Nordic nuclear safety research

NKS-300
ISBN 978-87-7893-376-8

The expected and experienced benefits of Human performance tools in nuclear power plant maintenance activities – Intermediate report of HUMAX project

Pia Oedewald[a]
Ann Britt Skjerve[b]
Christer Axelsson[c]
Kaupo Viitanen[a]
Elina Pietikäinen[a]
Teemu Reiman[a]

[a] VTT, Finland
[b] IFE, Norway
[c] Vattenfall, Sweden

February 2014

Abstract

In recent years most Nordic nuclear power plants have implemented so called human performance programmes. The programmes typically apply predefined *human performance tools (HU tools)* to maximize failure free operations by preventing human errors. Despite the prominence of human performance programmes, there is little research on the basic premises behind them and the concrete beneficial effects from using HU tools remain elusive. This document describes the intermediate results of a Nordic research project HUMAX which aims at providing knowledge of the impacts of the human performance programmes and to support the designing and implementing effective HU tools. The focus is on maintenance activities.

In 2013 HUMAX project carried out three case studies in Nordic NPP maintenance organisations and studied the expected and experienced benefits of HU tools. Furthermore HUMAX disseminated an international survey to human performance experts around the world to gain more insight into the motives, benefits and disadvantages of the programmes. The study is ongoing and the results presented in this report are preliminary.

The results show that often the espoused goal of a human performance programme is to prevent *events* by reducing errors. However, the interviews indicate that maintenance personnel associate many other benefits to the HU tools than reduced number of events. Smooth execution of work tasks, less rework and smaller occupational injury risk were often mentioned as practical benefits. The benefits also included indirect safety improvements: more rigorous work practices and shared knowledge on work tasks and risks.

Many of the practices have been used at the Nordic plants for a long time and there were questions why they are now labelled as HU tools and promoted with a programme. Despite of that, maintenance personnel held fairly positive view on the HU tools. However, a common opinion was that using the HU tools may require a lot of time. Further, strong focus on the tools may decrease the focus on tasks itself and impair the workers attention or judgement. In the Nordic plants HU tools were also sometimes perceived as awkward, and feelings of shame and blame may occur. Thus, the results highlight the importance of the implementation process, the way the HU tools are argued and promoted in the organisations.

Key words

human error, nuclear power, safety culture, safety management, maintenance

NKS-300
ISBN 978-87-7893-376-8

Electronic report, February 2014
NKS Secretariat
P.O. Box 49
DK - 4000 Roskilde, Denmark
Phone +45 4677 4041
www.nks.org
e-mail nks@nks.org

The expected and experienced benefits of Human performance tools in nuclear power plant maintenance activities

Intermediate report of HUMAX project

Pia Oedewald, VTT
Ann Britt Skjerve, IFE
Christer Axelsson, Vattenfall
Kaupo Viitanen, VTT
Elina Pietikäinen, VTT
Teemu Reiman, VTT

Abstract

In recent years most Nordic nuclear power plants have implemented so called human performance programmes. The programmes typically apply predefined *human performance tools (HU tools)* to maximize failure free operations by preventing human errors. Despite the prominence of human performance programmes, there is little research on the basic premises behind them and the concrete beneficial effects from using HU tools remain elusive. This document describes the intermediate results of a Nordic research project HUMAX which aims at providing knowledge of the impacts of the human performance programmes and to support the designing and implementing effective HU tools. The focus is on maintenance activities.

In 2013 HUMAX project carried out three case studies in Nordic NPP maintenance organisations and studied the expected and experienced benefits of HU tools. Furthermore HUMAX disseminated an international survey to human performance experts around the world to gain more insight into the motives, benefits and disadvantages of the programmes. The study is ongoing and the results presented in this report are preliminary.

The results show that often the espoused goal of a human performance programme is to prevent *events* by reducing errors. However, the interviews indicate that maintenance personnel associate many other benefits to the HU tools than reduced number of events. Smooth execution of work tasks, less rework and smaller occupational injury risk were often mentioned as practical benefits. The benefits also included indirect safety improvements: more rigorous work practices and shared knowledge on work tasks and risks.

Many of the practices have been used at the Nordic plants for a long time and there were questions why they are now labelled as HU tools and promoted with a programme. Despite of that, maintenance personnel held fairly positive view on the HU tools. However, a common opinion was that using the HU tools may require a lot of time. Further, strong focus on the tools may decrease the focus on tasks itself and impair the workers attention or judgement. In the Nordic plants HU tools were also sometimes perceived as awkward, and feelings of shame and blame may occur. Thus, the results highlight the importance of the implementation process, the way the HU tools are argued and promoted in the organisations.

Keywords [human error, nuclear power, safety culture, safety management, maintenance]

Contents

1. Introduction

Maintenance is a key function in any complex sociotechnical system, such as nuclear power plants (Reiman, 2011). Effective and reliable maintenance activities are of crucial importance since maintenance provides the technical preconditions for undisturbed operations and functioning of the safety systems. At the same time, however, poorly executed maintenance is one of the sources of technical failures and initiating events for plant disturbances. In various safety-critical domains, including railway, offshore oil drilling, chemical, petrochemical, aviation and nuclear industries inadequate or faulty maintenance has been found as one of the main contributors to events by accident investigations (see e.g., Reason, 1997; Hale et al., 1998; Kletz, 2003; Reason & Hobbs 2003; Perin, 2005; Baker, 2007; Sanne, 2008).

Human and organizational factors play an important role for improving safety of nuclear power plants. Safety management approaches have therefore been focused on developing practical means for dealing with the phenomena related to human behaviour. In recent years most Nordic nuclear power plants have been implementing so called Human Performance programmes which have their guidance from INPO (1997, 2006).

According to the Department of Energy (DOE), Human Performance programmes have two main objectives: to *reduce errors*, and to *strengthen controls* (DOE, 2009). Various approaches exist on how to develop, implement and conduct human performance programmes (e.g., Addison & Haig, 2006; IAEA, 2001, 2005; Pershing, 2006). Typically human performance programmes apply predefined ***human performance tools*** to maximize failure free operations by preventing and/or catching human errors. Human performance tools are conceived as simple aids or working methods to be used mainly by managers and supervisors, engineers and workers, although front line workers, typically maintenance and control room workers, most often are in focus. The human performance tools include, for example, peer checking of work, three-way-communication, pre-job-briefing and supervisor's work observations.

Human Performance programmes in the nuclear industry have mainly been developed by practitioners and disseminated through informal networks and international bodies such as INPO (1997; 2006) and WANO (e.g., 2002; 2006). However, despite the prominence of human performance programmes, there is little scientific literature on the basic premises behind the human performance tools. Also, despite their popularity, the concrete beneficial effects from using human performance tools in nuclear power plants remain elusive.

Human performance programmes are partially based on the so called *behavioural safety* approach, which has lately been criticised (e.g. Hopkins 2006, Le Coze 2008, Anderson 2007). Behavioural safety has been popular in the petrochemical industry since the 1990's, but the major accidents in the domain have resulted in vivid criticism towards the applied safety management practices, including behavioural safety approaches. One of the causes of criticism is that the programmes direct the attention toward individual workers instead of for example poor design or suboptimal organisation of the work. Hopkins (2006) states that: *"The reality is that unsafe behaviour is merely the last link in a causal chain and not necessarily the most effective link to focus on, for the purposes of accident prevention".* In addition, by focusing on front line workers behavioural safety programmes may foster a blaming culture rather than enhance the development of safety culture. Organisational trust is a key factor in successful behavioural safety programmes, but it has not been accomplished in all organisations (Cox 2004). A further concern related to behavioural safety programmes is that they seem to direct the attention to occupational (personnel) safety rather than system safety, since it is much easier to judge the safety or riskiness of behaviours in relation to occupational safety than in relation to system safety. Anderson (2007) states that *"these programmes tend to focus on intuitive issues and personal health and safety, ignoring low probability/high consequence risks".*

An interesting question concerns the human performance programme's primary goal of reducing errors and strengthening controls (DOE 2009a). Safety scientist, especially the proponents of *Resilience Engineering* approach suggest that this strategy has limitations (Woods et al. 2010, Hollnagel 2009). When safety controls are too rigid, smooth execution of the work becomes more complicated and the likelihood of 'cutting corners behaviour' increases. Thus, safety controls may become a liability. Further, the resilience engineering theory claims that the variations in the performance of workers should not be totally eliminated since variability gives rise to flexibility and thus ability to cope with unexpected and novel situations. Even in the highly standardised and proceduralised industrial settings like the nuclear industry, the army, the aviation maintenance etc. local adjustments take place frequently (Bourrier, 1996, Snook, 2000). This was identified also in the NKS-study MOREMO (Oedewald et al. 2012, Gotcheva et al 2013) which analysed maintenance working practices in Nordic power plants. The question thus is, how to design human performance tools and optimize rules and procedures which do not complicate the work too much and allow sufficient amount of flexibility in the performance.

Human performance programmes require resources, such as the time for developing the programme, training the personnel in using the human performance tools and time spent for management in follow up and observation. The organisations do not always adopt human performance tools without internal criticism. It has been claimed that the human performance tools take too much time to apply, the methods direct attention away from the core task or the methods feel clumsy or naïve for the workers. It is possible, that some of the tools which fit well for the working culture of Anglo-American companies are awkwardly perceived in the Nordic working culture where supervisory control is less prominent and employee's professionalism is highly valued. To improve the effectiveness of the human performance tools it may be necessary to tailor them to fit the local working culture. All in all, the pros and cons of using human performance tools need to be better understood.

2. Goals and research strategy

2.1 Goals and research questions

The overall aim of the study is to enhance understanding on how to maximize human performance in maintenance activities of nuclear power plants. Specifically, the objectives are to provide knowledge of the impacts of the human performance programmes and to support the design and implementation of effective human performance tools in Nordic nuclear plants.

The research questions are:

1. What are the expected benefits of human performance tools applied in nuclear power plant maintenance?
2. What have the measurable benefits of human performance tools been so far in the plants (e.g. reduced number of failures, reportable licensee event reports, human errors)?
3. How do maintenance personnel perceive the application and effects of human performance tools?
4. What characterizes successful human performance tools and implementation processes?
5. What aspects of maintenance work are most effectively met by use of human performance tools, and what could be solved by other socio-technical means?

The study is ongoing. Thus, in this intermediate report we will concentrate on the research questions 1, 3 and 4.

2.2 Research strategy and data

The study was carried out by two research institutes (IFE and VTT) and an expert from a power company (Vattenfall). The research strategy was to carry out three case studies at Nordic nuclear power plants and to complement that view with insights gained from an international survey. In addition to that a literature review into human performance tools and other means to deal with human errors was carried out. The analysis is in progress, thus the results presented in this intermediate report are preliminary.

2.2.1 Overview on the case studies in the Nordic nuclear power plants

Case studies were conducted in three Nordic nuclear plants in Sweden and Finland. The scope of the studies was maintenance activities because A) we wanted to narrow down the scope in order to discuss the practical application situations, error mechanisms, implementations challenges and benefits as concretely and thorough as possible and B) Human performance tools are typically implemented in maintenance activities since the work involves plenty of possibilities for human errors with significant consequences on plant availability and safety.

Two of the plants had implemented human performance programmes i.e. had set clear expectations and provided training for the personnel to use certain human performance tools. One of the plants differed from the other two in that respect that they had not yet implemented a Human performance programme, although they have adopted many similar practices throughout the years. They had, however, started a project where the aim was to decide a strategy to systematically implement selected set of human performance tools. The case organisations had selected slightly different tools to be included in their human performance programmes (Table 1). It has to be mentioned that Plants A and B did talk about questioning attitude and they do have operating experience practices but do not consider those as HU tools. Same applies to STAR-principle at plant B.

Table 1. The HU tools selected to be used at the case organisations. Note that the organisation A had not started the implementation yet.

HU tool	Plant A	Plant B	Plant C
Pre-job brief	(√)	√	√
Post job review	(√)	√	√
Independent verification	(√)	√	√
Peer checking (pair work)	(√)	√	√
Clear communication techniques (e.g. three way, phonetic alphabets)	(√)	√	√
STAR/two minute rule	(√)		√
Procedural Use and Adherence			√
Questioning Attitude			√
Task Observation/Coaching			√
Use of Operating Experience			√

Altogether 47 interviews were carried out in the Nordic plants (the data collection is described more in detail in the results section where each of the case studies is summarised). The interviewees included maintenance supervisors and managers, technicians and electricians. Couple of control room operators were interviewed as well. In two of the plants also a personnel survey was utilised to gather personnel opinions on their HU programme (in plants B and C). Furthermore, researchers familiarised themselves with the relevant documentation concerning the HU programmes and discussed the research questions with the case study HU coordinators frequently.

2.2.2 International survey

The study included an international web survey that was distributed also outside Nordic countries. The rationale for this was to gain a broader data set and better understanding on the expected and measured benefits, experiences on HU programmes and knowledge on success factors of the implementation. It was assumed that in many countries the HU programmes have been utilised for a longer period of time than in Nordic countries. One of the purposes was also to understand whether there are national culture differences, or more specifically, whether HU tools are received better or worse elsewhere in the world than in Nordic countries.

3. Results

Since the study is still ongoing the results presented here should be understood as preliminary. As the report is written, the cases studies have been analysed separately, but not compared yet. For this reason, the studies are described in separate sections below. In 2014, the outcomes of the three cases studies and the international survey will be compared to develop a common basis for working out recommendations on introduction and use of HU tools. The summaries of the case studies especially concern the research questions 1, 3 and 4: *What are the expected benefits of human performance tools applied in nuclear power plant maintenance? How do maintenance personnel perceive the application and effects of human performance tools?* and *What characterizes successful human performance tools and implementation processes?* The preliminary insights from the international survey with respect to those questions are presented briefly.

3.1 Case study A

3.1.1 Background and data collection

The plant A doesn't have a formal human performance program. Therefore the case study was a base line analysis of the experienced needs and attitudes towards such tools and programme. Specifically the organisation was interested in existing practices that already serve the same functions and thus, what should be taken into account when planning the implementation of the HU programme. Since the plant A representatives had not undergone a systematic human performance training the interviews provided a good opportunity to gain genuine knowledge on the personnel's views on risks in their everyday job. We also discussed what tasks they understand to be critical for plant safety and what kinds of errors they remember and consider to be possible in their own work. These themes were assumed to provide information about what sort of active errors the human performance tools should deal with and which work tasks could be those where the need for such tools is evident. The interviewees were also asked to name existing practices which help in assuring good quality and error free execution of work.

A total of 22 persons from the maintenance unit participated in the interview study. The interviews were semi-structured and the interviewees were chosen by the contact persons at the plant and they represented various levels of management including group managers, supervisors and maintenance planners. All the maintenance disciplines were represented.

3.1.2 Perceived risks and safety critical work tasks in maintenance

All the interviewees at plant A perceived their work to involve many types of risks; occupational, plant operations and nuclear safety related risks. The most common occupational safety risks that were brought up were bruises, cuts, falling from heights, radiation and risk related to failed electrical and mechanical isolations. Regarding plant and nuclear safety the interviewees identified risks related to heavy lifting especially in the reactor hall, working with large pumps, reactor works (incl. refuelling), and I & C work with safety and control systems. In addition to those, many interviewees mention torqueing as a critical work task from plant safety point of view. This is likely due to the fact the plant had recent events where torqueing was an issue. Many interviewees also mentioned that working with production equipment in general and any work involving Technical Specifications are critical tasks in their opinion. Other critical tasks that were mentioned by single interviewees were isolations, welding, working with high-pressure equipment, large modernization projects and on-call duty work.

In general, majority of the interviewees analysed the risks and safety critical work tasks quite easily. It seems that they are used to think in terms of more critical and less critical tasks. It became obvious that they utilise that kind of an intuitive categorisation of the tasks into critical/non critical, demanding/not demanding and routine/not routine when they prepare their workers for the job. The study did not aim to judge the accuracy of their perception concerning the risks and safety critical tasks. However, it seems that most interviewees were fairly knowledgeable of the risks related to plant safety e.g. they were able to explain on a generic level the possible consequences of the failures of those tasks they named as risky. The list of plant safety related risks that the interviewees produced cannot be considered exhaustive. For example, the researchers paid attention to the fact foreign object intrusion was mentioned as a risk by only one interviewee.

3.1.3 Examples of errors or work tasks that have gone or could have gone wrong

A few error types were repeatedly mentioned by the interviewees: issues with torqueing, unsuccessful operating of cranes, failure to follow procedures/cutting corners and working on a wrong work site. Interestingly, many interviewees said that the failures they mentioned were not necessarily straightforward human errors but in many cases there were technical issues e.g. phenomena related to ageing systems that caused the maintenance activity to fail. When asked, most of the interviewees struggled in naming incidents caused by active human errors. One supervisor explained that in his domain the most likely errors have been eliminated:

"what comes to my mind is the simulation thing [after an I&C test a simulation was left on which preventing a signal for some time] but we have done corrective measures since and in that sense it is a poor example because in my opinion it is impossible that similar mistake would occur ever again. […] No, there is no such work where there would be a big danger, not really. […] Just recently a master's thesis was done on calibrations. […] we aimed to identify human errors and the outcome was that there are practically none…"

Most of the human errors were related to minor carelessness or misunderstandings in communication, which didn't have serious consequences in their opinion. The interviews show that at plant A the maintenance supervisors didn't think human errors are a big safety issue at the plant.

Examples of errors and failures in maintenance work

Most commonly mentioned examples of errors at Plant A were related to torqueing. Some leaks were recently caused by issues such as misunderstanding the verbal instructions for the torqueing task or forgetting one of the bolts. The interviewees argued that some of the leak cases were caused by mechanical phenomena (e.g. thermal expansion) rather than human errors. Problems related to lifts and hauls were mentioned often as well. They were often considered equipment failures although some examples were given on clear communication errors between the crane operator and the instructor. General notions about workers sometimes ignoring instructions or having difficulty in interpreting them were mentioned as well. Several interviewees referred to a case of a potential fire hazard when too large amount of inflammable substance was brought to the work site. The interviewees thought that this was due to unclear instructions or poor communication of them. Also working in wrong work site or on a wrong component was a fairly typical error. Some of these cases were due to inaccurate work order and some of them just lack of attention from the worker's side.

Isolation phase and draining of the systems before starting the work on site had failed many times. The maintenance representatives clarified that the error is usually done by (field)operators since isolation is typically their responsibility rather than that of maintenance workers. The interviewees mentioned, again, that in many cases failed isolation or draining is not a human error because the isolation is in fact done correctly but is just not necessarily successful (e.g. some water or pressure remains in the line). The interviewees also came up with scaffolding related incidents. The construction of the plant makes it difficult to mount the scaffolds properly in certain places. It was also pointed out that there could be some "carelessness", especially during the dismounting phase which is always the last step and done in a hurry. Rushing and careless checking was also suspected in cases where I & C technicians had forgotten a simulation on after finishing the tests.

Some of the examples of errors described a situation where one accidentally damages the adjacent component or system. Many of the lifting and scaffolding related incidents are of that type. The interviewees also mentioned a case where a worker drilled through a wall without first checking what's behind and damaged a component. One interviewee mentioned foreign objects in the system, which could also be considered as human error.

The interviewees pointed out potential upcoming errors with programmable automation, mistakes in choosing software versions during upgrades, software configuration mistakes and information security.

3.1.4 Existing work practices which support good quality and error free maintenance

The interviewees were asked to describe existing work practices or other organisational means at plant A which aim at ensuring good quality and error free maintenance activities. This question clarifies maintenance personnel's view on human error prevention and, on the other hand, whether formalized human performance tools would add anything new to the palette of work practices. The interviewees came up with a rich variety of practices, some of them official, clearly documented and implemented, but some developed implicitly during the years. Some of the practices mentioned were identical to those in the HU tools list (e.g. pre-job brief and post job review) although there has been no formal human performance program. Below the most often mentioned practices are grouped in terms of the general function they might address.

Practices relating to workers' competence and professionalism

The interviewees emphasised that competence and professional pride of workers is the basis for good quality and error free work. Therefore, the organisation has qualification requirements and different types of training practices for in-house personnel as well as for the contractors. The plant has an induction training which aims for ensuring basic knowledge of the expectations and safety related practices. The induction training is complemented with task-specific introduction training and followed by continuous in-service training for example familiarising oneselves to new systems before they are installed. Many interviewees emphasised that professionalism includes more than qualification and class room training and that they prefer workers who possess qualities connected to professionalism. It involves professional pride, a dedication to high quality of the outcome of the work, ability to anticipate hazards, utilisation of appropriate work methods and protective measures. Supervisors told that they pay a lot of attention to who they send out to do the task. The supervisor takes into consideration employee traits and capabilities such as earlier experience, special competences and the way the employee works. In addition to supervisor's intuition and experience with the employee, competence is also evaluated by means of proficiency tests in certain jobs and employees knowledge on the systems and tasks are charted to keep track on their experience.

Practices related to acquiring and sharing knowledge

The interviewees perceived that knowing the machinery and the systems is crucial factor in achieving error free maintenance. Thus they described multiple means for acquiring and sharing knowledge concerning the technology, for example, visiting a supplier of a component in advance in order to familiarize the maintenance workers with the equipment beforehand or exemplifying the work task and its effects in a full scale simulator. The interviewees also mentioned practices focusing on learning from incidents and finished work tasks, such as discussions with supervisors, in peer groups and in trainings. In some work tasks post-job reviews are used. Furthermore, the plant had recently implemented a practice that all workers gather together to meet supervisors in the morning and before leaving home, which some of the interviewees considered a good opportunity to prepare for upcoming jobs and to share experiences.

Work permit practices and instructions

Written protocols such as work orders and instructions serve many functions from error reduction point of view: they remove the need to remember everything by heart and provide a check list on what to do next. They convey variety of information and thus remove the need to communicate it verbally. Safety measures are stated in the work orders and additional information is printed automatically along with work orders. The interviewees also mentioned that instructions are updated based on past incidents or found deficiencies.

Practices for risk identification and preparedness for work

Preparing for upcoming challenges before starting the work is currently handled by practices such as different types of kick off meetings, pre-job briefings, preplanning the task, risk analysis, filling a checklist to identify (occupational) hazards at the work site and visiting the work site beforehand. Preparations may involve steps for making sure that work prerequisites are met (e.g. correct tools, chemicals, settings, programs etc. are used) and checking the measurements of the component under work. Several interviewees also mentioned that ensuring proper condition of the tools and for example cranes improves quality and reduces errors. The interviewees also gave examples of situational practices that help them in preparing for surprises. Interviewees mentioned “carefulness” as a means for ensuring the quality of one’s own work. Practical examples of carefulness included calling the supervisor if there are any minor uncertainties or carefulness when working with isolations. Even though all the formalities of the isolations are done correctly, the norm is that the device is always first regarded as un-isolated, which means keeping distance, carefully inspecting the device and then opening it slowly. The organisation has introduced “stop and think” slogan to foster a careful mindset.

Practices for ensuring successful communication

Several practices exist to ensure successful communication between the workers. For example three-way communication is used when operating reactor loading machine. This practice was introduced by the supervisors after discovering deficiencies in communication at the loading machine. Supervisors brought up that they use a kind of “interviewing technique” to try find out whether their subordinates have understood what they have meant when they assigned a task or given instructions. This involves asking general questions about the task from the worker and thus trying to screen out misunderstandings and insecurities. Employees are also encouraged to call, ask and communicate about the progress of the work and this is enabled by making sure everyone has phones. Some use phonetic alphabets during phone communication but it is not systematically trained nor required. It is agreed that the workers leave noisy work scope while communicating. Despite the fact that the interviewees emphasised that verbal communication is vivid and encouraged and not very problematic, they mentioned that most things are stated in work orders and that essential things aren’t communicated only verbally. For example when discussing locations or coordination, work groups often visit the work site or look at the layout instead of trying to explain it only verbally. Standardized hand signs are used when operating cranes and it is agreed before starting the work task who communicates with the crane operator.

Using technical tools that remove human action or interpretation phase

Technical tools that remove human action are, for example, analysers that record data. In case of recording analysers, the human action of writing down data is removed and it is therefore not possible to have incorrect entries. The interviewees also mentioned other similar tools such as using a calibration system to check whether the measured results are meaningful, using cameras in challenging lifting and using bar code readers to identify correct equipment.

Practices related to other person verifying or checking the quality of the work

Work is typically done in pairs at the maintenance unit. Apart from some specific jobs, pair work isn't explicitly instructed, but is rather an established practice. However, working in pairs is resource consuming and sometimes working alone can be preferred due to not having enough workers. Four types of pair work could be identified from the interviews: peer-checking, participatory pair work, separated pair work and educational pair work. In peer-checking one performs the task while the other observes. The interviewees found this type of pair work heavy on resources and possibly socially unpleasant. However, in some specific, critical job types it was used and considered useful. In participatory pair work both workers are involved with the task. After completion, both approve the work. Separated pair work means the workers are working in the same area, possible on the same component, but don't interact with each other and are thus unable to verify each other's work preventively. Most of the pair work mentioned by the interviewees appears either participatory or separated. Educational pair work involves pairing a more experienced worker with a less experienced one for training purposes. Some interviewees also mentioned that varying the pairs is useful for transferring tacit knowledge and for avoiding competence accumulation on individuals.

In addition to pair work, there are several post-work checks that are required in work orders or instructions, such as verification by the supervisor, installation check, commissioning inspection and checks by QC department. The interviewees consider such checks useful both in encouraging carefulness and catching errors. In general, these independent verification techniques were welcomed and considered an integral part of work in nuclear plants.

3.1.5 Expected benefits and employee attitudes towards a formal human performance program at plant A

Lastly the interviews discussed how a formal human performance program would benefit the work and what the general attitude of the staff towards it is. The concept of “human performance tool/programme” was new to the interviewees, only one of them clearly understood the concept. When explained to the interviewees, they replied that the program might be useful as one part of continuous improvement of quality and safety. The proposed tools were considered useful as such. However, many interviewees were reserved towards three-way communication and perceived it being unnatural and unnecessary when communicating with persons one knows well on everyday work related themes. Similarly, peer checking was considered as awkward. Some respondents thought it is inappropriate to question colleague’s performance and watch over their work. The interviewees also expressed concerns about the extra resources that using human performance tools systematically might require, especially if the tools would become compulsory across the work tasks and if they are not scaled to the demands of the job. Less complicated or routine work tasks need to have less requirements and thus the tools need to be tailored for the job. In addition, the interviewees brought up additional paperwork, unnecessary meetings and other “non-work related things” as potential downsides of a human performance program. Somebody mentioned a risk of bigger maintenance backlogs since tasks will require more time. Overall the interviewees found that human performance tools should be carefully tailored for the need and they preferred that supervisors would be able to decide how and when to utilise HU tools.

We also inquired whether the interviewees believe that a human performance programme could bring measurable benefits i.e. changes that can be tracked with some of the indicators used for measuring safety and effectiveness of the activities. Most commonly mentioned indicator was rework rate suggesting that they believed that HU tools would help in getting the work right in the first time. Lead time of single tasks, number of near misses and maintenance costs were mentioned as well. Some interviewees were sceptical towards the idea that human performance tools would have such an effect on the way the organisation deals with the technology that they would be able to prevent any reportable events. Partly this was due to their conception that their current practices already serve the same functions and thus a HU programme doesn’t bring any new safety impacts, as the following example shows:

“Q: What kind of pros and cons do you perceive with respect to Human performance programme?

A: Well, we already use many of those, so I don't see negative effects[…] Except if we draft a procedure on these and we don't use them. Then there will be negative effects. [Q: What do you mean?] Then we don't work according to instructions…

Q: You mentioned earlier that pre-job briefs help in executing the work more quickly. Can you think of any other indicator than a lead-time where we could see the effects of a HU programme?

A: No, I don't believe the effects will show.

Q: Do you think the programme would help in reducing rework rate or number of licensee event reports?

A: No."

All and all the interviewees found that it may be difficult to conclude what is the effect of a human performance programme on the performance level measured by organisation level indicators.

3.1.6 Summary and discussion on case study A

Variety of practices that support good quality and error free maintenance had been developed and implemented at the plant A even though they did not have an official HU programme yet. The interviewees didn't seem to consider human errors as a big safety issue at their plant but were able to come up with examples where a job had failed partially due to suboptimal performance of the working group. The organisation had implemented changes in practices both globally and locally when they had identified repeated problems or significant risks in certain jobs. For example there are several practices to ensure that lifting, which were considered one of the most critical work tasks, are performed properly. Similarly isolations were addressed by several work practices.

When we explicitly inquired about human errors the examples given often involved communication issues: misunderstandings or misinterpretations. While there were a lot of informal practices to ensure effective communication, it seems that they are not utilised systematically in practice or that there are error-mechanisms that the current practices aren't quite able to reach. In order to be able to reduce those errors, it would be essential to first analyse what kinds of error mechanisms there actually are (for example what aspects of communication fail) and what functions do the proposed tools serve. In other words one needs to pick a tool which clearly addresses those mechanisms that cause problems in the work, and not implement a tool that merely adds on complexity and which overlaps with already existing and poorly functioning practices.

Currently the function of each of the human performance tools doesn't appear to be particularly well understood. For example three-way communication is generally speaking assumed to reduce communication errors although the protocol merely ensures that the information is repeated. It doesn't, for example, make sure that the information itself is correct or that the receiver understands the contents of the message after repeating it. In the case study A the interviewees were sceptical towards three-way communication and brought up an optional practice: an "interviewing technique" which they subtly use in order to probe whether there are any problems with comprehension. It seems that at least implicitly the interviewees understood that unless the communication is very simple and straight-forward, three-way communication wouldn't be particularly effective way to avoid communication errors because it ignores content errors and comprehension errors. In order to get the buy in from the end users the arguments of the needs and functions for each of the tool needs to be valid.

Other human performance tools also require a closer analysis of their functions as well. For example the way pre-job briefing was used according to this case study suggested that its primary function was to improve explicit (i.e. verbalised) coordination between the workers and to prepare for the job by mentally rehearsing the work task. In addition, a risk analysis might be performed during the pre-job briefing if the work task requires. Assuming these functions are valid, they imply that pre-job briefing wouldn't be a particularly useful tool if the job was very familiar to the workers and if the workers knew each other, because in such case they are already able to coordinate in implicit manner and they already have rehearsed the work by actually doing it before. A formal pre-job briefing might, in this case appear as a nuisance for them. The responses of the interviewees regarding pre-job briefing appear to be consistent with this reasoning since many of them commented that in the case of simple and familiar tasks, extensive pre-job briefings wouldn't be useful. In the case of unfamiliar and complicated tasks, pre-job briefings were considered really valuable.

When evaluating the functions of the different practices and tools, it becomes apparent that not all of them are solely aimed at reducing active human errors or are used primarily with error-prevention in mind. Instead, it seems that most of the practices, including some of those that are similar to human performance tools, are used because they further the work by making it smoother, faster and easier to perform. For example, the interviewees found that the existing pre-job briefing is a practice that ensures the smoothness of work by means of improved coordination and preparation. Post-job review on the other hand contributes to work by means of learning and documenting the work task. This view on the purpose of human performance tools might differ from the original idea which implies that human performance tools would be used to mitigate the effects of active errors (DOE 2009a). Improved safety or decreased amount of errors may emerge as a "side-product" and as an indirect effect of more disciplined activities.

All and all the results suggest that while the supervisors at plant A were fairly positive towards a HU programme the benefits they expected were not usually directly related to reduced plant events but rather to the smooth execution of the work tasks. The connection between nuclear safety, active human errors and the HU tools didn't appear as very clear. The interviewees were concerned about possible negative side effects of some of the tools and thus the implementation phase requires a clear strategy and support from the management. They were very keen on learning from experiences of other organisations about how to select, tailor and implement such tools.

3.2 Case study B

3.2.1 Background and data collection

At the plant B the Human Performance programme started a couple of years ago after a WANO peer review. Plant B includes five tools in their HU programme: pre-job briefings, peer checking, independent verification, clear communication and post-job review. The utilisation of these tools is supported in many ways. A multidisciplinary Human performance working group is responsible for training, developing and following up the utilisation of tools. The tools are often a theme in maintenance and operations department training days, they are described e.g. in a booklet which clarifies the expectations for the workers, and utilisation of HU tools is even one element in the organisations incentive system. Furthermore, in order to foster a systematic utilisation of the HU tools they are incorporated in work planning. The need to use a HU tool is expressed in work orders.

The plant B was interested in gaining an overall picture on how the personnel perceives the tools and which of them are considered as being most beneficial in terms of supporting safety. They also wanted to know in which work tasks do the personnel apply the tools in practice and how do they apply them.

The data was collected mainly during spring 2013. The data consists of 16 interviews; 13 maintenance workers and supervisors and 3 control room operators. A group discussion with the HU working group was organised as well. Furthermore, in fall 2013 three survey questions concerning the benefits of HU tools were addressed to the entire plant organisation including maintenance and operations department. Altogether 465 answers, of which 216 were from operations and maintenance personnel, were received. The questions were: “The HU tools have changed working practices in my work group”, “In my opinion utilisation of HU tools improves safety of the plant XXX”, “In my opinion utilisation of HU tools improves occupational safety at plant XXX”.

3.2.2 Expected benefits of HU tools according to interviews at plant B

According to the documentation at plant B the main purpose of the HU programme was prevention of human errors. The impact of the programme had not been systematically monitored, however. The interviews show that in addition to preventing human errors the HU programme was expected to serve other functions as well. They expected that HU tools enhance smooth, easy and quick execution of work tasks. Many interviewees also mentioned that HU tools are beneficial since they support knowledge sharing concerning the work tasks and promotes organisational learning and development of shared practices and norms. An example of benefits of pre-job briefings was given by a maintenance supervisor:

"It is beneficial to discuss what job it is, why it is done and maybe it is also good for the shop floor worker to know why the valve is there. I have noticed that especially when it comes to the summer employees […who take care of house-keeping tasks] the original attitude is a bit… They don't know, they are just cleaning. But when you tell them why the job is done their attitude changes immediately."

Some interviewees believed that HU tools can improve personnel wellbeing since the HU programme shows that the company cares about them. Quite different opinions were apparent as well: some interviewees felt that the HU programme is a sign that they have not performed well enough, that they have done something wrong. HU programme was sometimes described as a means to discipline and control sloppy individuals. One of the interviewee explained the following:

"It is quite clear that in every workplace where I've been one meets gang of workers [who seems to think that] it doesn't have to be so precise, we can do it like this without isolation and so on. But I believe that when we use these [HU tools] we get rid of that… For example working in pairs; if one is about to cut corners then usually the other one slows it down a bit: no, let's do it according to procedures."

Even the possibility to postpone or to avoid expensive technical improvements was seen as one underlying expectation related to HU tools: the workers can cope with suboptimal technology when HU tools help them to be aware of the risks and to be careful in their actions. It was also pointed out that one of the benefits is that a HU programme is easy to demonstrate to external parties who are reviewing safety.

These multiple and partially conflicting expectations towards HU programmes were linked to safety in the minds of the interviewees. In other words they believed that HU programme affects both occupational and nuclear safety because it helps in preventing errors but also because it helps in making the work smoother and quicker, improves knowledge sharing and facilitates organisational learning, improves wellbeing, and so on. The economic benefits were mentioned as well. Many of the above mentioned factors may affect productivity of the organisation and plant availability.

3.2.3 How did the personnel perceive the application and effects of HU tools at plant B?

Majority of the interviewees had a neutral or relatively positive attitude towards the HU programme. At least they did not see negative safety effects from it. They reported that perceptions are more positive now than during the first years of implementation. The survey results give even a more positive picture of the benefits and acceptance of the HU programme than the interviews. In I & C and electrical maintenance 26 of 36 respondents (72%) were of the opinion that HU tools improve safety of the plant (they responded “agree to some degree”, “agree” or “fully agree” to the statement). In mechanical maintenance the share was even bigger, 30 of the 33 respondents (90%). It has to be mentioned, however, that majority replied “I agree to some degree”.

Both interviews and survey show that mechanical maintenance employees have a more positive view on the HU tools than I & C and electrical maintenance representatives. One reason for this might be that I &C and electrical maintenance respondents did not see the practical effects of HU tools so clearly. 19 of the 36 respondents (52%) disagreed with the statement that “HU tools have changed the working practices in my work group” whereas in mechanical side the share of the negative answers was only 9 out of 33 (27%). In the interviews it was brought up that newcomers are more positive towards the HU tools than the experienced workers. That needs to be studied from the survey in the next phase of the study.

Although the HU tools were perceived in a fairly positive light the way they were implemented was criticised more often. The interviewees repeatedly stated that many of the tools are simple, even self-evident and that they have existed in their working groups for a long time. Therefore, they perceived the English-language concept “Human performance” and the high profile implementation style as artificial. The vocabulary changed but the practiced didn’t change so much. One of the interviewees summarised this as follows:

”I think these are good things, no problem, since they are already in my backbone. The tools were never new, even when the brochure was launched or when they brought this idea into our organisation. These are good and easy practices because we already did use them.”

On the other hand, when human performance tools had been required in some tasks where they had not been previously used it was not always well received. A small share of the interviewees was very critical towards the HU tools. They felt that by implementing this kind of a program the organisation questions their competence and ability to cope with their tasks. They claimed that tools have been implemented in tasks where human errors have never happened and wondered what is the rationale of that:

"…These people who have introduced [the tools] and have done observations in the field… It is obvious that they are implementing HU tools for work tasks they have no knowledge on what so ever. They pay attention to some detail, this needs an HU action. Hello! […] If we analyse the history there has never been a single mistake but a HU person deliberately wants to see a problem there."

Practical challenges in using the tools affected to the overall attitudes towards them. For example, sometimes there was no possibility for peer checking since the work was carried out alone due to resourcing and timing issues. That kind of double standard where the organisation on the other hand requires using human performance tools but on the other hand expects the work to be carried out without the tool was seen detrimental for motivation. The interviewees said that the tools shouldn't be required in all jobs. They mentioned that they are aware that in some countries HU programmes are fairly bureaucratic and tools are used in a rigorous manner. They didn't want their organisation to follow that development since it would conflict with national culture.

Even though HU tools had received a lot of attention in plant B the interviewees considered them to be not too different from other means the organisation uses in order to prevent errors and to ensure good quality of work. Instructions, physical/technical barriers, working together with a more experienced colleague, kick off meetings with the contractors, feedback meetings after outages, using same contractors from year after year, ICT systems such as work order system, safety class training for contractors, quality control, occupational safety card, fitness for duty principles, professional development practices and reflective way of working were mentioned as good practices which contribute to human error prevention. Based on the interviews the personnel emphasised unofficial relationships, trust between the workers and an interest towards each other's work as factors affecting the quality of work. A control room operator described this mechanism:

”Oftentimes a fitter or a supervisor comes here just to talk about things to come, what's up, about life in general, how are you and... I think it is very good and important because all the hesitation to ask something from us vanishes, such as what will happen if we do this or that. Competence of both parties improves when we gain knowledge of each other's work tasks.”

3.2.4 Summary and discussion on the case B

The plant documentation and interviewees described error prevention as the main purpose of HU tools. However, the interviewees did not concentrate on the benefits that error reduction might bring to the plant when they described the expected impacts. The expected benefits mentioned were, for example, quicker and easier execution of work, organisational learning, improved understanding of work tasks, wellbeing and discipline. It is obvious that different tools serve different functions and thus the benefits they bring may vary. Peer checking, independent verification and clear communication were often discussed from error prevention point of view, whereas pre-job briefings and post-job reviews supported improved understanding, organisational learning and smooth execution of activities. Although the official purpose of the HU tools was to prevent simple human errors the interviewees perceived those tools that serve mainly other purposes, i.e. Pre-Job Briefings and Post-Job reviews as most beneficial tools.

Plant B had aimed for a systematic implementation of the HU programme and have succeeded in that in a sense that knowledge of the tools and generic expectations was fairly good. Some clarification especially on the relationship between Peer Checking and Independent Verification is needed, however. The personnel experiences of the tools were, on average, mildly positive. Especially the less experienced workers and mechanical maintenance employees perceived the tools as beneficial for safety. There were less positive judgements as well. The main criticism related to the way the HU tools were promoted in the beginning. The interviewees maintained that HU tools were introduced with fancy titles and as new tools although similar practices were utilised already. On the other hand, some perceived the tools as naïve which, in fact, suggests that they have not used them routinely before the implementation. One theme that became apparent was whether HU tools question the competence of workers. Some interviewees clearly felt that way. This may partly stem from the fact that in plant B the tools were mainly focused for sharp-end workers even though DOE and WANO have defined HU tools for experts and management. The personnel attitude towards the tools has improved recently, however.

3.3 Case study C

3.3.1 Background and data collection

The study was carried out in a Nordic nuclear power plant, during year 2013.[1] The overall purpose of the study was to uncover factors impacting maintenance personnel's use of human performance tools and to understand how to promote successful use of them.

The human performance program at the plant comprised ten HU tools: *Clear Communication Techniques, Independent Verification, Peer Checking, Pre-Job Briefing, Post-Job Review, Procedural Use and Adherence, Questioning Attitude, Self-checking - STAR, Task Observation/Coaching,* and *Use of Operating Experience*. The research question was addressed based on analyses of how maintenance personnel perceived and used the ten tools individually: (1) What was the perceived usefulness of the tool? (2) What factors promoted use of the tool? (3) What factors worked against use of the tool? (4) May the HU tool and/or the way in which it is used be improved? In addition, the study addressed how HU tools should be introduced to maintenance personnel to promote that the tool was used as intended. The concept *intended* signifies that the HU tools should be used *attentively,* with due concern for the purpose they are intended to fulfil: to promote safety. It is used to emphasise that the purpose of a tool is *never* simply to be

[1] A detailed description of the study is presented in Skjerve and Axelsson (*in progress).*

used. For example, *Peer checking*, will only contribute to promote safety, if the *Peer checker* attentively follow the task performance of the *Peer*. If he merely watches the Peer's performance without actively monitoring for errors/unwanted events, the likelihood that Peer Checking will contribute to promote safety is limited. Likewise, situations may arise where the *Peer checker* cannot continuously monitor the task performance of the *Peer* (e.g. because task is carried out with in a room with limited space), the *Peer checker* and the *Peer* have to agree on how Peer Checking should be carried out in this situation to best fulfil the purpose of promoting safety, which requires that way Peer Checking is carried out is adapted to the characteristics of the situation.

Data was collected using interviews and a questionnaire survey. Nine maintenance staff members were interviewed to obtain detailed insights into how they perceived and used the ten HU tools. The interviewees comprised three employees from each of the three maintenance groups at the plant (Instrumentation and Control, Mechanics and Electricity): two maintenance engineers and a maintenance leader.

A questionnaire survey was distributed to all personnel in the maintenance group at the plant, based on recordings in the plant internal maintenance personnell mailgroup (n=337). In all, 216 persons responded to the questionnaire (64%) and of these 81 responded to *all* the mandatory questions (24%). In practice, around 115 respondents answered most or all of the questions (34%). A response rate of 34% falls within the scope of what is usually expected for web-based questionnaire surveys, i.e., 30-40% (Survey Guide, 2010).

Data from the interviews and the respondents' replies to questions with free-text response format in the questionnaire were analysed using a thematic analysis approach (Braun & Clarke 2006). A thematic analysis approach is a qualitative method that makes use of labelling and iterative restructuring of data segments, to identify patterns or themes in a dataset. Respondents' replies to questions in the questionnaire survey with pre-defined response formats were associated themes then are identified.

3.3.2 Expected benefits of applying human performance tools in nuclear power plant maintenance at plant C

A formal human performance programme was introduced in plant C in 2009. It implied that subsets of the current work practices were formalized as HU tools and also the introduction of additional tools. Overall, the HU tools were introduced as a part of the human performance program to reduce the risk for unwanted events and to ensure that the operational tasks would be carried out to the required safety standards. A central goal of the human performance program was to promote correct and systematic use of HU tools, and it comprised a training program on how to use them. Initially, only control-room operators had received basic HU tool training, this by the station operator training programme. By the roll-out of an interactive web-based training (e-learning) in 2010, also maintenance personnel received their first training in how to use HU tools.

The plant executed a simplified calculation to determine the economic impact of the human performance program (Axelsson, 2012, 2013) by relating mean value of annual losses over a period of ten years to human performance issues: The calculation indicated that *annual* cost savings in reduced occupational accidents were about 400.000 € (and mainly related to outage periods with 1000 staff). For the production losses *annual* cost savings were calculated to 3.000.000 €. The total financial investment in the station human performance programme roll-out and basic training during the years 2007-2012 is 500.000 €. Given this, the return on investment was calculated to approximately seven times, for every single year after the initial implementation phase (3.400.000 € ÷ 500.000 € = 6,8). Not included in the case is an actual production loss of 9 months in 2011, almost entirely related to human performance issues and at a cost of 250.000.000 €. Assuming a probability for one such event per 80 reactor year, in a plant of four reactors, increases the annual cost savings with another 12.500.000 €.

3.3.3 How maintenance personnel perceive the application and effects of human performance tools at plant C

The study showed that maintenance personnel at the plant largely held positive views on HU tools: 88% of the respondents considered that HU tools were generally useful and well integrated into their work processes, whereas 5% perceived

HU tools as superfluous “add-ons” to their work processes. 7% of the respondents marked the response alternative, “Other”. About halve of these held positive views on HU tools and half held negative views. More than 74% of the respondents fully or partly agreed in the statement that “HU tools contribute to promote plant safety”.

To obtain further insights into how maintenance personnel perceived HU tools, the questionnaire respondents were also asked to assess how frequently they actually *used* each of the ten tools. The results showed that maintenance personnel used four of them most frequently: *Self-Checking - STAR, Procedures, Questioning Attitude* and *Peer Checking.* Three of the tools were used with lower frequencies than the other tools: *Independent Verification, Task Observation* and *Post-Job Debriefing.*

The respondents were also asked to assess what the effect would be on *plant safety* and *personnel safety* if the ten HU tools were no longer used at the plant. The respondents had three response options: increase safety, same (no impact on safety) and decrease safety. The results showed that the majority of the respondents judged that safety would decrease if the HU tools were no longer used: Plant safety was assessed to decrease by 82% of the respondents and personnel safety was assessed to decrease by 80% of the respondents. The percentage of the respondents that found it would have no effect were 16% and 18%, respectively. Finally 2% of the respondents found that it would increase safety if HU tools were no longer used. The expected negative impacts were not equally distributed: Maintenance personnel assessed that the negative impacts on safety would be most pronounced if *Self-Checking - STAR* and *Pre-Job Briefings* were no longer used, and least pronounced if *Post-Job Debriefing* and *Task Observation* were no longer used.

Data obtained during the interviews with maintenance technicians suggested that *Task Observation* was generally perceived to be the least useful of the ten tools with respect to improving safety - by maintenance personnel, as opposed to by their managers. In some situations, *Task Observation* was even considered by maintenance personnel to increase the risk for unwanted events, because being observed and/or being questioned during task performance could disturb the task performers and reduce their ability to concentrate on their task. For detailed findings in relation to individual HU tools see Skjerve and Axelsson (in progress).

Post-Job Debriefing was most often seen as useful only in situations where a task had not been performed as planned. Since, tasks in most cases were carried out according to plan, this tool was not perceived to be needed very often. Moreover, the interviewees reported that there were challenges related to storing/retrieving lessons learned documented during *Post-Job Debriefings*, and that *Post-Job Debriefing* for this reason contributed less to promoting safety than it could have done.

3.3.4 What characterizes successful human performance tools and implementation processes?

The results provide a set of indications on what characterizes successful HU tools and implementation processes. To be successful a basic prerequisite is that the type of HU tool used should match the situational characteristics. The HU tools can be grouped depending on the extent to which they prescribe human performance. In a situation where potential errors may be predicted with a high degree of certainly, then HU tools with a high level of performance prescription may be the best choice to promote safety. If on the other hand, it is difficult to predict what type of errors and/or risks that may be encountered, then HU tools with a low(er) level of performance prescription may be a better choice.

The ten HU tools used at the plant C can be decomposed into four such groups (Figure 1): The highest level of performance prescription is implied by the group *Promoting adherence to procedures/instructions.* This is followed by the groups *Catching* errors, and *Sharing insights and experiences to promote performance*. The group with the least level of performance prescription is *Sensitizing to unexpected states/events.* The HU tools with the lowest level of performance prescription can be characterised as *mindful safety practices* (Skjerve, 2008). Their function may best be perceived as offering a buffer *functionality* to absorb excessive performance variability, rather as to prevent specific errors.

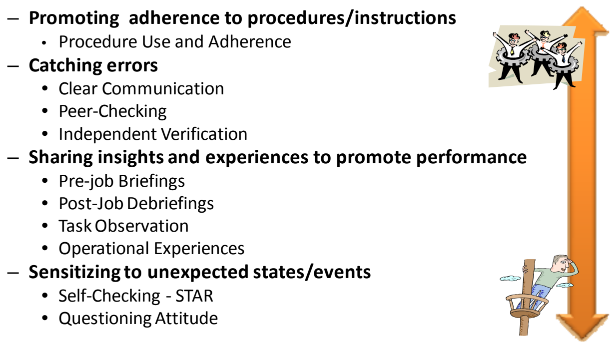

Figure 1. The ten HU tools used at the plant, structured depending on their level of performance prescription (Skjerve and Axelsson, *in progress*).

The results provide a set of indications on issues to attend to when HU tools are introduced in a plant. For current maintenance employees, *introduction of HU tools* may in some cases imply that *new work practices* are introduced, and in other cases rather that existing *work practices* are *formalised*. Introduction of new work practices requires *employees to change their current ways of working.* Even formalisation of existing work practices may imply that work practice adjustments are needed, either because currently applied practices deviate somewhat from practices implied by the HU tools and/or because the HU tools are required to be used in situations, where the particular work practices were never used before. For newcomers, on the other hand, the introduction to HU tools will rather be seen as simply an introduction to *the way work is being carried out in the plant.*

The results indicate that for human performance tools to be used as intended in maintenance work at least three factors need to be in place: maintenance personnel need to (1) be willing to use HU tools, (2) have the ability to use them, and (3) have the possibility for using them. These issues will be discussed separately below.

Willingness to use: HU tools must make sense

For maintenance personnel to be *willing* to use HU tools, use of them must *make sense.* This implies that HU tools must be perceived as *promoting* plant and/or personnel *safety*. If the HU tools (also) promote productivity and other aspects of performance, they may also in some cases be seen as making. During the interviews, maintenance personnel stressed that the most useful HU tools – and thus the HU tools it *made most sense* to use – are the ones that *directly support tasks performance. Pre-Job Briefings* and *Peer Cheeking* were used as examples on such HU tools. *Task Observation*, on the other hand, was pointed out to be the least useful of the ten tools applied at the plant by maintenance personnel, except maintenance leaders (see page 33).

To make sense, it was furthermore seen as important that the HU tools were as *simple as possible*: the HU tools should not be more complicated and/or take longer time to use than what is needed to fulfil their function. This also implies that a certain level of adaptability and/or scalability can be a very useful characteristic of HU tools: Pre-Job Briefings might e.g. be developed in a full or a light version depending on the complexity of the task to be performed.

Another issue concerned the frequency with which individual HU tools were used. Maintenance personnel stressed that tools, which are developed to instil *special alertness* - such as Pre-Job Briefings - should *not* be used routinely: If they are used as a routine, there is a risk that the HU tools will *not* be able to instil the required level of alertness in maintenance personnel, when needed, as one of the interviewees stated: *"If you use a human performance tool as a routine, then the feeling that it is an important task disappears. It becomes part of the everyday work. It just becomes something you have to do, you do not reflect deeply about it. In my opinion that is not the purpose of such tools."*

Finally, maintenance personnel emphasised that HU tools should never be used simply *for the sake of using them,* e.g. because bonus will be impacted by the number of times they have been applied. If a tool (e.g., *Task Observation* or *Pre-Job Briefing*) is required to be used (mainly) to achieve bonuses or to ensure the company's reputation, there is a risk that maintenance personnel may be frustrated, i.e., feel that they are wasting precious time on using a HU tool, which in the situation is not necessary to promote safety.

It is important that maintenance personnel understand ***how*** HU tools should be used. The interviews revealed a fair level of uncertainty among the maintenance personnel with respect to how some of the tools were intended to work. *Peer*

Checking was one such example. Some interviewees described Peer Checking rather as equal to a *Reader-Doer* way of working: one colleague in a pair would read the instructions, while the other colleague should perform the required actions. Other interviewees described that *Peer Checking* in some situations could be rather like *Independent Verification*.

Maintenance personnel again and again stressed that it was important to understand that HU tools should *not* be used *blindly*. For example: Even in a situation, where maintenance personnel were requested to adhere to procedures, they should always be aware that it might be necessary to adapt the procedures, depending on the situational characteristics.

Maintenance personnel further emphasised the importance of understanding ***when*** to use HU tools. The interviews revealed that some maintenance employees were uncertain with respect to when e.g. *Clear Communication Techniques* (i.e., Three-way-communication and using phonetic alphabet) should be used: Should this HU tool in principle always be used when communicating with a colleague during task performance? Or should it only be used when critical steps are performed?

Finally, maintenance personnel underlined the need to know ***why*** the HU tools are used, e.g., what function should the various tools should fulfil. This was seen as necessary to allow successful adaptation of the various HU tools to situational requirements. An example is the purpose of *Independent Verification* versus *Peer-Checking.* The former is an independent verification, e.g., of safety plant alignment prior reactor start-up (latent error), while the latter is aimed at avoiding mistakes which have the potential to cause a direct event or transient (active errors). Maintenance personnel that had not clear understanding of this would sometimes use modified versions of peer-checking to fulfil their current understanding of safety measures.

Possibility to use: Organizational Support

The study revealed a set of factors that could impact the possibility – in some situations rather the *perceived* possibility – for maintenance personnel to use HU tools as *intended.* These included: Availability of tools, availability of time, and group climate with respect to the use of HU tools.

Maintenance personnel stated that they sometimes lacked adequate support to use HU tools. This was exemplified with reference to the tool *Use of Operational Experiences*: At the plant operational experiences are stored in a database. However, maintenance personnel reported that they lacked good tools to searching through the database. The implication was that specific operational experiences of relevance to a current task were not always identified. Also, the plant provides general operating experience feedback in the format of *Just-In-Time briefs*. These are not used in Pre-Job Briefings as intended, but the reasons for this were not identified.

Availability of time was also reported to be a factor that might impact (the perceived) possibility of maintenance personnel to use HU tools: If the task load was high and time limited and/or if the leader's focus was (perceived to be) on keeping up with a particular time schedule (e.g. during outages), the threshold for taking initiative to use HU tools, such as *Questioning Attitude,* could be higher than usual. The questionnaire survey showed that time pressure was the factor most frequently found to work against the use of HU tools at the plant.

Group climate was another factor that was reported to impact the possibility for using HU tools. A subset of the tools involve that one colleague may identify errors in another colleague's performance, such as *Peer Checking* and *Questioning Attitude*. Some maintenance employees found that use of such HU tools could be challenging. A maintenance employee reported that if mutual respect/trust lacked between the two colleagues using *Peer Checking* could be demanding for both parties: The *Peer* could feel that the *Peer checker* mistrusted his/her ability to carry out the tasks properly and/or fear that the *Peer checker* would misuse the situation, as an opportunity to criticize him/her, e.g. by pointing out "insignificant errors". A questionnaire respondent wrote that, "...*feedback following Peer Checking can be perceived as rebuke and supervision, if it is provided in the wrong way*." From the perspective of *Peer checker*, it can be difficult to point out errors, if the *Peer* "*takes the feedback in the wrong way",* as a questionnaire respondent wrote. It can also be difficult for a less experienced employee to provide feedback to a highly experienced employee, e.g., in situations where the highly experienced employee have adapted work practices that may not be optimal (e.g. routinely are using some short cuts), etc. A questionnaire respondent reported that he felt uncomfortable, when errors he had committed was presented to and discussed within his group - even if this was done to share the insights gained from his mistake. If such feelings become pronounced in a group of maintenance employees, the likelihood that such HU tools will be used as intended, i.e. here: to learn from mistakes, may thus be reduced.

3.3.5 Summary and discussion on case study C

The study was carried out in a Nordic nuclear power plant, which applied ten HU tools. The overall research question was: What factors impacts maintenance personnel's use of HU tools in this plant to understand how to promote the use of them. Data were collected based on interviews and a questionnaire survey, and analysed using a thematic analysis approach (Braun and Clarke 2006).

The expected benefits of introducing HU tools in the plant were to overcome a set of unwanted repeat events and to reduce the risk for unwanted events in the future. The calculation indicated that *annual* cost savings in reduced *occupational accidents* were about 400.000 € (and mainly related to outage periods with 1000 staff). For the *production losses annual* cost savings were calculated to 3.000.000 €.

Overall, maintenance personnel had positive opinions about the use and effects of HU tools: 88% of the respondents found that the tools were generally useful and well integrated into their work processes and 82% assessed that plant safety would decrease, if HU tools were no longer used.

The study provided insights into factors that may promote successful implementation and use of HU tools. It was found that to use HU tools the tools must *make sense* to the maintenance personnel: they must promote safety, be as simple as possible and preferably flexible/scalable be required only when needed and not for other than safety reasons. Further, the maintenance personnel must have the *ability* to use the HU tools: they must know *how, when and why* to use the tools. Finally, maintenance personnel must have the *possibility* for using the tools: they must have available adequate tools and time, and the group climate must promote the use of HU tools.

The study involved only a subset of maintenance personnel at the plant. The outcomes of the interviews and the questionnaire survey correlate. However, different results might have been found if *all* maintenance personnel at the plant had participated in the study.

3.4 The international survey

3.4.1 Background and data collection

The survey questionnaire web link was sent to 1060 individuals who had participated in various human performance seminars and networks. We used mailing lists of those forums to reach experts from different countries. We did not aim to reach all the utilities around the world, rather we hoped for getting couple of dozens of answers to complement our primary data of three Nordic plants. We instructed the receivers to skip or redirect the survey if they are not involved with nuclear industry and HU programmes.

The survey received 135 responses from at least 47 organisations (many of the respondents did not indicate where they came from) in at least 13 different countries (56 % of the respondents mentioned their country). Those responses came from USA (35), Canada (10), United Kingdom (9), Sweden (6), France (3), Belgium (2), Germany (2), Slovenia (2), Spain (2), Finland (1), Hungary (1), Republic of Korea (1), Switzerland (1), and "International" (1). This comprises mainly North America and Europe with their associated regional and cultural aspects. Examples of countries not present in the results are Brazil, China, India, Japan, Pakistan and Russia.

The majority of the respondents worked at nuclear power plants (50), some at corporate fleet level and a few at nuclear service companies. The respondents included for example Human Performance Leads and Managers, Industrial Safety & Nuclear Safety Engineers, Supervisors and Managers in QA, Project and Training.

Of the 135 responses, 92 stated they were applying HU tools in a formal way. Of these 92 responses, 48 % had used HU tools formally for more than 10 years, 16 % for 8-10 years and 23 % for 5-7 years. Only 2 respondents stated less than one year. Only three respondents reported that they do not utilise HU tools in a formal manner in their organisation.

3.4.2 Expected benefits of utilising HU tools

The survey included a question: *What do you see as the main purpose of introducing Human Performance Tools in maintenance work?* The dominant purposes amongst the respondents are expressed in terms of "reducing errors" and "to prevent events". Big share of the answers pointed out a profound purpose, such as safety (nuclear or occupational) or business performance. Following categories represents the respondents' typical views on purposes for introducing HU tools (order by representation):

- Reducing errors
- Prevent events
- Support safety
- Minimize rework
- Improve equipment performance
- Improve business performance

Those categories can be bundled into a joint view of an overall purpose of HU tools as a support to safety and business performance via reliable human actions. As one of the respondent wrote: *"By reducing the number of errors, both on the job and off the job, our organization is less prone to safety incidents and more productive".*

Many associated error reduction with plant or occupational safety but the overall reliability and efficiency was a recurrent theme as well. It seems that reduced rework and thus saved time and resources is one of the frequently expected benefits: *"To achieve error free performance. This reduces re-work, component failures, and improves efficiency and customer satisfaction."*

The responses reflect the view represented in the international documentation (e.g. DOE 2009a, 2009b, WANO 2006). This set of answers does not necessarily reveal how big a share of the respondents have adopted the arguments that have been used in connection to human performance tools, such as, that humans are fallible and thus make errors which contribute to events, although some answers pointed directly to this argumentation: *“Prevent humans from doing 'human' things like misperception, memory lapse, habitual behaviour, etc.”*. It is obvious that HU tools have been promoted in those terms and maybe this is why in the spontaneous answers “error reduction” is the most common statement.

In order to study more concretely what kinds of benefits the respondents expected we asked: *In your opinion, what are the benefits of Human performance program/system in nuclear power plants in general?* The responses were more descriptive than those given earlier and the connections between error reduction and other benefits were explained more thoroughly.

In general the respondents refer, again, to reducing errors, but explained its significance in many ways. For example: *“Human Performance and Safety are dependent on each other. If you select the right human performance tool, your performance is as expected. If you make a mistake, such as not installing a gasket correctly; the component is subject to failure (maybe when the component is required such as during an emergency). IF the component fails because of human error during maintenance, it could result in a radiological or nuclear hazard.”*

Another respondent listed benefits which are not directly phrased in terms of events and plant safety: *“In the end; we have less rework, less accumulated dose and less issues with the regulator due to procedures being followed.”*

Some respondents indicated how error reduction has realized due to the human performance programme: *“For the company, the human error rate is divided by 4”.*

Another comment described the realized benefits: *“With the formal introduction of HU tools the Industrial Safety Accident Rate decreased significantly and Capacity Factor increased significantly”*

The notion that the benefits are dependent on the success of the implementation was brought up in couple of answers. One respondent analysed it the following way: "*If the Human Performance Programme follows a blueprint, everyone applies the same rigour to error reduction and it becomes part of normal business, it is then a vital ingredient. If it sits outside normal business as a never ending initiative then it can become dependent upon management knowledge, ability, preference and in some cases feel like a nice to have".*

3.4.3 Experienced downsides of using HU tools

To a question *"What disadvantages, if any, have you observed after formally introducing Human Performance Tools in maintenance work?"* the respondents brought up mainly two disadvantages; that HU tools are considered *time consuming*, and at times there is more focus on performing HU tools correctly than on *the task itself*. Also feelings of blame towards shop floor workers were mentioned.

Many respondents emphasised that management, as well as those who plan the implementation of the HU tools, need to recognise that using the tools changes pace of work. The following responses to the question of disadvantages summarise this message:

"Decrease in Production - it takes time to use human performance tools. However, there needs to be the right balance between Protection (use of human performance tools) and Production. The key is obtaining the right balance."

"The only [disadvantage] one that I have seen, which is easily overridden by safety is the time it takes to complete a given task. It takes 2-3 times longer to complete a task, and in the non-regulated market that can hurt the bottom line. Streamlining the PM processes and performing the right PMs at the right frequencies can help alleviate the effects."

The second cluster of disadvantages related to losing focus and employee self-initiative due to excessive emphasis on the correct application of the tools. This challenge is exemplified in the following responses:

"Too much focus on tools leading to a lack of understanding of the task."

"The use of tools does not guarantee fail safe operation. The people have to know, how to use the tools correctly. Over reliance on the tools might cause problems. The main tool is always "Use Your Brain".

“People tend to think like robots and stop when faced with an obstacles stop in their tracks and wait for someone else to solve the problem”.

However, some respondents have also made observations on how these drawbacks have transformed by familiarization of the tools. Some say on the issue of reduced work effectiveness that it is a consequence or perception that did go away after hands-on training, e.g. people found that Pre-Job-Briefing provided a clearer understanding of work scope, thus less risk for events or rework.

A graded approach, as mentioned by one respondent, may serve as more effective usage of HU tools: *“A tendency to try and focus on ALL the tools ALL the time – result is losing focus on the important tools that will ensure THIS job is executed correctly THIS time”*

The survey responses indicated that when HU tools are properly learned and trained, made a practise and embedded, they get understood and there are less confusion and time losses. This is an important aspect for the forthcomings of this study.

3.4.4 Factors which support successful implementation of human performance tools

The respondents were asked to rate a pre-selected set of key factors according to their importance for successful implementation of human performance tools. Table 2 shows that management support was prioritized high by nearly all the respondents. Interestingly external pressure (WANO, IAEA etc.) was perceived as two folded thing; many ranked it to be very important but nearly as many the least important factor of those presented here.

Table 2. Key factors of successful implementation of HU tools ranked according to their importance by the international survey respondents (1 most important, 12 least important). The figure in each cell represents the number of observations.

	Rankings											
Response	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Management support	31	21	7	3	3	3	3	4	0	0	1	0
Manager's observation and coaching	8	7	10	7	10	4	11	2	4	7	4	1
Workshops	1	2	1	4	6	1	11	11	9	13	7	9
Workers perceive HU tools sensible and reasonable	2	4	9	11	6	6	3	4	9	11	9	1
Shared values and practises	3	7	7	6	5	11	9	5	6	6	6	4
Regulator expectations	5	8	1	3	4	3	2	7	2	8	8	24
External pressure (INPO, WANO, OSART/IAEA)	14	2	5	3	3	3	3	6	7	4	13	11
Integration with Operator simulator training	0	2	1	13	3	10	2	8	10	5	8	13
Human Performance training programme	2	9	10	9	14	9	6	5	7	3	0	1
Dynamic Learning Activities (hands-on training)	1	2	7	4	7	14	10	8	9	6	5	2
Lessons learned from events	6	6	11	6	8	5	10	9	4	4	5	1
Human Performance Manager/co-ordinator	3	5	6	6	6	6	5	5	8	8	9	8

4. Discussion

4.1 What are the expected benefits of human performance tools applied in nuclear power plant maintenance?

The search for an answer to the research question *“What are the expected benefits of human performance tools”* led us to an interesting finding concerning the *purpose* of the human performance programmes: Although the espoused goal of the human performance programme typically is human error prevention HU tools were perceived to serve also a range of different purposes that are not necessarily directly associated with preventing *events* which are caused by human errors. In the interviews the expected benefits were often discussed in terms of smooth execution of the work with good quality, and thus, less rework. Further, indirect benefits such as sharing of knowledge, organisational learning and fostering a rigorous culture were emphasised as often. Similar comments can be found from the international survey. The finding was even more pronounced at the Nordic plant A where the personnel had not undergone human performance training. There the maintenance personnel and managers did not perceive classical active human errors to be a very big issue for them. Rather, they talked about poor coordination between workgroups and lack of preparation before going to the field, misunderstandings in communication situations, misinterpreting the instructions as factors affecting the *quality and smoothness* of the execution of the work.

At all the Nordic plants Pre-Job Briefing was perceived the most useful of the tools and its benefits were associated to coordination and preparation for complex and unfamiliar work tasks. Sometimes poor coordination may result in a clear human error in sense that the worker’s action results in an unwanted outcome e.g. malfunction of the machinery he/she is working on. However, often the consequence is that the work task takes longer time and is less coordinated and systematic, and thus costs more and is frustrating. The interviewees seem to consider these as important issues to get rid of.

However, based on the interviews in the Nordic plants B and C and the international survey it can be concluded that HU tools are associated with prevention of unwanted events caused by human errors. In maintenance HU tools are mainly intended to be used by employees working in the sharp end. The tools are believed to ensure that the operational tasks are carried out “right the first time” or according to required safety standards. The manner in which HU tools aim reducing human errors can take different forms, depending on the specific tool applied (see figure 1, page 35), e.g. guiding performance, catching active errors, sharing experiences, and increasing awareness to help identify errors/deviations. The function of each tool seems to be implicit for the users. They have not paid too much attention in thinking what kind of errors and problems each of the tools really help in avoiding.

What is the overall relationship between the tools and safety then? The results show that the respondents believe the HU tools bring mostly positive safety impacts. Some mentioned that the tools can help in catching such active errors that would at once cause a significant safety event. However, it can be stated that the nuclear/plant safety impacts were not usually described in a concrete manner. It was easier to give specific examples on occupational safety impacts, i.e. examples of cases where some of the tools had prevented an occupational incident or accident. It seems that the positive association between the HU tools and nuclear safety is strongly based on an idea that the more systematic, harmonious and rigorous working practices reduce the possibility of ending up in unexpected - and thus error-prone - work situations and latent technical flaws due to slips or lapses.

Based on the above mentioned findings there seems to be an underlying idea that reducing variability of performance is good for safety. While it is understandable that nuclear industry organisations aim to increase predictability of the performance it is also important to bear in mind that many current safety scientists claim that variability is a necessity to maintain safety of complex systems (Hollnagel 2009, Dekker 2011) and that organisations should be careful not to dampen that kind of variability of human performance that allows them to identify and respond to unexpected situations in an innovative way. The different HU tools differ in this aspect. Some of them, such as Three-Way Communication, prescribe the expected action and thus clearly aim at reducing variability. Others, such as STAR, Questioning Attitude or Pre-Job Briefing aim at increasing sensitivity to the situation and give more room for various responses from the actor.

From safety management theory point of view it also appears that human performance programmes embed an underlying idea of redundancy or multiple layers of barriers as a critical organisational safety mechanism. A large emphasis on redundancy as a safety mechanism can be traced to a tendency of linear thinking in safety management which has been criticised by organisation scientists (Reiman & Rollenhagen 2011). One of the risks of linear thinking and overemphasis of redundant means to prevent harm from actualising is that the interaction of the added practices and requirements creates more complexity and contributes to the system's opaqueness – which is often not taken into account (Dekker 2011; Perrow 1999). The international survey gave insights into this problem as many respondents view the negative aspects of HU tools relating to HU tools taking so much time that it affects the production, misdirecting the focus from the substance of the work and encouraging people to "not think for themselves".

4.2 How do maintenance personnel perceive the application and effects of human performance tools?

Corporate culture as well as national culture most likely affect the personnel attitude towards safety management approaches and workplace development (see e.g. Kim & McLean 2014). In Nordic countries corporate culture can be characterised as democratic in a sense that power distance is low (there is little hierarchy and employees are independent), employees participate in decision making concerning organisational development, and especially in Sweden, managers strive for consensus with their subordinates rather than use their formal power (Hofstede et al. 2001; Grenness 2003). In this kind of cultural environment safety management approaches which set straightforward controls and behavioural expectations to individuals' ways of conducting their everyday work are not necessarily easy to implement. Human performance programmes with tools that define how one should talk (Phonetic Alphabets and Three-Way communication) or tools that involve close supervision of behaviours and actions (Peer Checking, Task Observations) may seem alien to Nordic work cultures. There are also differences between Finnish and Swedish culture and management. Finnish managers are described as being more production and task-oriented whereas Swedes are more human oriented, “feminine” in Hofstede’s terms (Lämsä 2010; Hofstede 2001). Lämsä (ibid) claims that: *“one of the special features of Finnish management is impatience. Solving problems and handling in the chaotic circumstances is normal for the Finns. Often the task will begin although exact plans have not yet been fully performed”.* Taken this as starting point one might assume that the perceived need for the HU tools could be smaller in Finnish organisations.

Nevertheless, the maintenance personnel at all the Nordic plants held fairly positive views on the human performance tools. Many of the work practices implied by the HU tools had already been applied in the plants for several years (plant B and C) prior to the introduction. In plant A, many of the same practices were used, even if they were not formalized as HU tools. It thus seems that many of the practices implied by the HU tools had passed the test of time and had been assessed as useful already prior to being introduced as HU tools. In plant B, the majority of maintenance personnel in I &C and electrical maintenance, as well as in mechanical maintenance agreed that HU tools improve plant safety, i.e., 72% and 90% of the respondents, respectively. In plant C, more than 74% of the questionnaire respondents fully or partly agreed in the statement that “HU tools contribute to promote plant safety”. Further, 88% of the questionnaire respondents at plant C found that HU tools were generally useful and well integrated into their work processes.

One of the factors likely affecting the positive attitude towards the HU tools is the change of worker generation that has been ongoing for the couple of years at the Nordic plants. The newcomers were more positive towards the tools. Partially that may reflect the generic change among the younger generation in attitudes towards safety or “soft issues” such a human errors. However, the interview results imply that the newcomers’ positive perception of the tools relates to their need to develop a nuclear industry identity: the newcomers perceive the HU tools as concrete means to communicate the organisation’s expectations on how work shall be done here and how the newcomers can demonstrate that they are good workers. Thus, they are happy that there is such programme that helps them in understanding and adopting the behaviours and mindset expected in the industry.

The studies indicate that characteristics of the organisational culture may markedly impact the attitudes towards the HU tools and their use. For example, if keeping schedules is emphasised strongly in the culture personnel might be more restrictive in their use of HU tools to save time (e.g. increase their threshold for using Questioning Attitude). Overall, the use of the tools does take time, for example, sometimes maintenance personnel have to wait for the control-room operators to take part in Pre-Job Briefings for long periods of time. Time pressure – perceived or real – was reported to be a factor that negatively impacts the use of HU tools.

Also, when the use of the tools were perceived to be required for instrumental reasons – e.g. to achieve bonuses – the thoroughness of the use suffers. Unless using the HU tools *make sense* (see page 35), it cannot be assumed that they will be used as intended. Furthermore, issues related to feeling shameful and the fear of being blamed for errors, also work against the use of HU tools. The results indicate that formalising the human performance tools may either increase or decrease the feelings of shame and blame, it depends on existing culture and the implementation process. Essentially, the organizational culture may influence the ways HU tools are used in practice and thus the culture influences whether the tools promote safety or not. It could be that this impact is stronger than the impact of the particular tools applied.

4.3 What characterizes successful human performance tools and implementation processes?

The Nordic case organisations shared some challenges concerning HU tools implementation strategy and style. One of the shared questions related to the extent of the use of HU tools: whether they should be required in all work tasks in maintenance or only in selected ones. Similarly the organisations wondered whether it is good to tailor the tools or should they be kept identical across the organisation. In plants B and C the implementation strategy was criticized as being unclear in these aspects especially in the beginning of the human performance programme. The personnel opinion was clear: there is no point in requiring the tools to be used in a same way in all tasks. The maintenance personnel called for scalability of the tools, i.e. possibility to use some parts of them, or to use a lighter version of them when the work task is routine, non-risky and involves few individuals. The interviewees claimed, e.g. that conducting full scale Pre-Job Briefings and Post-Job Debriefs in all tasks take so much time and bring so little benefits that the resistance towards the tools would be inevitable.

If the tools are used only in selected jobs and tailored for the situational need the obvious question is who decides when the tools shall be used and how. Since the number and range of maintenance tasks is so huge it is impossible to come up with a generic list of tasks and HU tools required in them. Thus, it seems that in most cases the decision for selecting an appropriate HU tool needs to be on a supervisor or worker level. This is an interesting conclusion taken the underlying assumptions of the human performance programmes into account: can we trust the fallible and sometimes even sloppy individuals to make accurate judgement of the complexity and riskiness of the tasks, and thus a decision to utilise and tailor the tools in a good way? Or is it so that those workers that are careful and disciplined to start with are more willing to implement them thoroughly also in the future, and those who are less careful and thorough will judge more often that no tools are needed? All and all, the results suggest that management should take a clear stance on the HU tools strategy and support the supervisors in how to encourage the use of the tools and how to intervene if they are not used as agreed upon.

Our studies show that the fact that many of the tools have been used before a formal human performance programme was launched involved both pros and cons during the implementation phase. The interviewees perceived that some of the tools and their benefits are self-evident and they are an integral part of professionalism. When this is the case, one would expect that formalising such practices goes smoothly. Sometimes that was the case. However, there was criticism related to integrating familiar working practices in the human performance programmes. Many interviewees questioned the need to give new names to the practices and the need to label them as human performance tools. They argued that their organisation went for a human performance programme for external pressures, or that their management was unknowledgeable about the fact that they were already applying these practices.

All and all the maintenance personnel perceive many of the tools as normal maintenance working practices rather than specific "science based human factors methods to reduce errors" and we agree on their perception. This implies that implementation of HU tools or a human performance programme should be integrated in the process of continual improvement of working practices, work processes and competencies. However, the HU tools are promoted with a specific vocabulary: the practices are called tools and their rationale is argued with human error cases and statistics. Throughout the study we have asked ourselves why is this the case. The companies and their personnel actually associate many other benefits than error reduction to the HU tools. Could those be used as arguments rather than human error reduction, especially if the safety science community emphasises that it is more beneficial to focus on system level development rather than on individual level human errors? Furthermore, if the concept of human performance tools is perceived somewhat artificial (at least in non-English speaking organisations) and not necessarily fostering the implementation of the practices there are good arguments in changing the implementation strategy. On the other hand, it may be that safety experts or management have identified "a human error problem" and they want methods first and foremost for error management. In the case of the three Nordic plants they all had identified some repeat issues in performance of the organisation/workers when they engaged into the human performance programmes. However, none of them had, to our knowledge, assessed in detail what kind of errors they face and what kind of error reduction techniques could be beneficial. The nuclear industry peer pressure for HU tools affected their decision to implement the tools.

Based on the preliminary analyses of data obtained in plant C – which is supported by the data obtained from plant A and B - a set of issues to attend to when organising for introductory and/or training sessions directed at the use of HU tools can be identified. The basic underlying assumption is that the session(s) should be directed at practice and practical gains as much as possible: The issues are listed below in no particular order (Skjerve & Axelsson, *in progress)*

- The introduction should demonstrate how the HU tool should be used, when it should be used, as well as why it should be used: what function should the HU tool fulfil. Instructors might e.g. demonstrate how the HU tool should be used using role play in the classroom, and then show a video of how the HU tool can be used in a practical setting

- The program should demonstrate the benefits of using the HU tools. This is a very important characteristic of a program. It may be done, e.g., by referring to incidents that have been prevented to evolve into events because the HU tool was used, if there is such analysis available.
- Maintenance personnel should have the opportunity for practicing use of the HU tool.
- If "additional competencies", i.e. competencies that the maintenance personnel might not currently possess, are needed to use the HU tools, skill training should be provided. This may amount to tips on how to give and receive feedback in a Peer Checking situation, etc.
- Maintenance personnel should be encouraged to reflect on and have a dialogue with colleagues about how the HU tools make sense in the context of their own work.

5. Conclusions

The first phase of the study focused on the expected and experienced benefits – and disadvantages – of HU tools in three Nordic nuclear power plant maintenance organisations. The results are based on personnel and maintenance management perceptions on the matter. Further, a preliminary analysis of same themes in the international survey amongst human performance experts in nuclear domain was carried out as well.

The results show that there are big expectations towards Human Performance Programmes and the HU tools in the power companies. The espoused goal of a Human Performance Programme seems to be reduced number of nuclear safety events through prevention of human errors. Not all the respondents of the Nordic studies or the international survey shared that view completely. Many emphasised that the likely benefits relate to generic quality and smoothness of the work and show in indicators such as rework or occupational injury rate. It is obvious that the tools serve different functions; some of them more directly aim at preventing or catching human errors and some have more indirect connection to errors, and thus their benefits are often viewed in different light.

The employees in the Nordic plants perceived the HU tools in a fairly positive light. Some critical opinions and concerns towards the Human Performance Programmes were expressed in the Nordic sample as well as in the international survey. In most cases the criticism focused on the implementation strategy and style rather than to the tools themselves. The results partially resonate with the concerns expressed by some scientists towards error and behaviour focused safety management approaches. There is a risk that the employee attention focuses too much on the tools instead of the task itself and the self-initiative suffer. Also some indications of feeling blamed for errors were reported.

In 2014 the HUMAX project continues. The analysis of the international survey will be completed and the Nordic case study results are combined and compared with the international survey findings. The project focuses on following questions:

- What have the measurable benefits of human performance tools been so far in the plants (e.g. reduced number of failures, reportable licensee event reports, human errors)?

- What characterizes successful human performance tools and implementation processes?

- What aspects of maintenance work are most effectively met by use of human performance tools, and what could be solved by other socio-technical means?

The aim is to provide guidance to the power companies for selecting HU tools and other means to improve human performance. Further, the aim is to gain understanding on how the existing organisational and national culture should be taken into account when implementing and promoting Human Performance Tools.

References

Addison, R.g. & Haig, C. (2006). The performance architect's essential guide to the performance technology landscape. In Pershing, J.A. (eds.). Handbook of human performance technology. Principals, practices and potential. 3rd edition. San Francisco: Pfeiffer.

Anderson, M. (2007). Behavioural safety and major accident hazards: Magic bullet or shot in the dark? Health and Safety Executive. (retrieved 10.10.2012).

Axelsson, C., (2012). NPP Business Improvement Plan 2012-2014 - HP-tools - Human Performance Safe Performance. Plant C.

Axelsson, C. (2013). Nuclear Oversight - HuP-strategy for safe and reliable operation. Fundament for business decision on HuP Strategy. Plant C.

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

Bourrier, M. (1996). Organizing Maintenance Work At Two American Nuclear Power Plants. Journal of Contingencies and Crisis Management, 4, 104–112.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2): 77-101

Cox, S., Jones, B. & Rycraft (2004). Behavioural approaches to safety management within UK reactor plants, Safety Science, 42, 825–839.

Dekker, S. (2011). The complexity of failure: Implications of complexity theory for safety investigations. Safety Science, 49, 939–945.

DOE (2009a). Human performance improvement handbook. Volume 1: concepts and principles. DOE Standards. Washington, D.C.: U.S. Department of energy.

DOE, (2009b). Human performance improvement handbook, DOE-HDBK-1028-2009. (Vol. 2: Human performance tools for individuals, work teams, and management). Department of Energy Washington, DC: Government Printing Office.

Gotcheva, N., Macchi, L., Oedewald, P., Eitrheim, M. H. R., Axelsson, C., Reiman T., Pietikäinen E., et al (2013). Final report of MoReMO 2011-2012. Modelling Resilience for Maintenance and Outage. NKS-279.

Grenness, T. (2003). Scandinavian managers on Scandinavian management. International Journal of Value-Based Management, 16, 9–21.

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

Hofstede, G. (2001). Culture’s consequences: Comparing values, behaviors, institutions, and organizations across nations. London, England: Sage.

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

Hopkins, A. (2006). What are we to make of safe behaviour programs?. Safety Science, 44, 583–597.

IAEA (2001). A systematic approach to human performance improvement in nuclear power plants: Training solutions. IAEA-TECDOC-1204. Vienna : International Atomic Energy Agency.

IAEA (2005). Human performance improvement in organizations: Potential application for the nuclear industry. IAEA-TECDOC-1479. Vienna : International Atomic Energy Agency.

INPO (1997). "Excellence in Human Performance". INPO training manual.

INPO (2006). Human performance reference manual. INPO 06-003.

Kim, S. & McLean, G. (2014). The impact of national culture on informal learning in the workplace. Adult Education Quarterly, 64. 39–59.

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

Le Coze, JC. (2008). BP Texas City accident: weak signals or sheer power? In Proceedings of the third symposium on Resilience Engineering, 2008.

Lämsä, T. (2010). Leadership styles and decision-making in Finnish and Swedish organizations. Review of International Comparative Management, 11, 139-149.

Oedewald, P. et al. (2012). Intermediate report of MOREMO: Modelling Resilience for Maintenance and outages. NKS-262report. Available at: http://www.nks.org/download/nks262_e.pdf .

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

Perrow, C. (1999). Organising to reduce the vulnerabilities or complexity. Journal of contingencies and crisis management, 7, 150-155.

Pershing, J.A. (eds.) (2006). Handbook of human performance technology. Princi-pals, practices and potential. 3rd edition. San Francisco: Pfeiffer.

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

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

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

Reiman, T. & Rollenhagen, C. (2011). Human and organizational biases affecting the management of safety. Reliability engineering and system safety, 96, 1263–1274.

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

Skjerve, A.B. (2008). The Use of Mindful Safety Practices at Norwegian Petroleum Installations. Safety Science, 46, 1002–1015.

Skjerve, A.B., Axelsson, C. (in progress). Towards an understanding of the Use of Human-Performance Tools in Maintenance Work as seen from the Perspective of Maintenance personnel – a Case Study on a Swedish Nuclear Power Plant.

Snook, S. (2000). Friendly fire. The Accidental Shootdown of U.S. Black Hawks over Northern Iraq. Princeton, NJ Princeton University Press.

Survey Guide (2010). Survey fundamentals. A guide to designing and implementing surveys. Version 2.0, December 2010: University of Wisconsin-Madison. University of Wisconsin System Board of Regents.

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

WANO (2002). Guideline 2002-02, Principles for Excellence in Human Performance.

WANO (2006). Guideline 2006-03, Guidelines for Effective Nuclear Supervisor Performance.

Title	The expected and experienced benefits of Human performance tools in nuclear power plant maintenance activities - Intermediate report of HUMAX project
Author(s)	Pia Oedewald[a], Ann Britt Skjerve[b], Christer Axelsson[c], Kaupo Viitanen[a], Elina Pietikäinen[a], Teemu Reiman[a]
Affiliation(s)	[a] VTT, [b] IFE, [c] Vattenfall
ISBN	978-87-7893-376-8
Date	February 2014
Project	NKS-R / HUMAX
No. of pages	56
No. of tables	2
No. of illustrations	1
No. of references	41

Abstract

In recent years most Nordic nuclear power plants have implemented so called human performance programmes. The programmes typically apply predefined *human performance tools (HU tools)* to maximize failure free operations by preventing human errors. Despite the prominence of human performance programmes, there is little research on the basic premises behind them and the concrete beneficial effects from using HU tools remain elusive. This document describes the intermediate results of a Nordic research project HUMAX which aims at providing knowledge of the impacts of the human performance programmes and to support the designing and implementing effective HU tools. The focus is on maintenance activities.

In 2013 HUMAX project carried out three case studies in Nordic NPP maintenance organisations and studied the expected and experienced benefits of HU tools. Furthermore HUMAX disseminated an international survey to human performance experts around the world to gain more insight into the motives, benefits and disadvantages of the programmes. The study is ongoing and the results presented in this report are preliminary.

The results show that often the espoused goal of a human performance programme is to prevent *events* by reducing errors. However, the interviews indicate that maintenance personnel associate many other benefits to the HU tools than reduced number of events. Smooth execution of work tasks, less rework and smaller occupational injury risk were often mentioned as practical benefits. The benefits also included indirect safety improvements: more rigorous work practices and shared knowledge on work tasks and risks.

Many of the practices have been used at the Nordic plants for a long time and there were questions why they are now labelled as HU tools and promoted with a programme. Despite of that, maintenance personnel held fairly positive view on the HU tools. However, a common opinion was that using the HU tools may require a lot of time. Further, strong focus on the tools may decrease the focus on tasks itself and impair the workers attention or judgement. In the Nordic plants HU tools were also sometimes perceived as awkward, and feelings of shame and blame may occur. Thus, the results highlight the importance of the implementation process, the way the HU tools are argued and promoted in the organisations.

Key words: human error, nuclear power, safety culture, safety management, maintenance