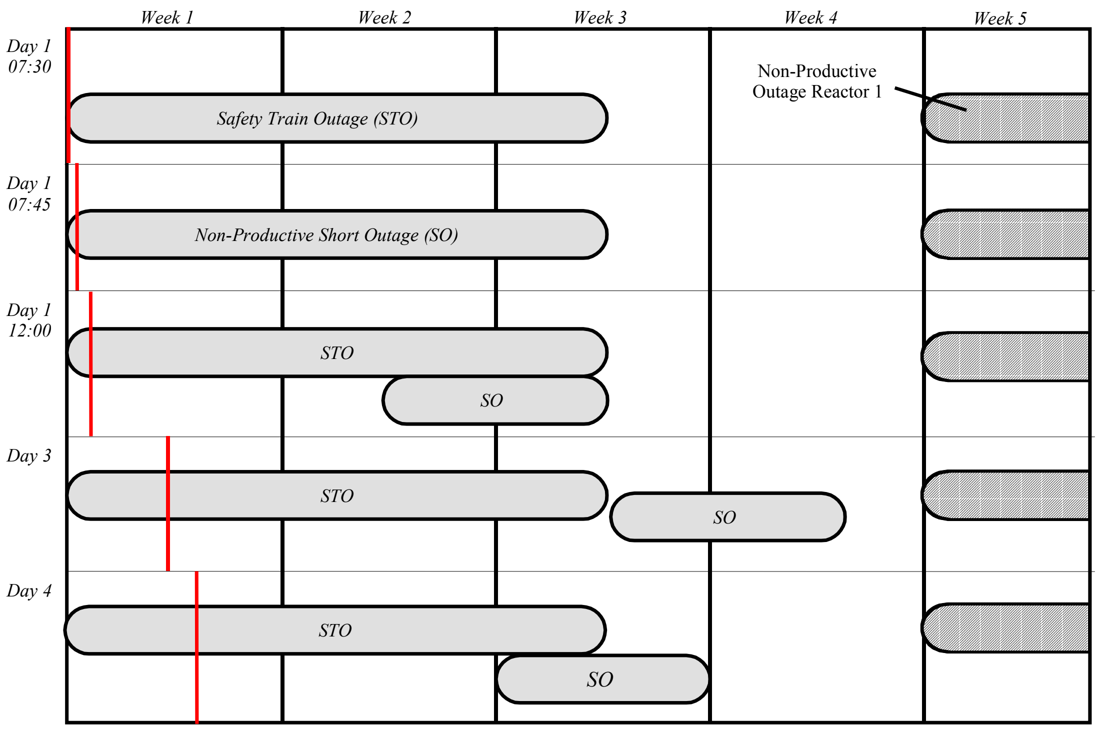

Figure 11: Changing views on the safety train outage start.

To conclude, it appears that all the signals sent during this week underlined the same message: "*what we are going to do next week is not exceptional, it is not complex, it is not uncertain, we know exactly what we are doing*". Yet on the other hand, a tension was present. This tension uncovered the employees' worry about the events to come.

Finally, the decision to set up a decision meeting to clarify the situation was another signal of confidence sent to the organisation, and the fact that it finished the week was probably significant.

4.9.2 Second Week: "Getting Real!"

On Monday morning (Day 8) all the work orders were assumed to be ready and altogether 36 were submitted for review on Monday evening. On Tuesday (Day 9), the number of jobs increased to forty-nine! On Wednesday (Day 10), a production memorandum containing the schedules for the SO was distributed to the organisation. On Thursday (Day 11), an information meeting took place for the shift that should take the reactor to a non-productive state (a shut down); the plan was to shut down the unit at 20:00 on Friday evening. On Friday (Day 12), it looked as if the number of jobs scheduled to be carried out during the SO was almost 60. To this should be added the general experience that during the shut-down operation a number of additional failure reports usually appear, thereby increasing the number of jobs to be performed even further.

Another interesting issue is how interactions between the SO and the safety train outage were managed (Figure 12). We saw that during the first week it looked as if the staff did not consider any relations between the two events. However, on Monday morning (Day 8), the members of the organisation were informed that deviations from the safety train outage operating orders were necessary (because of the SO), and that an examination meeting would take place. This meeting was planned for the coming day (i.e., Tuesday, Day 9). The possible interactions between these events gave rise to more informal discussions: different interpretations of when the safety train outage would ends would lead to different work procedures. And though the train under outage was not to be considered operationally ready before the middle of the following week (Week 3), everything apparently had to be done before the start of the SO in order to demonstrate that the train was "clean" (with the exception of the diesel engine).

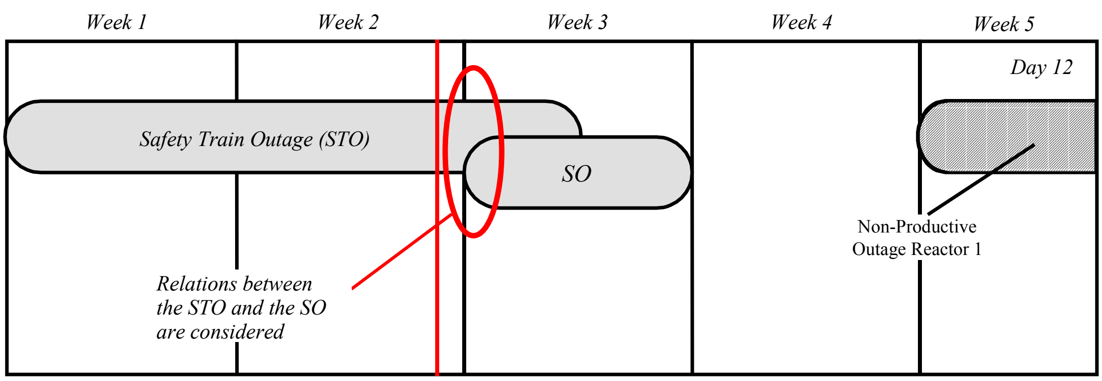

Figure 12: Interactions between Safety Train Outage and Short Non-Productive Outage.

4.9.3 Third Week: "Adapting the plan…"

The third week also corresponded to a third phase in the activities of the plant. The SO started on the night between Friday and Saturday (Days 12 and 13) and on Monday morning (Day 15) the activities of the plant were organised around it. In the control room, for instance, the reactor operator's workplace was re-arranged to follow the control of the fuel bundles. The schedule on the wall of the control room furthermore completed the picture of a plant in an unusual – or at least not in productive – phase.

During the third week everything went according to the plan, at least from the employees' point of view. Of course, deviations from the plan could be observed: for instance, a problem with the machine handling the fuel bundles delayed work in the reactor during the first weekend (days 6 and 7). This deviation, however, did not require the sequence of the plan to be rearranged. Twice a day, the updated schedule was put on the control room's wall but in reality no real changes were made to the plan: it just highlighted how the work in plant was going according to the original schedule. The main concern was naturally to check that work was not delayed and that the activities would start up in time. However, when after a few days the plan showed that work was going too quickly, comments were made that being early was not good either!

One day before restarting the unit (day 18) an event forced the sequence of events to be reviewed. The reactor containment had been sealed, when a leak was discovered. After performing various tests from the control room, the decision was made to go and manoeuvre a valve by hand. The decision was later taken not to repair the leak, and to go on with the plan to restart the plant the next day. Apart from an analysis of the decision process, which undoubtedly would be interesting, we will focus on the re-planning this event required. Tests had been performed to control the sealing of the containment: double check of valve positions had been performed, physical control by police force had been done, etc. It appeared, however, that none of these tasks were done again after the leak was discovered. Instead, the organisation focused on restraining access to the area to a very small number of individuals who were to do nothing else than manually manoeuvre the valve in question. Thus no actual re-planning occurred, especially since the decision was taken not to repair the leak. In terms of the concepts applied above, this can be seen as a good illustration of the ETTO principle. Rather than repeat the whole test procedure, the solution was to control access so that the need to retest was negligible.

4.9.4 A Brief Summary: Three Weeks / Three Phases

Looking at this three-week period in the life of the unit, we can see three quite different types of organisational behaviour. The first week could be described as unstructured. The work in itself is, of course, not totally unstructured, nor chaotic: work is performed in an orderly manner, with method, and the planning of the work to be performed during the short outage was done as seriously as possible. However, the level of uncertainty seemed to worry the employees. While the employees readily acknowledge that only approximately one third of the jobs to be performed during the outage can be planned long in advance and while they usually can handle such a level of uncertainty, the lack of clarity of the situation to come (or at least the lack of communication about it) created a rather noticeable concern. The end of this first phase set the rough structure for the SO to come and while the content was still unclear, boundaries were defined. The second week differed from the first in the sense that the employees focused their attention on planning and on preparing the upcoming events in more detail. Preparing this rather exceptional event (i.e. the simultaneous occurring of a safety-train outage and of a short non-productive outage) in the life of the plant had become quite of a routine work. People fell back on routines learned that had been learned (and mastered?) during previous outage planning. Even the major documents (operating orders) were borrowed from earlier outages. The third week was about following the plan; more concretely, it was about adapting it to the circumstances.

5. Discussion

5.1 Learning Processes – The Role of ABH

While ORV is clearly defined as being the responsibility of the control room operators (and more specifically of the SS), important roles are played by both maintenance staff and the people ensuring the coordination between these two Communities of Practice: ABH (Arbets-Besked Hantering). This section will explain that in more detail by focusing on the ABH's coordinating role.

5.1.1 Two Communities of Practice (CoP)

At first glance, the maintenance and operating communities seem clearly to be two separate CoP. They appear to have different cultures, and there is a physical separation between them that may reinforce possible social boundaries. However, Lave & Wenger (1991) point out the risk in relying on simplified criteria to define and identify CoP. In actual fact, the nominal boundaries between the maintenance and the operating communities are insignificant, since everyone involved participate in the same activity and have the same basic understanding of it. The common understanding is, however, not complete. Several times during the data collection we heard comments that indicated potential differences in the understanding of the activity: "*U vill jobba så mycket som möjligt, och sen Tobbe och Jag, och driften, måste tänka på säkerhet*", "*Vem bestämmer vad som ska göras? Det känns som det är U som bestämmer*".

There is further evidence to support the existence of two different communities of practice. One is the way in which staff moves through different roles and responsibilities in the operating community. A person usually starts as station technician (station technicians), going around the plant (first together with a more experienced station technicians) manipulating systems on the order of the control room operators. When not out in the plant, station technicians usually sit in the control room (MCR) and learn from the operators' work. Most of the time this takes place through simple observation of the socially correct behaviour of operators (the "how" of the operators' work), supplemented by a more active involvement in the operation of the plant where they learn on the content of the operator's work. See for instance in Table 3 – lines 1-5, a strategy developed by one particular shift supervisor. Shift meetings happen every time a new shift takes over, however, it is usual that the MCR operators go through the events of the past shift(s) first, not the STs! Reversing the order allows the STs an increased participation in the community.

Then, the normal path leads the station technician to the Turbine Operator (TO) role, through a similar pattern: theoretical formation completed by co-working periods. Then, as a TO, the presence in the MCR leads to increasing participation in the plant operation. This increased participation leads to the shift supervisor's (SS) role, through

Reactor Operating work (see for instance in Table 3 – lines 11-14 for an example of increased participation), and the position of shift supervisor assistant that includes the same work content than the position of shift supervisor with the exception of personnel responsibility.

It is also interesting that this process takes place in the control room: although this is built with the SS "seeing everything without being seen", also gives important opportunities for learning due to the openness of operators' activities to each others (see for instance in Table 3 – lines 9-10). To summarise, the distribution of knowledge in the MCR can be symbolised using a notation used by Ed Hutchins (1995), cf Figure 13. When tired of shift work, operators usually end up working for D3, the operation support department.

Table 3: Protocol excerpts illustrating communities of practice.

	Field Notes: Control Room, Day 12, 16:00
1	The incoming shift gathers for a "shift meeting".
2	One ST tells what he knows happened during the previous shift.
3	The TO completes these information
4	Another ST tells what he knows has happened.
5	The Reactor Operator completes!
	Field Notes: Control Room, Day 1, approx. 14:00
9	In the control room, The Reactor Operator asks a question to the Turbine
10	Operator: the question is intercepted by the SS who answers it.
	Field Notes: Control Room, Day 10, 13:28
11	A test of sprinklers is being done by the SS.
12	SS looks at its computer screen, and calls the TO.
13	The TO approaches the SS's desk and is then being explained what is
14	happening by the SS.

The maintenance community also has its own learning processes; in which increased participation in the plant maintenance leads the members from maintenance technician, to maintenance chief.

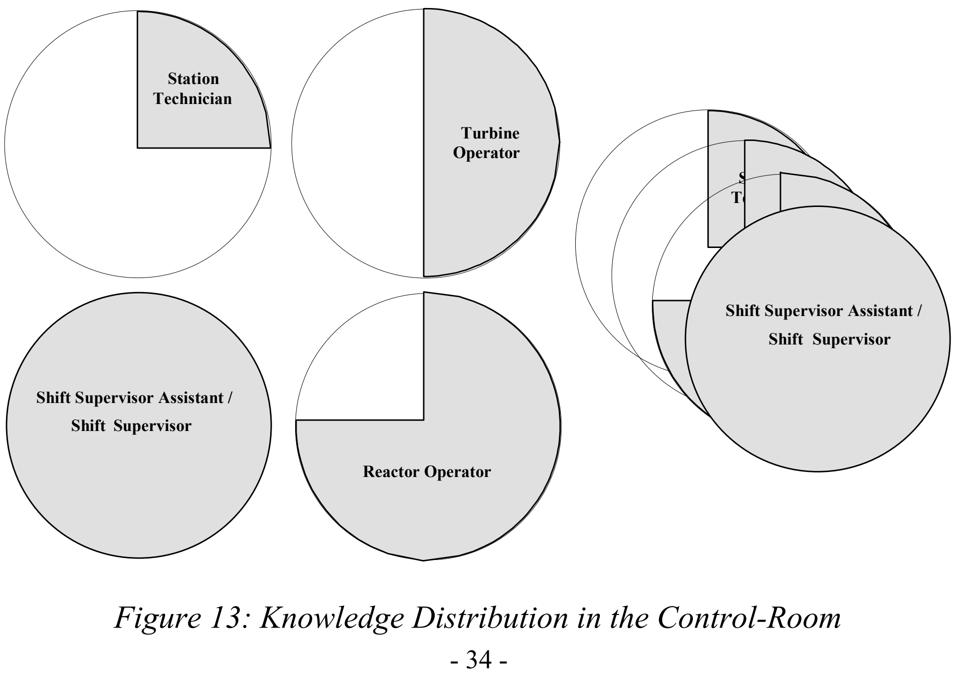

Figure 13: Knowledge Distribution in the Control-Room

The almost total separation between these two generative processes as described above, lead to the definition of two communities of practice which nevertheless are focused on one activity, around one object (the plant), although with sometime different understanding of the activity. Studies of High Reliability Organisations (HRO) have pointed out the need for all members in the organisation to share the same focus. However, research in HRO also point out that they ground their resilience in the diversity of views they can provide, cf. the following piece of observation:

Obs. pr. # 86: "Det är bra att det är så: om de tycker att deras jobb är viktigast så utför de det jobbet på ett bra sätt (...) Det är ingen konflikt, men att båda sätt finns är viktigt".

In any case, for the construction of safety, the coordination between these two communities of practice seem crucial , and thus, ABH's role becomes central also.

5.1.2 ABH As Facilitator Of Communication

In the workflow presented earlier, the role of ABH is to coordinate the two communities of practice described above. The close links to operational readiness is evident from the preparation of the "umbrellas", and in the gathering of performed work-orders. While precision of the former tasks builds on good communication between the three parts involved, the later ones demands good exchange of information between ABH and U.

HRO researchers have pointed out the importance of, among others, inter-departmental communication (Haber et al. 1992). They also state that in their quest to fight the negative consequences of complexity, actors in a HRO usually try to give priority to direct sources of information, against indirect sources (Roberts 1990: 107). This characteristic of a HRO was often observed in the studied NPP.

While the computerised information system provide ABH staff with information on the maintenance tasks to be carried out in the plant, ABH would often call the person responsible for preparing the task in order to get more complete information, even if it was only a repetition of the content of the form filled up in the computerised system. In fact, ABH needed some kind of confirmation from the person who was the source of the task. Once it was also observed that this source of information was not considered sufficient, and one of ABH's staff actually took the time necessary to go in the controlled side of the plant to "see" the component itself, to "see the leak" which had to be dealt with. Control Room operators were also observed looking for more direct sources on information than the work-permits: "*och sen man kan kolla i larmlistan om det finns något kvarstående fel*" (Obs. pr. #453).

In the previous section, we listed a number of situations where information was exchanged between departments. Most of these situations allow direct exchange. In fact, even when face-to-face exchange is part of the plant design (delivering of the work permit through hatches), people tend to make the exchange more direct by, for instance, entering the room and avoid having a hatch interfere with direct communication.

On the other hand we also saw that the management of operations takes care of facilitating direct information exchange. The "morning prayer" is thought as a perfect direct information exchange between departments. We can, however, see hindrances to direct communication. In fact, while face-to-face contact is made possible, the information exchanges does not create what Heron (1980, in Reason 1994) defines as experiential knowledge of the plant. As information travels through levels of the hierarchy, it gets transformed and thereby looses its experiential value. Another hindrance to direct information exchange during the morning-prayer is the strong behaviour setting which defines specific social rules. For instance, every morning most of the persons present at the meeting write down the production output of the plant over the past 24 hours, and the cooling water temperature, while most of the interviewed persons could not really explain why they write it down: "*Det är ju intressant att veta*". In fact, an episode during another meeting clearly sheds light on the strictness of the setting programs for all the meetings taking place at the plant. Here comes the transcript of a discussion between two operation-support's employees (Obs. pr. #185-201):

"- Då ska vi ha ett beslut möte!

- Det är inga som blir ledsna...

- Tvärtom!!!

- Så kl 3 kan vi....

- Om det ligger sent idag är det bättre måndag

- Nej... det är bättre att vi är mentalt klart"

Then the content of the meetings is being discussed for approx. 3 minutes.

"men vad är det för möte?

- Det är ett 'beslutmöte'

- Men beslutet finns... eller?

- Ja men inte ramen?

- Är det inte planeringsjobb

- Nej....

- Men i så fall det blir ett kort möte.. 10-15 min...."

This episode was later discussed with a few of the persons present, and all of them stated the importance of clear definitions of the meetings.

It is a reasonable conclusion that this strict social control of the employees' behaviour during the morning-prayer makes direct exchange of information more difficult. (Indeed, the term itself emphasises the rigid structure of this meeting.) More precisely, the social control is a hindrance to the exchange of experiential information. For instance, in one case misleading information was given and this was later explained by "*I did not want to bother them with the details*". The shift supervisor then told the assistance that system 712 had been activated (*driftsatt* in Swedish) the previous night, but he did not specified that the system was not operationally ready (*driftklart* in Swedish), a fact that most of the staff present at the meeting probably took for granted.

The informal meetings following the morning-prayer are therefore a natural response to the employees needs for direct sources of information. On the other hand, we do not refute the importance of these meetings. A as one employee puts it: "*mest besvärligt är alla rykten som cirkulerar, att vi inte vet vad som gäller*" (Obs. pr. 49), and information meetings are precisely a good way to inform about "*vad det är som gäller*"! In the next section we will see how the organisation of the plant enables less formal and more direct exchange of information to take place.

5.2 Values of planning

5.2.1 Planning And Improvisation

The essence of planning is prediction. A planned action is one where control can be based on feedforward: the anticipation of an actions' outcome directs the action. In our case, although the staff's experience with SO was limited, their experience from similar events, especially from refuelling outages, was relevant for the planning. However, in order to build on this experience the staff needed to recognise the situation that was to be dealt with. Without a proper frame of reference, the goal of performing a SO is too under-specified to allow the staff to plan.

Defining the start and the end of the SO provided the staff with a structure for their future actions. This is similar to what has been found by studies of improvisation in jazz (e.g. Barrett 1998; Mirvis 1998): the basic structure of the song permits each player to anticipate the actions of others, not in a precise manner but in a way that allows coordination. While the guiding structures should allow some flexibility, they should also be stable, hence predictable, (Barrett 1998, p611) in the sense that they cannot be changed at will. These basic structures are a prerequisite for improvisation; it is due to these that "everyone knows where everyone else is supposed to be" (Ibid., p. 612). The lack of a minimal structure, as observed during the first week, clearly left the staff in a rather uncomfortable situation. We could nevertheless see that individuals performed their tasks. Once again the jazz metaphor seems useful: while preparing themselves for a concert, musicians do not need to know which songs will be played in order to perform certain task. Instruments need to be tuned quite independently of what is going to be played. Moreover, for the persons directly concerned with planning activities, preliminary schedules could be seen as design prototypes or as a minimal structure that "provided imaginative boundaries around which they could explore options" (Ibid., p. 612).

Once this minimal structure has been defined, improvisation could theoretically begin. However, in our case the organisation had one more week to prepare itself for the event. This week enabled more detailed planning. An interesting observation during this week was that some persons were eager to start the SO as soon as possible. One person even stated that an unplanned SO would be easier. Everybody seemed to acknowledge that no matter how carefully a SO was planned there would always be new tasks to be performed, which would only be discovered when the plant was in a non-productive state. In fact the preparations observed during this second week, were more about further defining of the structure, than about careful planning of the content.

During the third week, i.e., during the SO itself, there were no indications that employees intentionally deviated from the plan. On the contrary, the plan was followed as closely as possible. When deviations occurred, they were goal oriented: the aim was not to improvise for the sake of improvisation. Instead external factors forced adjustments to be made. And even in that case, the structure was kept unchanged.

5.2.2 Managing The Centralisation-Decentralisation Conflict

Since Perrow's (1984) Normal Accident Theory, the literature concerned with safety in organisation has often looked for solutions that manage both centralisation (as a solution to the problem of tight-coupling) and decentralisation (as a solution to the problem of complexity). A vital characteristic of HROs is their capability to maintain both (Weick, 1987; Rochlin, 1989). Yet it has as also been noticed that people in such organisations usually do not concern themselves with this centralisation-decentralisation conflict (Rochlin, 1999). The findings in the present study could be interpreted as a successful management of the two opposite: a central planning on the one hand providing coordination between individuals, and local improvisation of individuals actions on the other hand. Yet for the people involved the situation was not one of carefully balancing the two opposites, but rather one of going through a quite unproblematic process of planning and improvisation. What needs to be studied is how people decide when to improvise and when not to, i.e., how they trade off the simple efficiency of following a plan with the improved thoroughness of making local adjustments. More than anything else it is this that in practice determines whether the organisation will be robust and resilient.

Although it is necessary to understand safety in relation to practice (Woods and Cook 2002), practice itself changes over time (Lave and Wenger 1991; Rochlin 1999). Understanding the dynamics of practice is therefore essential. As in most dynamic systems, change takes place on several levels simultaneously. Or to put it differently, there are several types of change with different dynamics or temporal characteristics. Some occur quickly and are related to the task at hand, i.e., the sharp-end operations. Others take place more slowly and are related to the monitoring and coordination of activities. Others have an even more sedate pace and refers to the slower development of criteria and goals. It could be worthwhile to describe the centralisation/decentralisation conflict by invoking multiple types of simultaneous control and how the ETTO principle affects each. Having centralisation and decentralisation at the same time is a problem if there is only one type – or one level – of control. But when the organisation (or rather, the organising) is described on several levels at the same time, it is possible to have centralisation on one level and decentralisation on another without any conflicts. On each level the exercise of control is generally subject to local optimisation, as accounted for by the ETTO principle. The criteria for the local optimisations are different, and reflect what one may call centralised and decentralised concerns.

5.3 ORV: Buzzword Or Useful Communication Tool?

After having described the practice of ORV as observed through this study, it is possible to assess the meaningfulness of the concept.

To begin with, the study focused on tasks, which were previously defined as part of the general activity of ORV. This prior understanding of ORV as an activity was based mainly on the first phase of the study (Hollnagel and Gauthereau 2001). Following incidents, which had been classified as due to problems in ORV, the activity of ORV was formalised. ORV as a set of tasks is something that has always been present in the plant's life. However, insufficiencies highlighted by the incidents led to the need of identifying these tasks and their relations with each other. ORV thereby became real, it became something that could be identified and thus improved. In short it could be said that the image of ORV as an activity had yet to be proven when the study started. In fact, it was observed that post-condition ORV and pre-condition ORV seemed to be two quite different activities, even though only the general term of ORV was used at the plant.

For these reasons it was it interesting to study in more details how the staff used the concept. Let us first look at when the term ORV was heard around the plant, in which situation did it come up, who brought it up in the discussion, etc. Later, we will see how the term was used in interviews.

Table 4: Proposed differentiation form.

		Volunteered	Directed by Observer	Total
Statement	To observer alone			
	To others in everyday conversation			
Activities	Individual			
	Group			
Total				

The original idea was to use Table 4, as proposed in (Bernard 1995, p 362), since it specially seemed interesting to differentiate between situations where the term was used to the attention of the observer, and situations where it was used between staff members. While the use of ORV toward the observer could be judged political in the sense that as one observant put it "*det är ett modesord*", its use between staff members could be interpreted as a need to communicate upon the activity of ORV. However, this table became irrelevant when it was filled out: almost all of the observation felt into the same category. Instead, we decided to differentiate among four categories (Table 5; the numbers refers to the coding of the empirical data). First, whether the term was used to describe the activity as such, or whether a more political value was aimed at. The second dimension was whether it was used to the attention of one person only, or to the attention of many (in a meeting for instance).

Table 5: Uses of the ORV term.

	Activity	Buzzword
One to one conversation	545, 858, 869, 969(?) **4**	418 (med SKI), 853, 904, 914, 969(?) **5**
Meeting	76, 78, 89(?), 812 **4**	204, 778, 866 **3**

Interviews conducted with both operation and maintenance personnel showed a wide variety of use of the term. These different definitions seem to reflect the different point of view on the matter. Maintenance staff rarely use the term and then only in relation to component testing. Historically, check lists called "ORV lists" (DKV listor in Swedish) were developed with the help of the maintenance staff, but the use of ORV in relation to these check lists seem today confusing for operation personnel which rather understand them as "*objekt prov*" (component testing). But the ambiguity of the term does not only come from different perspective. Even among the Control Room operators there is no clear definition of ORV. While rarely concerned with component testing, they understand ORV sometime as function / system testing or as what was before defined as precondition-ORV, and more specifically the time-out period left before restart. While the first understanding refers to physical tests of function, the later refers to an administrative check.

The use of ORV by the ABH staff seems to confirm both a contextual understanding of ORV (i.e., depending on the task in focus), and the role of ABH in co-ordinating the two main department of the plant (see Figure 14).

Other ambiguities are sometime stated: whether ORV is only used in relation with safety systems (and thus in relation to a quite formalised activity), or for any system (thus referring to a set of tasks ensuring operational readiness). This distinction between a formal ORV and a process of assuring operational readiness points out one more time the dimension of ORV no contained in the tasks it includes, a more conceptual dimension. Another difference stated once by a control-room operator during an interview is between upstart-ORV and running-ORV ("*löpande DKV*" in Swedish). The ambiguities around the term ORV are important and it is therefore appropriate to ask the question of whether the activity of ORV is one or more – as many as the definitions!.

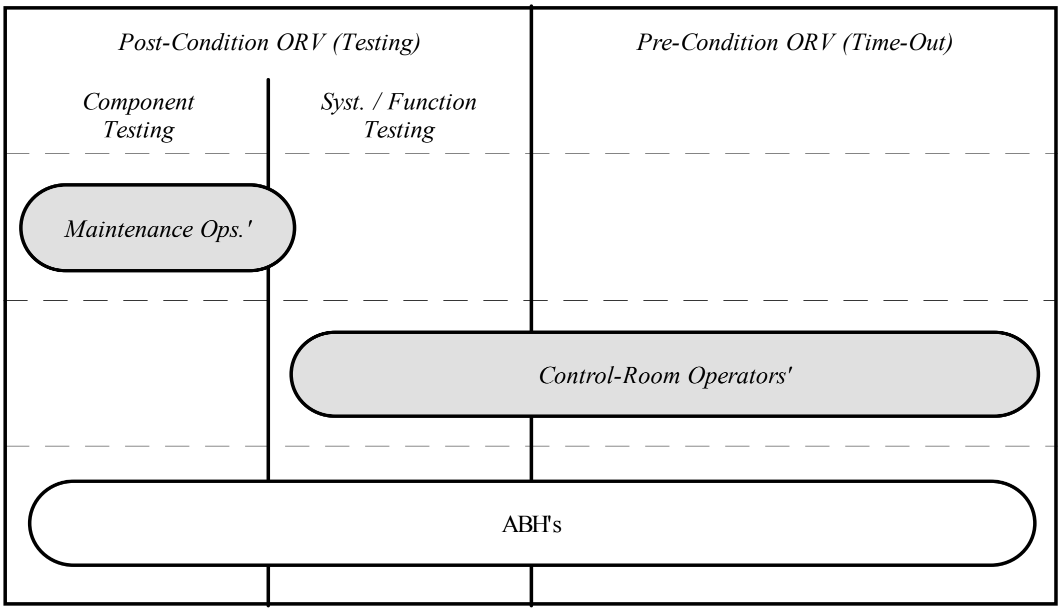

Figure 14: Different understanding of ORV

The discussion above leads to the conclusions that ORV is not a well-defined concept or term, i.e., there is not crisp definition of it that is shared by all. On the other hand, it is clearly more than a buzzword. It has a specific meaning for specific communities of practice, and although these meanings are slightly different, the term is valuable as a common referent in communication. Since there could be a risk in the different meanings of the term, it is important to see the practices subsumed under the term by the different communities, and to understand how these practices interlink with each other. This is therefore one of the problems proposed for further study in Phase III.

6. Summary

One conclusion from the first phase of the study of operational readiness verification (ORV) 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. This should be done during a partial outage (*subavställning*) at an NPP since that would allow empirical work to be conducted with better accessibility to technical staff than during a full outage period. A second purpose was 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.

One result of the field study described in this report is that the conclusion from the first study was based on an incorrect premise, namely that there is a clear distinction between the three types of tests in the way they are carried out. In that sense, the conclusion was therefore incorrect. Although all three types of test occur, there is no simple relation among them in the sense of a clear procedure for their order of occurrence. Figure 1 illustrates the relations among the three types of tests when viewed as a series of barrier functions. The experience from the study is, however, that the different tests are used according to need rather than according to an internal logic or structure. 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.

These days it is almost a platitude in the behavioural sciences that human performance depends on the context, and that one therefore must understand the context in order to be able to understand human action. This truism is recognised in fields as diverse as Human Reliability Assessment, in the distinction between first-generation and second-generation HRA methods, and in the study of decision-making, where the current view emphasises naturalistic decision-making and ethnographic methods. In order to be of practical value it is, however, necessary to be more precisely about what the context is, i.e., to have a set of more specific concepts, terms or categories.

As described in the analysis of the field study data (cf. Section 4), three concepts turned out to be essential in analysing and interpreting the observation. The first was the concept of a Community of Practice, defines as a small groups of people who have worked together over a period of time and through extensive communication developed a common sense of purpose and a desire to share work-related knowledge and experience. The second was the concept of embedding, which means that all tasks and activities take place in an environment or context that may be physical, social, or historical (cultural). The concept of embedding thus corresponds closely to the MTO-perspective, since the M, T, and O can be seen as representing a characteristic type of embedding. The third was the concept of the Efficiency-Thoroughness Trade-Off (ETTO) principle, which characterises the ways in which people try to adjust what they do to the local conditions of work (temporal, physical and organisational).

The concepts of Communities of Practice and embedding were useful in understanding the role that each group or community of practice at the plant played in the ORV. Three communities of practice turned out to be of particular interest: the control room operators, the maintenance personnel, and the ABH (cf. Section 5.1) Each CoP has established a mode of working (an institutionalised practice) which is effective under the common working conditions, although it at times may differ from the formal work descriptions. The concept of CoP was useful to understand how practices emerge from the general conditions of work, and especially how communication practices are established. The understanding of the details of specific tasks and actions was greatly helped by describing the various environments in which the activities were embedded (cf. Section 4.6). The embedding is a way of characterising the detailed assumptions that various people make when an activity is carried out, both as pre-conditions for doing something and as the background for interpreting the outcomes.

The ETTO principle is of a somewhat different nature, since it purports to characterise how people meet conflicting demands to work. 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.

By using these terms to understand the practice of ORV, it becomes easier to understand how actions at times can be carried out in such a manner that the outcomes differ significantly from what was desired. It was found that the organisation and the different communities of practice are able to improvise in the sense of adjusting the 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. But while the ability to improvise is practically a necessity for work to be carried out, it is also a potential risk. The solution to this is not to enforce more rigid practices of work, but instead to understand better the nature of the risk, i.e., to understand how work is shaped to meet demands.

The three concepts may also be useful parts of a method to identify vulnerable barrier functions and potentially insufficient defence-in-depth sequences. This would in turn make it possible to develop a method for assessing the safety level during outages. The starting point would be a detailed description of the organisation and of the tasks required by the outage. The tasks should be described in terms of the communities of practice that are involved, and the various types of embedding that can be foreseen. Together this will provide an account of the outage activities and how they are carried out. For each main activity, the likely efficiency-thoroughness trade-offs can then be described, since these are fairly regular across domains. Having done that it will then be possible to identify vulnerable tasks and functions, as a prerequisite for proposing efficient countermeasures.

6.1 Phase III

Based on the findings form the two previous phases of the study, it is proposed that Phase IIII has the following specific objectives.

- A further study of how tasks are adapted relative to the different types of embedding, specifically but not exclusively the physical embedding (i.e., how the physical environment determines the task sequence). This will 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 prescribed or provided for by the procedures and rules. 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.

It is the unforeseen combination of such conditions that can lead to ORV events, and means are therefore needed to understand when they can arise and how they can be detected and compensated for. This may be accomplished as a part of training or as an operational rule.

The work will comprise a preparatory phase, including focused interviews with personnel in key positions, and an empirical phase which should comprise an in-depth study of a short outage (productive or non-productive) with focus on communication among communities of practice (and how it can be facilitated), ETTO, planning and improvisation.

The results will be instrumental in identifying the possible shortcomings of the current approach to ORV and in indicating how can they be remedied. The results from Phase II have pointed to the risks that may arise from different meanings of the term. It is therefore important to see which practices the different communities subsume under the term, and to understand how these practices are coupled to each other.

7. Glossary

	English	Swedish
ABH	Work Permit Management	ArbetsBesked Hantering
CoP	Community of Practice	
D3D		Drift-3-Drift
D3P		Drift-3-Planering
DKV	ORV	Driftklarhetsverifiering
Embedding		
ETTO	Efficiency-Thoroughness Trade-Off	
HRO	High Reliability Organization	
MCR	Main Control Room	Central Kontroll Rummet

MTO	Man-Technique-Organization	
NPO	Non-Productive Outage	Kort-Stopp
NPP	Nuclear Power Plant	
ORV	Operational Readiness Verification	DKV
RO	Reactor Operator	
SO	Short-Outage	Kort-Stopp
SS	Shift Supervisor	Skift-Chef
ST	Station Technician	Stationstekniker
STF	?	?
TO	Turbine Operator	
TR	Technical Calculations	Tekniska Beräkningar
U	Maintenance Department	Underhåll

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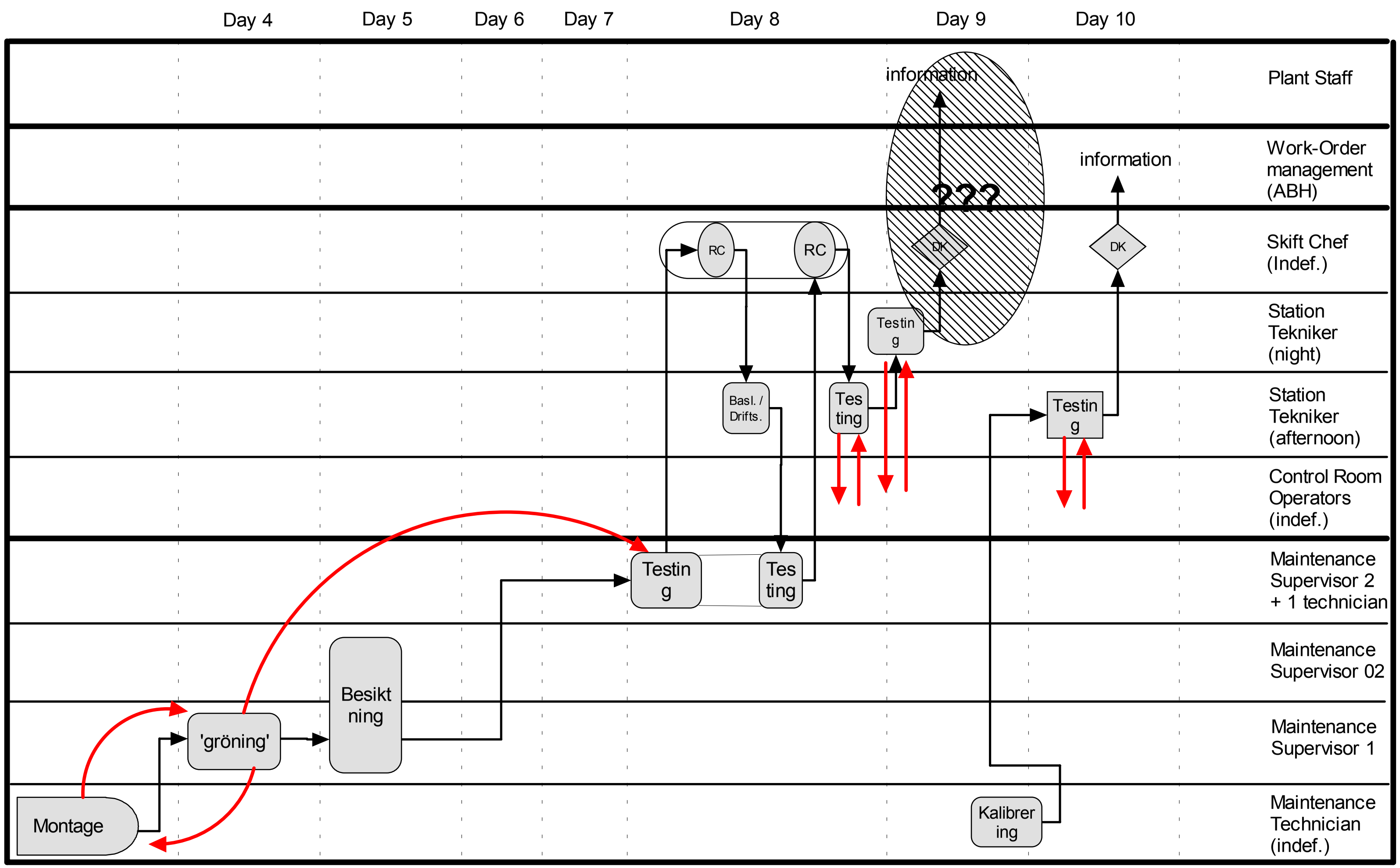
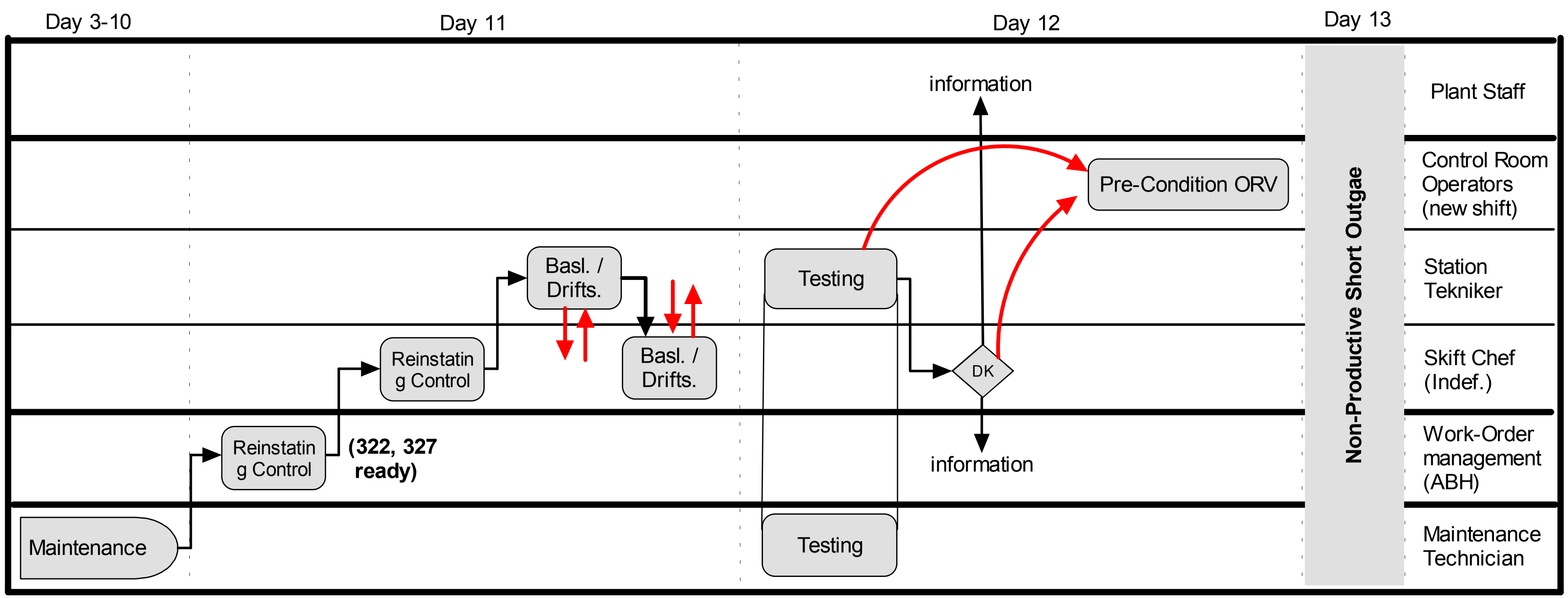
Appendix A: ORV process for system 712.



Appendix B: ORV process for system 323.



Appendix C: ORV process for system 650.