

Research

Human Factors in Maintenance: Development and Research in Swedish Nuclear Power Plants

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SKI PERSPEKTIV

Bakgrund

I samfinansiering med NKS initierades detta projekt för att behandla en inventering av befintlig forskning samt behov av forskning rörande mänskliga faktorn i samband med underhållsverksamhet vid svenska kärnkraftverk.

Deltagare från samtliga kärnkraftverk och SKI ingick i studien. I intervjuerna fick deltagarna ge svar på frågor som behandlade dessa frågeställningar.

SKI:s syfte

Detta arbete har syftat till att kartlägga avslutade, pågående och planerade forsknings- och utvecklingsarbeten med fokus på den mänskliga faktorn och underhållsverksamhet genomförda vid de svenska kärnkraftverken och SKI. Dessutom var syftet att kartlägga vilka behov det finns av framtida forsknings- och utvecklingsarbeten.

Resultat

Projektet resulterade i en översikt av pågående och planerad forskning som har finansiering och/eller ledning från kärnkraftverken eller SKI.

Projektet resulterade även i en beskrivning av forskningsbehov som ännu ej planerats från industrins sida. Intervjuerna gav inblick i olika synsätt på arbeten relaterade till den mänskliga faktorn och underhållsarbete. Dessutom, genererade intervjuerna en lista på möjliga intressanta framtida forsknings- och utvecklingsprojekt.

Fortsatt verksamhet

Eventuell fortsatt verksamhet är att för de identifierade forskningsbehoven se över vilka som behöver initieras och omformuleras till forskningsprojekt för att sedermera kunna utgöra underlag för SKI:s fortsatta tillsynsverksamhet.

Effekt på SKI:s verksamhet

Denna översikt tydliggör de forskningsbehov som finns inom området och därmed den forskning som behöver initieras.

Projektinformation

Projekthandläggare på SKI: Anne Edland
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Summary

The present report investigated previously completed, ongoing, and planned research and development projects focusing human factors and maintenance work carried out at Swedish nuclear power plants and SKI. In addition, needs for future research and development works were also investigated. Participants from all nuclear power plants and SKI were included in the study. Participants responded to a set of questions in an interview. The interviews also generated a list of future research and development projects*.

Sammanfattning

Föreliggande rapport undersökte tidigare avslutade, pågående och planerade forsknings- och utvecklingsarbeten med fokus på den mänskliga faktorn och underhållsarbeten genomförda vid de svenska kärnkraftverken och SKI. Dessutom, undersöktes även vilka behov det finns av framtida forsknings- och utvecklingsarbeten. Deltagare från samtliga kärnkraftverk och SKI ingick i studien. I en intervju fick deltagarna ge svar på frågor som behandlade dessa frågeställningar. Intervjuerna gav inblick i olika synsätt på arbeten relaterade till den mänskliga faktorn och underhållsarbete. Dessutom, genererade intervjuerna en lista på möjliga intressanta framtida forsknings- och utvecklingsprojekt. Förslag på några sådana projekt och åtgärder ges sist i rapporten.

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1. Introduction

The purpose of this study is to review the research and development concerning maintenance already completed, current and planned activities– in Swedish NPP's (nuclear power plants). The focus is on human factor aspects.

Most previous studies on *human error* (HE) have focused primarily on control room operators, in particular in disturbances during power operation (Swain & Guttman, 1983; Hollnagel, 1993; 1998; Gertman & Blackman, 1994; Jacobsson & Svenson, 1994; Kecklund & Svenson, 1997). When it comes to HE and maintenance the focus has been on primarily stable conditions in the system tested. As for example, in the Swedish studies on psychosocial work strain of maintenance personnel during outage (e.g., Jacobsson & Svenson, 1991), or time pressure during ultrasonic detection of cracks as in an ongoing Swedish study (Enkvist & Edland, in progress).

One starting point for a review of studies in the area of maintenance and HE, is a study on HE related to maintenance and modifications in Finnish NPP's (Laakso, Pyy, & Reiman, 1998). The study showed that HE's that occurred during maintenance work during planned production stops (for e.g., refueling) remained in the system until power operation and even beyond. This was true both for *single-* and *dependent-* HE's. The first type of error affects primarily single components in subsystems and, when detected, are more easily remediated. The second type of error can cause multiple errors (serial or parallel) in redundant subsystems, which often makes detection and remedy more difficult. As a consequence latent errors become part of and continue to live in the systems.

Laakso et al. categorized errors as *human related common cause failures* (HCCF), *human related common cause non-critical failures* (HCCN), and *human related shared equipment faults* (HSEF). HCCF and HCCN are primarily of the type dependent-human failures, while HSEF are single human errors, which affect different subsystems or parallel components.

The results showed that *instrumentation*, *automation*, and *electrical equipment* were more frequently affected by human errors than other systems. Both single and dependent human errors were identified as causes. The above systems were regarded as more easily affected than other systems, but also as causing a higher degree of complexity. *Mechanical equipment* was primarily affected by single errors. Errors were caused not only by the maintenance personnel specifically related to a specific system, but also by other personnel.

One conclusion was that human errors related to maintenance and modifications apparently have significant influence on safety. It was also suggested that the fault classification taxonomy was in need of improvement (introduction of multiple failures, more detailed taxonomy).

The following was proposed in order to prevent CCF's: (a) improved coordination of projects, post-installation checks and start-up test programs to further reduce the relative frequency of dependent errors; (b) enhanced information transfer between different organizational departments and professions, by implementation of formal turn-over and acceptance procedures (e.g., control and reviews between different phases of modification projects); (c) enhanced responsibility and involvement among operators and maintenance personnel in the decisions and reviews during early stages of modification projects. It was suggested that the nature of safety related training for maintenance personnel is more heterogeneous compared to that of operating crews, and the need for better training of maintenance personnel has often been a topic of discussion.

The Finnish study by Laakso and co-workers gives important data concerning the relation between system safety and human factors in maintenance, data that may also apply to

Swedish plants. This was illustrated in an analysis of LER's (licensee event reports) from four Swedish nuclear power reactors (Svenson & Salo, 2001). The results showed that many errors remained undetected in the systems for longer periods of time.

The main aim of the present study was to review research and development projects related to human factor issues in maintenance during recent years in Swedish NPP's and SKI. We wanted let the personnel, representatives of maintenance and human factors, report projects that they, themselves, considered important and illustrative of such work at their plants. To specify, we wanted people working with maintenance speak about what they related to human factors and maintenance work in an open structured interview. Another goal was to list future research and development projects that the personnel at the plants consider as urgent and/or important for human factors and maintenance.

Altogether, interviews would give an illustration of completed, ongoing, planned, and research and development work related to problems of human factors in maintenance, and, needs for future research/development projects related to specific problems, the way personnel at the plants themselves look at it.

2. Method

2.1 Participants

All four Swedish NPP's and the Swedish nuclear power inspectorate (SKI) participated in the study. The four plants and the inspectorate are labeled NPP 1 to 4 in the following, and SKI. An interview group was formed at each location. The composition of the interview groups varied across sites depending on the availability of personnel. All persons included in the groups were professionals in areas of maintenance and/or safety. Table 1 shows the composition of participants for each plant and SKI according to number and professions.

Table 1: Interview group constellations on the four plants and SKI according to number and professions (n=number of participants)

Site	n	Professions
NPP1	4	-MTO-coordinator, -head of maintenance department, -safety engineer at maintenance department – primarily MTO concerns, -head of planning unit at maintenance department
NPP2	4	-MTO-coordinator, -prior head of maintenance department - responsible for maintenance and operation handbook -foreman (electrical-) maintenance -maintenance engineer – working with methods for maintenance optimization
NPP3	4	-head of operational maintenance department -operational maintenance engineer -safety department - includes work with MTO -maintenance department - includes work with MTO
NPP4	1	-manager process support - technology maintenance
SKI	2	-inspector -engineer - dept of mechanics of material (SKIRH)
Σ	15	

2.2 Questionnaire

A semi-structured questionnaire was used for the interviews. It asked the participants to give answers related to four main categories of questions. The main categories were: (I) previous research/development projects; (II) ongoing research/development projects; (III) planned research/development projects; and (IV) and research/development projects in the future related to problems that would need solutions. Additional questions and background questions with more general characteristics (V) were also included in the questionnaire (see Appendix A). Question I to IV constituted the target questions of the interview. Questions subordinate to the target questions, and question V are here considered as optional and were not asked in all interviews. These questions were mainly used to prompt the staff taking part in the interview or used by the researchers to “go on with the questions” in cases of silence from the interview group. These questions will not be considered any further in this contribution.

2.3 Procedure

First, initial contacts were established with each site. A preliminary contact person was nominated at each site and contacted per telephone. He/she was then sent a letter that included information about the project, a proposal for dates of the interview, and, of course, the question if the site was willing to accept participation in the interview. For plant 1 an additional pre-meeting was also held. All sites compiled an interview group consisting of experienced personnel related to the areas of maintenance and/or safety and human factors. Presently, no person is specially focused on maintenance only, at SKI.

Second, the interviews were held at each site. For sites 1 to 3 and SKI, two researchers were performing the interviews. One researcher asked the questions and both researchers wrote down the answers in parallel. For site 4 (the last interview) one researcher conducted the entire interview.

Third, after the interviews had been summarized a copy was sent back to the sites for referral, comments, changes, and additions. Thus, all sites had an opportunity to add information and/or correct the written synopsis of the interview.

3. Findings

First, the answers to interview questions I to III will be reported separately for each plant and SKI. For each of these sites, reports on research or development projects will be treated separately. Each interview report represents the revised version of the interview summaries (i.e., after the interview summaries had been submitted for review at the plants on "a second round"). Numbers in bracket indexes the given interview report.

3.1 Previously completed research/development projects

NPP-1

Research.

(1) A survey of *psychosocial attitudes* and climate among the employees of the plant has been conducted each year since 1997. The main reason for this is to follow up attitudes in different

departments and department sub units. An important purpose of the studies is to use the results as safety indicators guiding action to counteract any decreasing safety standard that may appear at the plant. The managerial body initiated the study.

(2) A study on *procedural violations* was conducted in 1999. The study was a cooperation between the plant, another plant, and SYCON AB and was coordinated by a student of Växjö University, also working with the entrepreneurs (SYCON AB). The study was also part of his Bachelor degree paper at Växjö University. The study describes various categories of causes to procedural violations in different groups of personnel, not only in nuclear power production, but also in public health care, pharmacy, and the building industry.

(3) A survey of *safety culture* was conducted on a representative sample (20%) of all personnel at the plant. Included in the survey there was a question concerning an individual's apprehension of his/her *own importance to safety* of the plant. The results showed that operators found themselves much more important for safety than the maintenance personnel considered themselves to be. The "quality and safety staff" initiated the study.

Development.

(4) A *failure mode effect analysis* (FMEA) was conducted 1995-96. It was planned to be implemented 1997 but this was never done. The FMEA is documented in 8 to 10 work procedures across different systems. The service department initiated the FMEA, and consultants were engaged. The FMEA was made for all departments of the plant, and estimates of the risks of failure were in focus. Where the risks were greatest, countermeasures were taken (to change a routine etc.). During the FMEA, 40 persons from the plant were sent for training (in 3 and ½ days).

(5) During 1996-97, all staff including consultants and contractors participated in *STARK* training (Stop, Think, Act, Reflect, (K) Communicate). The management of the plant initiated the STARK training.

(6) In 1999-2000 the organization for maintenance was reorganized. One change from the old to the new organization is that the new organization appoints the maintenance department as responsible for the maintenance planning. The department is also expected to carry out maintenance work within their own budget limits. Previously, each maintenance job was ordered and charged internally.

NPP-2

Research

(7) Two models of *RCM (Reliability Centered Maintenance)*, one traditional very detailed method and one simplified and less detailed method were studied. The first method was found to be too time consuming and therefore less valuable. The second method was found to be like a "black box" where reasons for actions and decisions were difficult to follow. It was concluded that neither model was appropriate for implementation at the plant. The studies were finished during 1999 and the findings are documented in a report (procedure descriptions). The study was started by an initiative from the plant.

(8) A study on human factors related to refueling was made around 1990. A change in attitudes towards the work among the personnel was discussed. The plant in cooperation with SKI initiated the study. The study has been documented (scattered documentation during several years).

(9) A couple of studies on safety in NPP work situations concerning both work related factors, barrier functions and the interaction between human, organizational and technical subsystems, have been carried out by a doctoral student at Stockholm University. The results were documented in a doctoral dissertation (Kecklund, 1998).

Development

No previously completed development projects were reported.

NPP-3

Research

No previously completed research projects were reported.

Development

(10) In order to reduce the radiation dose load on test personnel, measures have been taken to decrease the number of test occasions. The program was initiated around 1990 through an internal initiative and was documented in a report.

(11) Detection of valve leakage and cracks by means of a method including the principles of acoustic emission was tested in the late 1980's. The project was driven by an internal initiative and the results were documented.

(12) During a period of organizational change, an analysis was made on MTO (man-technology-organization) connected event reporting (1992-96) and its relation to the current process of organizational change. The results had some importance for maintenance, and especially in relation to modification in the areas of electricity and instrumentation. The analysis was conducted by the local MTO-group and the results were documented in a report.

NPP-4

Research

No previously completed research projects were reported.

Development

(13) The maintenance organization was recently restructured into one department operating across units. The new organization includes different branches of maintenance (electric, mechanics, service, and technology) and one maintenance coordinator represents each of the units. In the previous organization all units had its own maintenance department.

The new organization allows a better overview of maintenance operations concerning both planning and distribution of work, and the purpose of the reorganization is also to strengthen the general awareness or/and involvement in maintenance issues. Some problems are expected during the transition period, (for example, related to learning about new systems and components) because personnel who previously worked on one unit now will work across

units. The process of organizational change has taken a lot of resources and few other projects have been conducted during this change.

(14) The MTO organization has been reviewed recently and structured as an organization that is constituted as a network across branches and units at the plant. The “forum” of this organization includes coordinators from all departments. The general approach to MTO issues has had a focus on analyses of already occurred events (and not on preventive MTO analyses). Examples of such work are MTO related root cause analyses of incidents. These analyses have been documented in internal reports.

SKI

Research

(15) SKI developed (within research projects in 1992-95) inspection guidelines for assessing safety-related maintenance programs. It also included reference materials on essential elements of an effective maintenance program. The perspective of the inspection guidelines included assessments of the status of the essential elements of maintenance programs and the need for safety improvements. The development of the products was done in co-operation with Battelle Human Affairs Research Centre, Seattle, USA. Also, a paper was presented on the topic "Managing maintenance for improvements: an international perspective" in 1993 at the International Maintenance Conference in Toronto, Canada (Chockie & Sandén, 1993). Three key issues were discussed: (a) how to determine if the maintenance program needs improvement; (b) if improvement is required, where should the efforts be focused; (c) how to determine if progress is being made towards achieving the goals of the maintenance program.

Development

(16) The results of the above project were used in the development of the “SKI Maintenance Reference Book” and the SKI Inspection Guidebook “Maintenance. A Maintenance Reference Book was developed. The books provides: (a) a structured survey of functions and their most important activities within an effective maintenance program considered as a system; (b) a foundation for preparation and organization for questions/problem areas for the inspection; (c) a primary frame for general acceptance criteria; (d) the general course of action in information analysis and identification of improvement; (d) a structured way of presenting the results concerning the improvement/development operations.

3.2 Ongoing research/development projects

NPP-1

Research.

(17) An interview study on *procedural violations* is being conducted during 2000, and is planned to be completed April 1, 2001. A student (mentioned above) in cooperation with Växjö University, the plant, and another plant initiated the study. The study is also part of the students Masters degree paper at Växjö University. The study will focus on the problem of procedural violations. Especially, criteria and preconditions likely to prevent the occurrence of procedural violations will be studied and mapped. The main research question is: *how to prevent the staff from deliberately committing violations of instructions/routines*. The major

part of the empirical work will be conducted at another plant (NPP-2). Interviews may also be conducted with personnel from the aviation industry.

Development

No ongoing development projects were reported.

NPP-2

Research

(18) A project on operational readiness verification (DKV, driftklarhets-verifiering) on the level of system components is included in the RCM study (see interview 7, above). This study has been postponed until further decisions concerning RCM have been made.

(19) An interview study on *procedural violations* was conducted during 2000, and is planned to be completed April 1, 2001. The study was initiated by a student at Växjö University in cooperation with two other NPPs. The study is also part of the student's Masters degree paper (as previously mentioned). The study will focus on the problem of procedural violations. Especially, criteria and preconditions ideal to prevent the occurrence of procedural violations will be studied and mapped. The main research question is *how to prevent the staff from deliberately committing violations of instructions/routines*. The major part of the empirical work will be conducted at the plant. Interviews may also be conducted with personnel from the aviation industry.

Development

(20) Improvements on Condition Based Maintenance (TBU, Tillstånds Baserat Underhåll) is investigated. One important question here, is how information from operators, and gauge data from systems and components in operation can be utilized in maintenance planning. To make this possible the IT support systems have to be upgraded. In addition to the technical improvements, it is hoped that operators' involvement in maintenance will be enhanced.

(21) The competence needed for conducting maintenance is analyzed in one of the plant units with a simple method called "Tabletop". The method is previously used for operations. Demands on competence and needs for education are central problems here. Also the possibility to use the method in other units and departments of the plant is investigated. This project is related to requirements of competence in SKIFs (SKIF = SKI Författningssamling). This is demanded by SKIFs 98:1. The regulator requires a documented system for describing and displaying the needed and available competence for each individual working with safety related equipment.

(22) A project on "how to write instructions" is ongoing, and will result in a handbook for this purpose. Questions such as – scope, and detail of instructions, for whom are instructions written, and the role of instructions compared to other activities such as post checkings are discussed. The general aim is to integrate the quality systems of the different units of the plant.

NPP-3

Research

Currently, no ongoing research project was reported.

Development

(23) A project on “process oriented work” across different work areas (also including maintenance) was started 3 to 4 years ago, initiated by a managerial board decision. The sequential process of work with various work tasks is presented in a task analysis, which, for example, facilitates the detection of erroneous paths leading away from the final goal-state of the task. However, the current versions of the analyses have to be revised to be useful as instructions in practice.

(24) According to the process of organizational change a new executive MTO group has been structured. The new (more flexible) MTO group entails representatives across production units including maintenance personnel. The group carries out work on orders of, for example, MTO analyses. As a result, hopefully the maintenance work will become identified as related to the other activities in a higher degree, and following this as more structured. Another purpose is to make maintenance personnel more involved in the MTO work. However, the former, MTO organization that was common to the whole plant still exists. Positive characteristics of the former organization have been utilized in the new organization, for example, the existing channels of communication, and (of special importance for the maintenance personnel) the positive spirit and work structure belonging to the operations personnel.

(25) A project related to online computer monitoring of component and system status is currently in progress in one of the units.

NPP-4

Research

(26) A project on improved methods for "outage analyses" within the framework of PSA (probabilistic safety analyses) was initiated and carried out by an initiative from the plant in cooperation with consultants. The main focus of this project is on the probability of various system damages during the outage period, and sequences and events that contribute most to the probability of damage. Here, human factors (MTO) is considered as a more important factor, compared to other methods with a more technology- and less human factors-, oriented approach.

Development

(27) As one consequence of the organizational change a review of various instructions has been carried out. Currently, most effort is focused on the administrative instructions (for example, instructions on: responsibilities/authority; planning; reporting; authorization, etc.). Changes of specific maintenance instructions are more operationally initiated and are reviewed as they "pop-up".

(28) The BiCycle project (in more detail below) with possible applications, is currently evaluated at the plant. Another system system for operation and maintenance (IFS) is already implemented at the plant, and is currently being upgraded with a new version.

(29) How previously experienced aspects of MTO are (and should be) fed back into the preventive maintenance work was also discussed (for example, experienced consequences

following the use of improper methods, components, and materials), this in relation to regular duties of the maintenance engineer.

SKI

Research

(30, 31) Two projects initiated by SKI are currently in process. First, a project on operational readiness verification (DKV, driftklarhets verifiering) is being carried out on NPP-4. Second, a project on human factor aspects of non-destructive testing is carried out in co-operation with Stockholm University. Both projects have implications for human factors and safety.

Development

Currently, there are no development projects in progress.

3.3 Planned research/development projects

NPP-1

Currently, no new research/development projects have been planned.

NPP-2

Currently no new research/development projects have been planned.

NPP-3

Research

Currently no new research project has been planned.

Development

(32) Among the projects that are planned, three are relevant for maintenance. First, the plant (in cooperation with Marintek) is participating in a large international project on maintenance planning and optimization labeled IMADS (Intelligent Maintenance Advisory Systems). The project is planned to be financed partly by EU funding.

(33) Second, another project, financed partly by EU funding, supported by SKI and related to maintenance decisions, labeled BiCycle, is planned. The project focuses on preventive maintenance optimization partly through RCM (Reliability Centered Maintenance). BiCycle BV (Netherlands) has in cooperation with the other plants developed a method concerning how to improve maintenance, tools to support the method, and a method for implementation of continuous maintenance improvement in a large organization (see Figure 1).

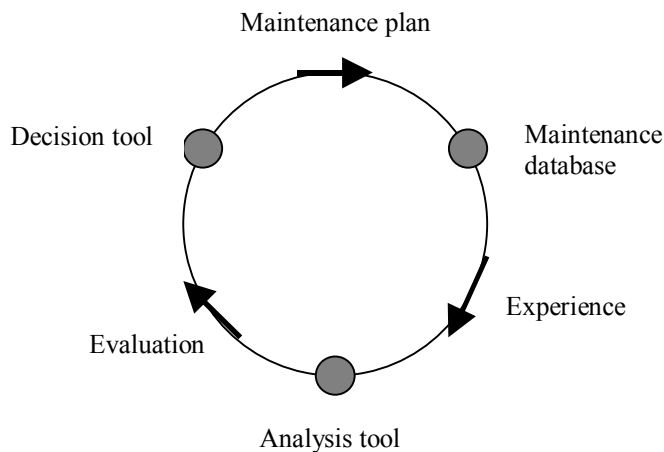


Figure 1: Summary of the BiCycle process

The analysis tool gives support in diagnosing resources needed for maintaining each system/object. The decision tool supports the RCM-analysis and RCM databases, sources which can (and will) be shared between partners.

(34) Third, a project on crack prevention including operator detection and characterization of cracks is under way (Enkvist, Edland, & Svenson, 1999, 2000).

(35) In addition, the plant has also been cooperating in the Norwegian Eureka-project on Aging and Management. As a part of this project a methodology has been developed to assess the technical conditions of industrial systems. A database was developed for storing information about equipment degradation processes. The database is called DegraLex.

NPP-4

Research

Currently no new research project has been planned.

Development

Currently no new development project has been planned.

SKI

Research

Currently no new research project has been planned.

Development

Currently no new development project has been planned.

3.4 Needs for future research/development projects related to maintenance problems

The following needs for future research/development projects related to specific problems were discussed.

NPP-1

- (I) *The relation between economy and safety.*
- (II) *Deviations in maintenance (event deviation reports).* How to gain knowledge from prior errors, faults, failures, etc.
- (III) *Attitudes towards safety in maintenance work.* Attitudes towards work and attitudes towards the own personal role for safety. The role of attitudes in, and dependency on the management of a plant.
- (IV) *Safety criteria.* Introduction of baseline (pre-post implementation measurements) measurements to analyze the effects of change. Benchmarking.
- (V) *Shortage of instrumentation engineers.* Vacancies, recruitment difficulties, workload.
- (VI) *System 500 (station control equipment, including for example: reactor control systems; process control; activity supervision).* Very important, many improvements needed.
- (VII) *The use of event reports as safety indicators.* The questionable bonus systems – for example, “the fewer the number of reported work injuries, the better”. Better criteria for event reporting – usefulness. Feedback systems.

The following research was identified as possible projects for a doctoral student.

- (VIII) *The importance of leadership for safety.*
- (IX) *International comparisons of maintenance.* To gain knowledge about how and why “some are better than others”. Comparisons of test personnel etc. System focused – for example how and why some plants can maintain system 500 better than other plants.

NPP-2

- (I) *Instructions.* About 8000 various instructions exists at the plant. At the same time some procedures have no instructions. Problems are often solved by writing new instructions (see student’s project above). Is this necessarily a good tradition? Some argue that instructions may not be necessary everywhere (as for diesels). It can be argued that some instructions are important only during metagenesis – when all knowledge and skill accumulated in the prior generation are leaving the plant. Are there other purposes except outward-credibility, to instruct, and move info from the prior to a following “generation”? Typical problems are that instructions tend to be too long and there is a difficulty to compress them without losing essence. Another difficulty is to make standardized instructions across different units. One interesting angle of research is to find out if and how different designs of instructions affect quality of work relative to different degrees of competence (see figure 2).

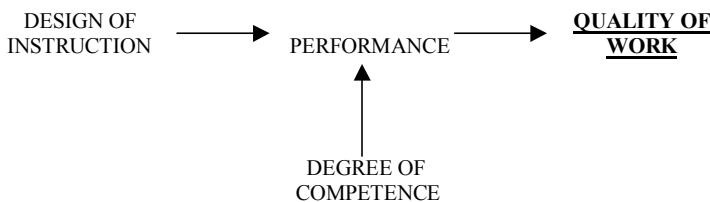


Figure 2: Instructions and competence affecting quality of work through performance.

- (II) *Latent and hidden failures.* How do they occur? How shall they be prevented (instructions, event reports (feedback), cause analysis)? This is especially important during modifications. In such a context unintended modifications, for example routine replacement of specified components by similar components not specified, and possible consequences are of interest (for example, replacement of a computer hard drive with specified data to another with higher performance - cause negative consequences to the system as a whole because of incompatibility). Studies on CCF's (common cause failures) are important here.
- (III) *Organizational research.* To create common "platforms" across different sub units in order to enhance unity of communication, attitudes, and safety. Should reactors constitute units? Group constellations across various disciplines to enhance safety, for example aggregating electrical, mechanical, instrumentation departments to a common platform for maintenance. Get maintenance personnel to understand that they have importance for safety (change of attitudes). "Ownership" as one attitude towards safety?
- (IV) *Feedback systems.* "Natural channels" of communication. Computer vs. Paper as media for input and reading. This includes for example event reports.

NPP-3

- (I) *Worker accidents.* How to utilize MTO analyses more efficiently in the prevention of person accidents at work. Communication of the analysis results, a structured approach towards accident prevention, and a plan for implementation are needed. Such an approach could, for example, include improvements of work instructions, safety barriers concerning labor force accident protection, and organization of work (for example in cases of delivering-receiving risky equipment and instructions for use belonging to the particular equipment).
- (II) *Demands on competence.* Younger employees sometimes have a difficulty meeting the competence demands. Older employees possess a great deal of accumulated knowledge seldom found in instructions etc., but includes information which is sometimes highly valuable for work efficiency. Following generation shifts a lot of this information is lost. This informal knowledge should be utilized and accessible to all. Diaries, databases etc. were discussed as means for taking advantage and distributing such information.
- (III) *"Prevent unnecessary maintenance".* A great amount of work time is spent on testing. This is true for all areas not only maintenance. But testing is also one source for the introduction of errors and faults (improper use of tools, inappropriate force, etc.). In addition to existing systems of (post-error) detection of outwearing etc., measures should be taken towards how to prevent unnecessary maintenance.
- (IV) *Introduction of human factors as a new perspective.* For example, in the functional specification stage of new constructions and/or changes of existing systems.

The following research was identified as possible projects for a doctoral student.

- (V) *Organizational issues.* For example, issues related to: (a) the interplay between different actors at the plant; (b) transfer of valuable characteristics and functions of a former organization to a new one during organizational change (learning); (c) how to introduce human factors into a maintenance organization.
- (VI) *"Prevent unnecessary maintenance".* See above.

NPP-4

- (I) *Integration of MTO.* To find out proper measures of how to fully integrate human and organizational aspects in the maintenance policy, instructions, and the practical maintenance work. Human and organizational features of maintenance should be perceived as natural features of the "backbone" of maintenance, and not as an "attachment".
- (II) *MTO in risk evaluation.* It is considered to be important to find out how MTO can be included in the evaluations of risks in the planning of maintenance work. This could, for example, include demand characteristics/specifications (what resources do we have, which do we need?) to ensure that proper measures have been taken towards the prevention of MTO related events.
- (III) *Generation- and competence- shifts.* Difficulties may occur not only when new personnel take over duties left by (older) experienced crew (generation shift), but also in routine work in a new environment. This may be encountered, for example, when doing maintenance work in another unit with slightly different configurations than the personnel is used to work with. New duties are sometimes also added to the routine duties ("competence shift" - not always age related). It is important to find out proper measures to make such transitions as smooth as possible.
- (IV) *A small note on change processes.* It was discussed that it is more desirable to find out the "small things that make a difference" and are possible to implement in the existing organization (cost effectiveness thinking).

The following research problems were identified as possible projects for a doctoral student.

- (V) *Common methodology - common language.* To find out a general methodology (accepted by both the plants and SKI) for analyses, for example PSA. The current approaches are slightly different which often results in that (unnecessary) efforts in defending the particular methodology used have to be made. A development of a common/general method of analysis (concerning which factors to include, and how the factors should be weighted) would probably not only solve the problems of comparison between analyses, but also improve the communication of the results.
- (VI) *Early planning for MTO.* The earlier MTO is introduced in the activities (for example: inventions; functional testing; design; etc.), the better. It is important to find out how MTO in the best of ways can be introduced as early as possible in the planning of various activities at the plant.

SKI

- (I) *Plant modifications and maintenance.*
- (II) *Co-ordination between maintenance and operation personnel.*
- (III) *Evaluations of maintenance intervals.* Methods for verification of maintenance measures.
- (IV) *The role of "instructions" in maintenance work.* How to keep up motivation.
- (V) *Development of methodology for qualification of NDT personnel with a view to general personnel qualifications.* At the present, the personnel qualification is valid only for inspection in accordance with the particular procedure used in the "blind" qualification demonstration, which is expensive and unreasonable.

(VI) *Issue of practical recommendations*, concerning working environment and organization conditions while performing NDT in field.

The following research problem was identified as a possible project for a doctoral student.

(VII) *A project on learning in the maintenance process*.

4. Summary of findings

4.1 Previously completed, ongoing, and planned research/development projects

As can be seen in Table 2, 35 interview reports that related to research questions I to III, were collected. They were distributed with 16 reports on completed projects (7 research and 9 development), 15 reports on ongoing projects (6 research and 9 development), and 4 on planned projects (development only). The numbers varied across plants. A slightly higher number of development projects (22) compared to research projects (13), according to our categorization, were reported. However, it is important to make the remark that the distinction between research and development is often fuzzy. Very few of the reports qualify as research-projects without further development.

Table 2: Numbers of reported completed, ongoing, and planned research (res) and development (dev) projects at each plant and SKI.

	Plant 1		Plant 2		Plant 3		Plant 4		SKI		Tot across plants	
	res	dev	res	dev	res	dev	res	dev	res	dev	res	dev
Completed	3	3	3	0	0	3	0	2	1	1	7	9
Ongoing	1	0	2	3	0	3	1	3	2	0	6	9
Planned	0	0	0	0	0	4	0	0	0	0	0	4
Σ	4	3	5	3	0	10	1	5	3	1	13	22

The content of the reports answering questions I-III varied largely across locations concerning the problems and work areas that had been in focus. In order to illustrate the work done in categories relevant for our research questions, every single interview report was categorized. Two main dimensions each containing three categories (3x3) were used. The dimensions were, *main focus* (categories: A technological; B human and technological; and C organizational), and *related work area* (categories: 1 maintenance; 2 others including maintenance; and 3 others not including maintenance). Accordingly, each interview report was coded according to the dimensions. For example, if one study focused "how to write proper instructions" (related to both human and technological issues), and the study related to work in all departments of the plant (also including the maintenance department), this particular interview report was coded B2. However, it is important to note that our categorization is just one of many possible ways to structure the material, and we make no claims about its appropriateness other than for illustrative purposes. Table 3 shows all interview reports categorized in such a scheme. For the convenience of the readers, all interview reports in Table 3 are indexed according to the numbers given for each interview in section 4.1-4.3 above.

Table 3: Interview reports categorized according to the dimensions main focus of the work and related work area. The table gives figures on number (n) of reports according to the two dimensions, the problem-question (topic), and the number of each interview answer belonging to this categorization (i).

related work area	Main focus								
	A-primarily technological			B-human and technological			C-primarily organizational		
	n	topic	i	n	topic	i	n	topic	i
1-maintenance	4	-RCM -BiCycle -IMADS -Bicycle	7 28 32 33	5	-reference book - //- -competence -instructions -feedback	15 16 21 22 29	2	-reorg. -reorg.	6 13
2-others including maintenance	2	-DKV, RCM -status monitoring	18 25	13	-attitudes -violations -safety culture -FMEA -STARK -refueling and HF -academic -violations -violations -TBU -process oriented work -outage analyses -DKV	1 2 3 4 5 8 9 17 19 20 23 26 30	3	-reorgMTO -reorgMTO -reorgMTO	12 14 24
3-others not including maintenance	3	-dose-load -detection -aging	10 11 35	3	-Adm. instructions -NDT and HF	27 31 34	0		
Σ	9			21			5		

In Table 3, cells B1-2, and C1-2 (organizational aspects of maintenance are here seen as important contributors to consequences in practical maintenance work) are most related to the research questions in this study. Hence, the result shows that a majority of the interview reports could be categorized to areas that are important for human factors and maintenance (n=23). Work belonging to areas outside the primary focus of this study (A1-3, B3, and C3) were also reported (n=12).

As can be seen in Table 3, the topics of interest in the various works differed largely concerning human and technological aspects of maintenance (B1-2). When it comes to organizational aspects of maintenance (C1-2), all work was related to topics of recent reorganization of the maintenance departments and the MTO groups.

4.2 Needs for future research/development projects related to specific maintenance problems

The answer concerning specific future research/development projects the sites considered important varied largely between the sites. From the reports, it is impossible to tell if some problem area is considered uniquely more or less important than others. Instead, one can tell that many areas seem to be interesting for future research. In order to make the material comprehensible the material was reduced in relation to our research questions. First, possible problem areas (e.g., reporting, feedback, methodology, failures, etc.) were extracted from the interview reports. Second, the different reports (n=32) were coded according to the different problem areas. Third, related problem areas were collapsed into new more general categories. This procedure was repeated a couple of times. Interview reports that did not match the created categories were gathered in 3 more general categories (labeled "other-"). This gave 10 problem areas (see Table 4). However, it is again important to note that our categorization is just one of many possible ways to structure the material, and we make no claims about its appropriateness other than for illustrative purposes.

Table 4 shows all interview reports categorized to such a scheme. For the convenience of the readers, all interview reports in Table 4 are indexed according to the numbers given for each site (1-4, and SKI), and each interview report (roman numerals) in section 4.4 above. A brief description for each project proposal is also given.

A project for a doctoral student will in a near future be established at the center for nuclear technology (kärntekniskt center, KTH). One possible line in such a project could be related to issues of human factors and maintenance. This is a less costly opportunity for the sites to gain research in the area, so we asked the sites which projects they thought would be appropriate for a doctoral project. Seven projects, included in the 32 above, were specified as suitable for a doctoral student. They are marked with a capital D following the Roman numeral index.

According to the research question, it could be assumed that projects related to specific failures or errors, or projects related to specific components or systems should be common in the reports. That was not the case. Most interview reports gave much broader perspectives.

Table 4: Thirty-two future projects categorized in 10 problem areas. The table gives a brief description of the project proposal, which site reported it (1-4, and SKI), and the index number of the interview report (roman numerals). Projects proposed (by the plants and/or SKI) as a doctoral thesis project are marked with a capital D following the Roman numeral index.

Problem-area	Project proposals in brief	site	nr
reporting-feedback	-maintenance event deviation reports	1	II
	-use of event reports as safety indicators	1	VII
	-natural channels of communication	2	IV
instructions and recommendations	-to improve work quality by means of improving instructions (various aspects)	2	I
	-the role of instructions-motivation	SKI	IV
	-practical recommendations (environmental, organizational, etc.) for NDT in field	SKI	VI
organizational	-how to create common platforms across subunits	2	III
	-organizational issues (various aspects)	3	V D
	-co-ordination between maintenance and operation personnel	SKI	II
	-shortage problems of specific personnel	1	V
	-leadership and safety	1	VIII D
competence and learning	-demands on competence, utilization of informal knowledge	3	II
	-generation and competence shifts	4	III
	-learning in the maintenance process	SKI	VII D
methodology	-create a common methodology for similar analyses	4	V D
	-methodology for qualification of NDT personnel	SKI	V
	-safety criteria, pre-post implementation baseline measures	1	IV
	-evaluations of maintenance intervals and verification of measures	SKI	III
failures	-latent and hidden failures, occurrence and prevention	2	II
system specific	-system 500 maintenance	1	VI
other MTO related	-integration of MTO	4	I D
	-MTO in risk evaluation	4	II
	-early introduction of MTO in new activities	4	VI
	-utilization of MTO analyses in prevention of worker accidents	3	I
	-introduction of HF onto new perspectives	3	IV
other maintenance related	-how to prevent unnecessary maintenance	3	III(VI) D
	-plant modification and maintenance	SKI	I
other/general	-the relation between economy and safety	1	I
	-small things that make a difference	4	IV
	-international comparisons of maintenance to gain improvement	1	IX D
	-attitudes toward safety in maintenance work	1	III

5 Concluding remarks

A majority of the interviews on completed, ongoing, and planned research/development projects gave interesting answers on how professionals on the plants and SKI view their work and progress on issues related to maintenance and human factors. The interview answers clearly illustrated rather diversified viewpoints on this matter. A number of reasons may explain these differences. For example, specific or general differences between the sites (e.g., technological, organizational, cultural, etc.) give rise to different problems, different angles of approach, and different solutions to the problems.

Following the results, it would be important to investigate which underlying processes and structures contribute to differences in the view of human factors in maintenance and how they relate to maintenance work and safety in practice. We suggest that an organizational culture approach is appropriate for this research problem.

The interviews on needs of future research / development projects gave interesting answers concerning which problem areas related to issues of maintenance and human factors, professionals at the plants and SKI consider as important. Because of the great diversity in the answers among the sites, no single (uniform) priority problem area could be identified. Instead, a number of possible problem areas for future research/development were generated, each including one or more specific proposals for future project. The problem areas concerned: (1) reporting-feedback; (2) instructions and recommendations; (3) organizational; (4) competence and learning; (5) methodology; (6) failures; (7) system specific; (9) other MTO related; (10) other maintenance related; and (11) other general.

It is impossible to decide if a particular problem area is more important than another. Instead, the local circumstances at a plant must be taken into consideration in a prioritization process. However, there are a number of specific project proposals that we suggest to be important and possible to manage within the near future, some of them also suitable for a doctoral thesis project. They are [site (interview nr.)]:

-*Deviations in maintenance (event deviation reports)*. How to gain knowledge from prior errors, faults, failures, etc. [NPP1 (II)].

-*Attitudes towards safety in maintenance work*. Attitudes towards work and attitudes towards the own personal role for safety. The role of attitudes in, and dependency on the management of a plant [NPP1 (III)].

-*The use of event reports as safety indicators*. The questionable bonus systems – for example, “the fewer the number of reported work injuries, the better”. Better criteria for event reporting – usefulness. Feedback systems [NPP1 (VII)].

-*Latent and hidden failures*. How do they occur? How shall they be prevented (instructions, event reports (feedback), cause analysis)? This is especially important during modifications. In such a context unintended modifications, for example routine replacement of specified components by similar components not specified, and possible consequences are of interest (for example, replacement of a computer hard drive with specified data to an other with higher performance - cause negative consequences to the system as a whole because of incompatibility). Studies on CCF's (common cause failures) are important here [NPP2 (II)].

-*MTO in risk evaluation*. It is considered to be important to find out how MTO can be included in the evaluations of risks in the planning of maintenance work. This could, for example, include demand characteristics/specifications (what resources do we have, which do we need?) to ensure that proper measures have been taken towards the prevention of MTO related events [NPP4 (II)].

-Early planning for MTO. The earlier MTO is introduced in the activities (for example: inventions; functional testing; design; etc.), the better. It is important to find out how MTO in the best of ways can be introduced as early as possible in the planning of various activities at the plant [NPP4 (VI)].

-Development of methodology for qualification of NDT personnel with a view to general personnel qualifications. At the present, the personnel qualification is valid only for inspection in accordance with the particular procedure used in the “blind” qualification demonstration, which is expensive and unreasonable [SKI (V)].

-Issue of practical recommendations, concerning working environment and organization conditions while performing NDT in field [SKI (VI)].

-A project on learning in the maintenance process [SKI (VII)].

Among the previously completed work at the plants the following follow-up studies were suggested:

-safety culture related to individual apprehension of own personal safety [NPP1 (3)].

-models for RCM [NPP2 (7)].

5.1 Recommended actions

The following recommended actions are proposed:

- (1) Further analysis of the problem areas suggested for further research.
- (2) Reformulations of problems into research projects (when possible), and for each research project:
 - (2.1) Compile a theoretical literature review.
 - (2.2) Collection of empirical based on data from plants.

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List of abbreviations

CCF -common cause failure
EU -european union
FMEA -failure mode effect analysis
LER -licensee event report
HCCF -human related common cause failure
HCCN -human related common cause non-critical failure
HSEF -human related shared equipment fault
HE -human error
IMADS -intelligent maintenance advisory systems
MTO -man-technology-organization
NDT -non-destructive testing
NPP -nuclear power plant
PSA -probabilistic safety analysis
RCM -reliability centered maintenance
SKI -statens kärnkraft inspektion, Swedish nuclear power inspectorate
SKIF -SKI författningssamling, SKI statute-book
STARK -stop, think, act, reflect, (k)communicate
TBU -tillstånds baserat underhåll, condition based maintenance
DKV -driftklarhets verifiering, operational readiness verification

Appendix

Appendix A. Questionnaire

Intervjuinstruktion

Inventering av forskning och behov av mänskliga faktorn forskning om underhållsarbete vid svenska kärnkraftverk

Presentation

Bakgrund

Finska forskare har under flera år intresserat sig för den mänskliga faktorn vid underhållsarbete i kärnkraftverk. En kopia på en ganska tidig rapport som rör detta bifogas denna sammanfattande projektbeskrivning. Genom NKS har på finskt initiativ ett svenskt projekt startats med syfte att kartlägga svensk pågående, planerad och behov av forskning inom detta område.

Syften

Att inventera (1) tidigare avslutad (2) pågående (3) planerad och (4) behov av utveckling/forskning inom området underhåll och den mänskliga faktorn vid svenska kärnkraftverk och vid SKI.

Genomförande

Insamlingen av informationen sker under våren 2001 genom intervjuer vid de olika kärnkraftverken och SKI.

Dokumentation

Då hela projektet med information från alla verk och SKI avrapporteras under 2001 skickas en kopia till alla som deltagit i intervjuerna för kännedom och eventuell distribution till andra intresserade. Slutrapporten utformas till slut med utelämnande av verksidentifiering för publicering i NKS och SKI rapportserierna.

Procedur

Vi ställer frågorna och antecknar parallellt. Frågorna är 1-4 ovan (se OH). Om det blir tid över vill vi gärna ställa några andra frågor också. För samtliga frågor skall i första hand *human factors i underhåll* fokuseras.

Efter intervjun skriver projektledarna en sammanfattning av intervjun vid kraftverket och skickar denna på tillbaka på remiss (till kontaktperson) för eventuella korrigeringar och eller kompletteringar.

Intervjufrågor

1. TIDIGARE AVSLUTAD FORSKNING OCH UTVECKLING

1.1 Finns det någon egen tidigare genomförd forskning/utveckling på verket med anknytningen underhåll-mänskliga faktorn

Vilka frågeställningar var det som undersöktes

Dokumentation ?

1.2 Finns det någon tidigare forskning/utveckling på verket med anknytningen underhåll-mänskliga faktorn som genomförts och eller initierats av andra

Vilka frågeställningar är det som undersöktes

Vem genomförde/initierade forskningen/utvecklingen

På vems uppdrag genomfördes forskningen/utvecklingen

Dokumentation ?

2. PÅGÅENDE FORSKNING OCH UTVECKLING

2.1 Finns det någon egen pågående forskning/utveckling på verket med anknytningen underhåll-mänskliga faktorn

Vilka frågeställningar är det som undersöks

2.2 Finns det någon pågående forskning/utveckling på verket med anknytningen underhåll-mänskliga faktorn som genomförs och eller initierats av andra

Vilka frågeställningar är det som undersöks

Vem genomför/initierar forskningen/utvecklingen

På vems uppdrag genomförs forskningen/utvecklingen

3. PLANERAD FORSKNING OCH UTVECKLING

3.1 Finns det någon egen planerad forskning/utveckling på verket med anknytningen underhåll-mänskliga faktorn

Vilka frågeställningar är planerade att undersökas

3.2 Finns det någon planerad forskning/utveckling på verket med anknytningen underhåll-mänskliga faktorn som initierars/skall genomföras av andra

Vilka frågeställningar är planerade att undersökas

Vem kommer att genomföra/initiera forskningen/utvecklingen

På vems uppdrag kommer forskningen/utvecklingen att genomföras

4. BEHOV AV FORSKNING OCH UTVECKLING

4.1 Vilken forskning/utveckling vill ni ha utförd på kort sikt (1-2 år)

Vilka frågeställningar är mest relevanta att undersöka i detta fall

Moment som är utsatta

Säkerhetsmässig betydelse

System utsatta för mänskliga fel

Säkerhetsmässig betydelse

Mänskligt felhandlande som är av betydelse för uppkomsten av systemfel

Säkerhetsmässig betydelse

Vilken forskning/utveckling skall prioriteras

4.2 Vilken forskning/utveckling vill ni genomföra själv på lång sikt (3 år)

Vilka frågeställningar är mest relevanta att undersöka i detta fall

Moment som är utsatta

Säkerhetsmässig betydelse

System utsatta för mänskliga fel

Säkerhetsmässig betydelse

Mänskligt felhandlande som är av betydelse för uppkomsten av systemfel

Säkerhetsmässig betydelse

4.3 Vilken forskning/utveckling skall prioriteras

4.4 Vilken forskning/utveckling hade varit intressant ifall ni haft helt fria ekonomiska resurser

(Doktorandtjänst på kärntekniskt centrum KTH)

5. ALLMÄNT

5.1

Kontroll av underhåll (driftklarhetsverifiering, procedurer-underhåll, checklistor)

Förebyggande-underhåll, avhjälpande-, tillståndsbaserat-, tillförlitlighets-

Kommunikation av underhåll som ej fungerar

Experience based maintenance

Filosofi jämförbar med drift (event reporting)

5.2 Hur utnyttjar man kunskap om mänskliga faktorn i samband med underhåll

Egna erfarenheter

Moment som är utsatta

Säkerhetsmässig betydelse

System utsatta för mänskliga fel

Säkerhetsmässig betydelse

Mänskligt felhandlande som är av betydelse för uppkomsten av systemfel

Säkerhetsmässig betydelse

Utbildning/fortbildning

Tid för remiss på sammanfattning av intervju

Jag skickar: ___/___

Remissvar tillbaka senast: ___/___ ifall det finns behov av korrigeringar och /eller kompletteringar

Kontaktperson att skicka till: _____

E-post: _____

Tel: _____

EGNA FRÅGESTÄLLNINGAR

ÖVRIGT