Finnish Institute of
Occupational Health

Participative development for improving nuclear safety – results and implications of three methods in nuclear maintenance work

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ABSTRACT

This research report summarizes the results and implications of three participative methods, which we applied and evaluated in nuclear maintenance in the PARSA project in 2019–2021. We aimed to assess whether these methods are applicable and whether they add value to participative orientation in nuclear safety improvement.

The nuclear industry is highly proceduralized and technology intensive, which sets special demands for bottom-up and human-centred approaches. The changes facing the nuclear industry are ageing personnel and technology, modernization, and new ways of organizing work in nuclear power plants. This situation emphasizes the relevance of participative development (PD). New ways to commit and motivate personnel, and to develop competence, work practices and new learning through human contribution are necessary to maintain high safety levels in the nuclear domain.

As an approach, PD is embedded in the art and practice of human factors (HF), which is regarded as mandatory in the nuclear energy industry. HF strives towards improved system performance, safety, and well-being.

The three methods evaluated in the PARSA project were video-based reflection of workplace learning, collaborative work process analysis of maintenance work phases, and nuclear-specific human performance (HU) tools, especially pre-job briefings and post-job review. These methods are considered to improve learning and work practices, work process knowledge and mutual co-operation across organizational levels and units.

This research report introduces the aims and needs of three evaluated methods as approaches to PD in the nuclear energy industry and summarizes the findings and the implications of our project. The final results of the PARSA project will be published in the end of 2022.

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TABLE OF CONTENTS

1. INTRODUCTION

In this section, we introduce our motivation for studying participative development (PD) in the nuclear industry, participatory orientation as an approach of human factor (HF) science and practice, and nuclear maintenance as an object of research.

1.1. Motivation and need for participative development in the nuclear industry

Over the decades (and often in the aftermath of severe accidents), several organizational learning and safety improvement measures have been established in the nuclear industry. Safety demands are updated, harmonized, and followed by international bodies such as the International Atomic Energy Association (IAEA) and the Western European Nuclear Regulators Association (WENRA). Nuclear power plants (NPP) regularly conduct work atmosphere and safety culture surveys and have procedures for analysing the operating experience and the assessment of risk probability. NPPs have committed themselves to regulatory inspections and assessments of plant safety conducted by the national Radiation and Nuclear Safety Authority (STUK) and international bodies such as the World Association of Nuclear Operators (WANO). Safety committees utilize external experts for advice on safety improvements (Schöbel et al., 2022). International co-operation for improving nuclear safety is active through joint activities such as OECD/NEA audits and work groups.

However, the nuclear industry is facing several changes in its functional environment: the modernization of ageing technology, and new technologies and ways of organizing and structuring work. Ageing personnel, transferring tacit knowledge, maintaining nuclear knowhow and recruiting new generations to positions of operators, managers and experts are ongoing activities in nuclear organizations (MEE, 2018), as well as more generally at work. (Botti et al., 2022). Nuclear safety is also challenged by economic pressures and public confidence. The nuclear industry is characterized by formal systems and practices, and the need to take people’s views into account through communication, feedback, guidance, and appraisal has already been recognized for some time (Wahlström et al., 2005). The need to focus on priorities is an everyday requirement, and the measures and means for facilitating openness and trust at all levels of nuclear organizations is of utmost relevance.

New ways to commit and motivate personnel and to develop competence, work practices and new learning are necessary to maintain and further improve safety in the nuclear domain. This will also promote proactive safety management, stressed in the latest safety science by resilience and Safety-II approaches (Hollnagel, 2014).

Modern threats such as pandemics also affect management and operations in NPPs, as do regulative changes. On the other hand, the nuclear industry has attracted an increased interest through the climate change debate, due to its benefits of producing climate-friendly electricity, and its role in reducing CO_2 emissions.

This further emphasizes the relevance of the constant improvement of system safety, efficiency, and well-being in the nuclear industry, in which the art and practice of HF offer innovative approaches. In this study, we regard PD as an essential approach for applying HF thinking and practices.

Operative personnel and experts are essential for enabling the transition and development of organising work and knowledge. Supporting a good safety climate and participative decision-making is critical for NPPs to provide energy in a safe and sustainable manner. In high-reliability organizations, frontline employees' suggestions and concerns enable the early identification of problems with potentially catastrophic consequences (Weick & Sutcliffe, 2001). Despite this, previous research has mostly focused on the person-centred antecedents of participation and paid less attention to the importance of contextual factors in work and organizations (Silla et al., 2020).

Researchers can also be of assistance in knowledge-sharing, by providing a fecund context for learning and by modelling work assignments that enable features of expertise to be communicated in written and pictorial form. This is facilitated by the rich theoretical and methodological groundings of vocational learning studies, work, organizational and social psychology, and other strands of developmental and collaborative research. The emphasis on safety, which defines the nuclear domain, provides a fascinating setting for this kind of developmental research, entailing aspects and avenues absent from other contexts of human behaviour. Some aspects of experts' knowledge may potentially be formalized and proceduralized through the generation of new human performance tools (HuP); existing procedures can also be reviewed in this process.

Awareness of the variety of methods representing PD is useful at all organizational and functional levels of the nuclear industry. At the strategic level, authorities and top management play the key role in supporting this orientation. They need to be aware of the benefits and limitations of using PD as part of safety improvement or strategic decision-making. At the tactical level, middle managers and experts in NPPs play an essential role in implementing processes and procedures that utilize the PD orientation, for example before or during organizational changes or procedure modifications. At the operative level, there must be enough resources to participate in the use of PD models and tools.

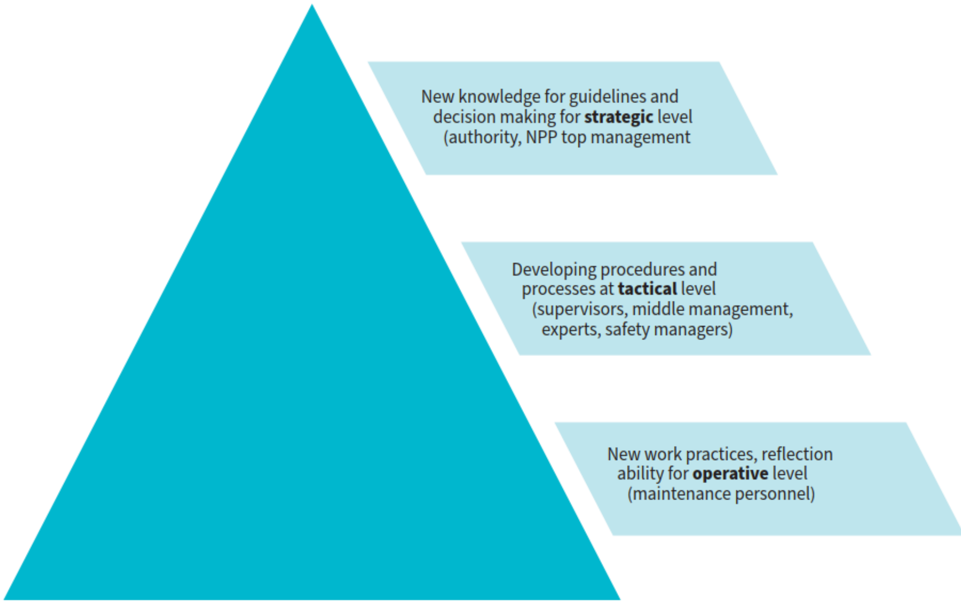

Figure 1. Exploitation and usefulness of PARSA results related to nuclear industry needs for new knowledge, methods, and tools.

1.2. Participative development as an eminent part of nuclear safety improvement

The orientation of participative work development is evident in the HF field (conceptions of human factors HF, HF and ergonomics HF/E, and human factors engineering HFE are used). The conception of participative ergonomics has also been used in Finland, (Lehtelä & Launis, 2011). In brief, HF aims to improve system performance, safety, efficiency, and well-being (IEA; Wilson, 2014; Dul et al., 2012).

Applying HF to systems demands a collaborative rather than a confrontative or top-down approach (Kirwan, 2003; Hendrick, 2008; Teperi & Leppänen, 2011). Research on HF and/or ergonomics shows that the best results are achieved through a co-operative and participatory approach that allows the actors in the organization to take responsibility for developing work and the organization's operations (Hendrick, 2008; Leppänen & Lindström, 2009). Good results are achieved through step-by-step development that combines scientific and practical approaches (Zwetsloot, 2014). Where successful, earlier participative interventions have resulted in better co-operation and co-ordination, a sense of community, and improved productivity (e.g., Robertson, 2008). To summarize, research in these fields should utilize diverse, participatory methods that encourage participants to identify existing risks, learn new practices, engage in joint planning, and evaluate the results of the applications used and the related work performance.

Participatory methods in maintenance work expose the features of current practices. Participative processes have the potential to improve commitment to safety in workplaces, and to offer collaborative ways in which to conduct in-depth evaluations and find new solutions for work practices and safety management processes. (Botti et al., 2022).

This kind of orientation – an 'upward voice', verbalizing and opening up tacit knowledge through participatory research – also meets the current demands of nuclear industry authorities (Silla et al., 2020). The regulator (STUK in the Finnish nuclear industry) can reduce the number of its inspections and take more of a coaching role when operators can prove that the safety level of their operations is good (STUK strategy 2018-2022). Therefore, the development of new tools, work methods and practices can also support the strategic goal of the regulator. STUK could emulate knowledge exchange and a participative approach by generating new practices in inspection coaching. Generally, changes in the regulator's role demand new evidence-based knowledge, competence, and performance-based indicators, and require regulators to evaluate and facilitate processes and procedures in the organizations in question (Kelly, 2017).

Participative orientation is not explicitly mentioned in the national nuclear safety regulation, but it is implicitly acknowledged. For example, co-development and participatory orientation are mentioned in managers' competence requirements. The supervisor must ask the employees for their views on changes in their work, be open to their feedback, discuss issues that arise, and answer questions that concern them. Active interaction and the ability to guide and resolve conflicts and to understand the specificities of employees' work have also been mentioned (YVL A.4.) The participative orientation is also considered to be embedded in safety management procedures referred to as safety culture (YVL A.3) and joint handling of operative experience (YVL A.10).

In the nuclear industry context, the participation of the maintenance experts themselves is essential for exploring issues of competence, for example, understanding the characteristics of tacit knowledge, which presumably plays a prominent role in maintenance workers' expertise. Tacit knowledge is by nature considered to be implicit and difficult to disseminate or share widely (Tsoukas, 2005; Nonaka & Takeuchi, 1995). Thus, organizations need awareness, competence, and concrete methods and tools to externalize their current tacit knowledge – reflected in methods, work practices, processes, and procedures.

However, the competence and resources of the organization and the personnel themselves for reflecting and modelling may be restricted in dynamic everyday work, in which time pressure or even cultural, structural, and historical strains and barriers may limit the allocation of self-reflection and conscious analysis of work (Boreham, 2002; Bussing & Herbig, 2003).

Based on the ideas outlined above, we presume that PD is needed as part of nuclear safety improvement. These needs are important targets in the Finnish nuclear industry, as well as in scientific debate.

By using the term 'participative', we refer to hierarchical or vertical collaboration in organizations, or inter-organizational collaboration. This means collaboration between organizational levels or functional units of NPPs, between NPPs and authorities, and between research and business. In this study, we have mainly focused on collaboration between the organizational levels or functional units of NPPs. However, our findings may be used to speed up organizational learning and development in educational and academic institutes, industry, and authorities.

In this study, we use the term PD to refer to methods, models, or tools that are used to

- facilitate, commit, or motivate personnel to analyse their work,
- make suggestions for improvements, or
- apply good work practices,

and thus, actively take part in organizational development and learning.

Our focus has been on the implications of applying PD methods. We believe that applying PD does not mean blurring the basic roles or tasks of NPP personnel (management, supervisors, operative personnel), authorities or businesses. On the contrary, PD may help clarify these roles, improve work and safety practices, and provide information that would not otherwise be known or emerge.

By using PD, we focus on work, work practices, processes and procedures, and workplace learning. For each case study, we provide a more detailed description of how the specific method, model or tool represents PD.

1.3. Nuclear maintenance as an object of research

The need to develop adequate ways of organizing and managing work and competencies is highly relevant in nuclear maintenance, which has been left in the margins in comparison to control room studies in HF research. The claim has been that maintenance in safety-critical fields would have less safety relevance or competence demands than controlling operations. However, maintenance in safety-critical domains in general has several safety-critical features, such as knowledge-intensive work phases conducted by teams, guided by specific regulations and safety requirements (FAA, 2005; Drury et al., 1999).

Regarding maintenance in the nuclear industry, personnel and maintenance activities may help the entire organization be more aware of the boundaries of safe activity, the condition of technical equipment, and the effectiveness of current practices and conceptions in creating safety. In addition to its preparatory and anticipatory role, maintenance plays a critical role in recovery from expected breakdowns and unexpected system perturbations (Reiman, 2011). For these reasons, of the many functions of expertise in a nuclear power plant, maintenance is a justifiable object of focus for developmental research.

However, despite the numerous changes taking place in this field, topical research on nuclear maintenance is lacking, particularly research that specifically defines, applies, and evaluates forms of PD in the context of nuclear maintenance work.

As maintenance in the nuclear industry is our focus, we also consider the generic restrictions and characteristics of PD in safety-critical domains. Safety-critical fields typically regard their own domain as so specific that lessons learned in different domains are not fully utilized and inter-organizational implementation of best practices is limited. However, safety-critical fields do have several joint, shared demands and practices, which gives reason to suppose that the lessons learnt in one field can also be reflected, evaluated, and applied in other safety-critical fields.

2. AIMS

The PARSA research project (2019–2022) presents the PD approach to promote continuous improvement of nuclear safety. We have aimed to study the appropriateness of PD and its models and methods, and to create new knowledge and approaches in PD research that are suitable for the proceduralized nuclear domain but also more generally for other safety-critical fields.

The PARSA project has conducted case studies at the maintenance of two NPPs. It intends to disseminate its findings and lessons learnt throughout the whole nuclear sector, especially to NPPs and authorities.

In this study, we evaluated whether three specific methods/models/tools promote PD in the nuclear industry.

In this research report, we focus on:

- case studies that have applied three methods as examples of PD
- the results and lessons learnt from the methods applied
- presenting some examples of the work and its needs for development, based on what the three methods have revealed.

The results of the study may be useful for safety experts, managers, supervisors, regulators, occupational health and safety officials, and operative personnel working in the nuclear power industry, to help them apply PD to improve nuclear work and safety

3. APPLYING PARTICIPATIVE DEVELOPMENT – MATERIAL AND METHODS

In this study, we evaluated three different PD methods in nuclear maintenance (Figure 2).

The case studies covered the following aspects of maintenance work, from a general overview to more specific phases of the work:

- Selected maintenance work processes (fault repair, planning, reporting)
- A specific safety-critical work phase in outage (lifting)
- Good work practices (pre-job briefings, post-job reviews)

The conclusion of the case studies is summarized as added value from PD for improving nuclear safety.

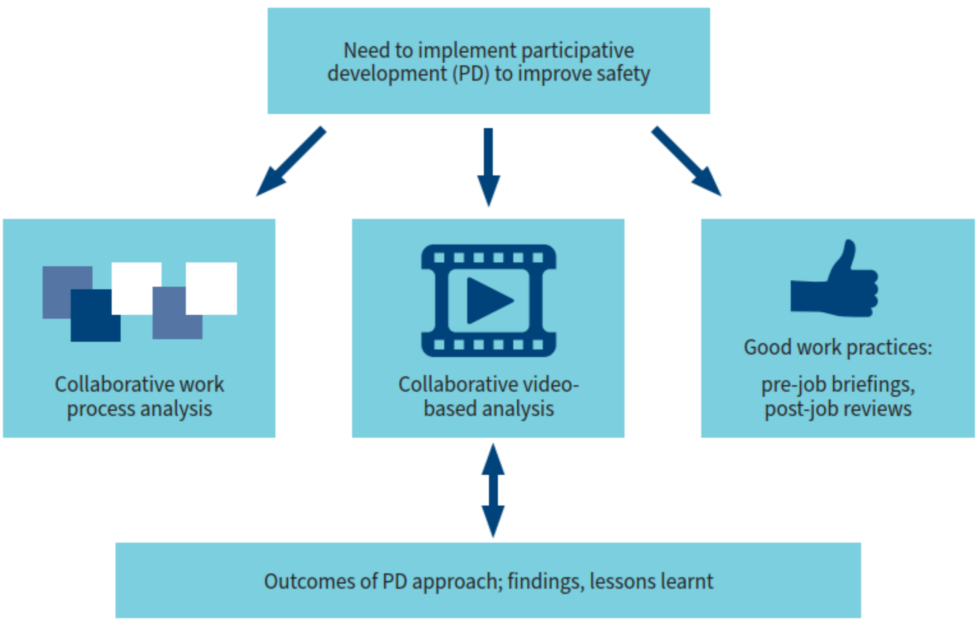

Figure 2. Three Participative Development (PD) methods evaluated in the nuclear industry, PARSA project, 2019–2021.

Each case study with its specific method is presented as follows:

- theoretical background of the applied method
- method and material used
- implementation
- results and conclusions of the method.

3.1. Collaborative work process analysis

3.1.1. Theoretical background of the method

The digitalization and increasing technological mediateness of work; dynamic, interdependent processes; organizational restructuring into teams and networks; and expanded work tasks and responsibilities require that all employees have good theoretical and practical knowledge of processes and their related issues. Moreover, for co-operation, communication, and decision-making to succeed, employees should have a common understanding of work processes (Zuboff, 1988; Hollnagel, Cacciabue & Hoc, 1995).

Such a shared understanding creates grounds for safe work and promotes resilient performance as it supports the performance of both systems and humans by improving the ability to anticipate and learn in both everyday operations and more demanding situations. (Hollnagel & Nemeth, 2021),

Understanding a work system with all its interactions and interdependencies requires applying good conceptual and theoretical knowledge to the specific work context and work situation. **Work process knowledge** (Kruse, 1986, Boreham 2002) refers to understanding of the work system as a whole, including work processes, the interdependencies of activities in different departments, work roles, and organizational culture. It covers knowledge that is useful for work and supports practical activity, as opposed to knowledge in general. Work process knowledge is formed while solving problems and contradictions at work by combining practical experience (knowhow/competence) and theoretical knowledge.

Sandberg (2000) and Norros (2004) point out that the essential basis for competent actions at work is understanding the work. Sandberg (2000) uses the term *conception of work* to denote a worker's way of experiencing or making sense of their work and shows how a worker's conception of their work crucially affects which knowledge and skills they actually use to perform a task. A key requisite for deeper conceptions is a more profound understanding of the interactions and interdependencies of the object of work. Deeper conceptions also cover more phases of work and compile them into a coherent entity to be analysed and acted on as a whole. Norros (2004), in turn, has studied appropriate actions in different situations, especially in dynamic, complex, and uncertain work environments. She uses the concepts of **core task** and **habits of action** to explain the differences between the actions of different actors. The core task denotes the result-critical content of work that the actors should consider to achieve the objective of their work. The workers' conceptions of the core task influence their actions. Thus, the more accurate and the deeper their conception of the core task is, the more successfully they can judge various situations and decide on the appropriate actions for the task. Interpretative (vs reactive) habits of action promote the construction of a comprehensive picture of events and their dynamics, and thus improve the choice of appropriate actions for specific situations.

Work Process Analysis (WPA) (Leppänen, 2001; Leppänen et al, 2008) is a collaborative, development-oriented method that facilitates the accumulation of work process knowledge and shared understanding of work. It aims to increase the participants' ability to see the work process as an entity and to encourage them to take an active role in improving and developing it.

In this study, we used the term Collaborative Work Process Analysis (CWPA), to emphasize the use of a method to improve co-operation between different organizational levels or partners, functions, and units.

The core of CWPA is the sharing of knowledge and experiences through dialogue among participants. Participants have different views and knowledge of processes due to their varied education, work experience, work tasks, and responsibilities, and this enriches the discussions on and resulting conclusions regarding the history, current state, and development opportunities of processes. Dialogue combines the theoretical and practical knowledge of participants to form shared local concepts and theories of work – shared work process knowledge.

The method is based on steered discussions and knowledge-sharing between participants. During the analytical sessions, the participants work in different groups and analyse their work processes, work methods, materials, products, and co-operation as well as the related problems and needs for development. The themes of the analysis and development of the work are selected according to the aims and goals of the project. Typically, discussions cover issues such as who, what, why, when, and how, in terms of the way in the work is to be done. Aspects include quality and cost, problems, and development proposals.

Preparing development proposals is an essential part of CWPA. In earlier development programmes, participants have made hundreds of development plans concerning the entire work process from technical development to co-operation (Leppänen, 2001; Leppänen et al., 2008). The purpose of development plans is to reveal the aspects of the work process areas that need developing and to provide adequate information to initiate actions. They are not merely the occasional views of one person. Development plans cannot be formed without proper modelling of the work.

In this project, we used a modified version of a method that was developed in safety-critical air traffic management (Teperi & Leppänen, 2011), and further used in aviation maintenance (Teperi et al., 2019). Evaluations of these projects proved that using CWPA supported systematic co-operation between different actors in the organizations. It helped define and create a mutual understanding among the organizational actors of the safety-critical characteristics of maintenance work, and that these could be further supported by improving work processes in practice.

The starting point of CWPA is that operative personnel are experts in their own work, and that their competence in and views of work development and system design need to be recognized and made visible. This kind of expertise is typically 'silent', tacit knowledge. Making the invisible visible is called modelling (Nonaka & Takeuchi, 1995).

Based on earlier research, we chose CWPA for this study because of the need to:

- make tacit expertise in maintenance work more visible and concrete
- analyse and learn directly from everyday work (not only from operative events, audits, or other current safety management models in use)
- understand and develop work by modelling it collaboratively, jointly by the personnel themselves, from operative to expert and management levels.
- find appropriate corrective measures more collaboratively.

3.1.2. Method and material

As a method, CWPA focuses on describing the basic characteristics and demands of operative work. The method consists of different phases, during which participants model and share an understanding of the entire work process, its phases and main tasks, critical phases, and problematic tasks, as well as its areas that need developing. Modelling includes critical analysis and discussion of possible shortcomings; recognizing safety-critical tasks, quality assurance, and needs for collaboration, depending on the targets of the development and learning process. Finally, ideas, solutions and good practices are modelled, through collective idea generation and planning. The ultimate aim is better productivity, safety, and well-being, in line with the aims of the art and practice of HF research.

This study applied CWPA in NPP maintenance to describe the work processes, critical phases, irregularities, and influences, as well as interfaces and needs for collaboration in maintenance work. A further aim was to support organizational learning, knowledge sharing and safety in maintenance work.

3.1.3. Implementation of CWPA

During the three years of the PARSA project, CWPA has consisted of different phases. The target group and scope were negotiated during the process, as the modelling revealed a variety of needs. Figure 3 describes the time, modelling groups and aims of the modelling, as does Table 1 later in more detail.

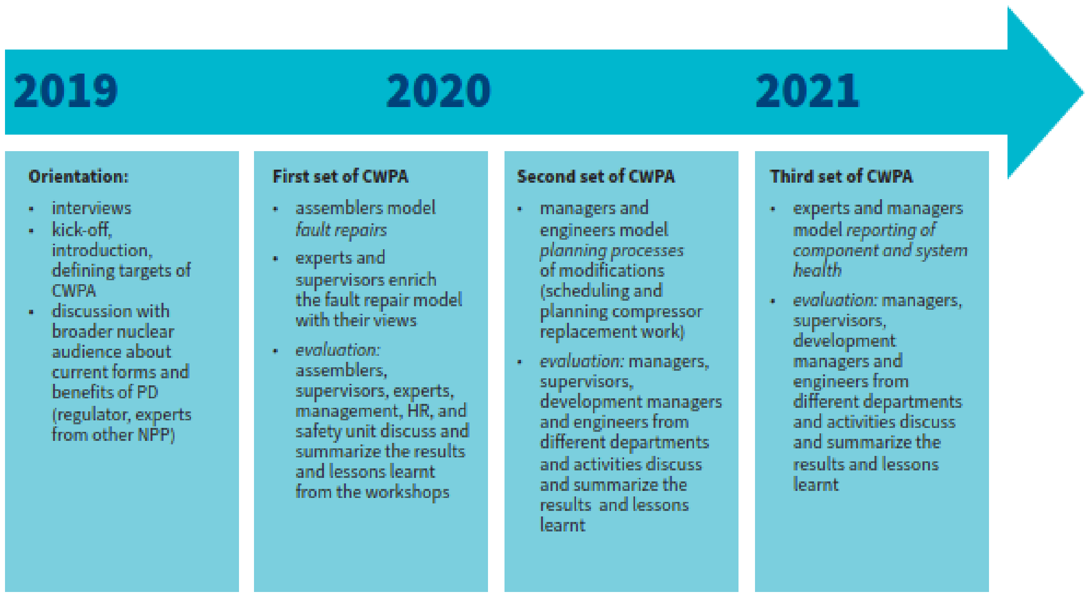

Figure 3. Main phases of CWPA in NPP in 2019–2021

In this study, we collected data in a nuclear power company which had two plants. In this report, we refer to these plants more generally as NPP.

Orientation – interviews and kick-off workshops before conducting CWPA

Prior to the CWPA workshops, we interviewed selected personnel, to obtain preliminary information to orientate researchers, to find the specific, topical needs in NPP maintenance, and to finally select the work processes for further analysis.

The interviews were held in June 2019. We interviewed nine maintenance team leaders, supervisors, technicians, and engineers from NPP1 and NPP2. The interviews were in the form of thematic group interviews, and the groups had two to three people and were administered by two researchers. Each interview lasted 90 minutes.

The main themes of the interviews were:

- the interviewees' personal tasks and duties
- leadership in NPP and participant's own unit
- changes in work and organization and processes
- overview of maintenance work
- organizational factors that affect current work
- critical phases, tasks, and features of maintenance work
- collaboration in work
- potential conflicts and their resolutions

An introductory kick-off workshop (Figure 3, Table 1) was conducted to present the results of the interviews, to introduce the CWPA as a method, and to select a work process for the first application of the method. Nine representatives of assemblers, supervisors, technicians, engineers, and one plant manager, covering mechanical, electronic and automation maintenance participated in the kick-off workshop.

The themes selected for the work process modelling were **handling fault repairs and needs for collaboration in maintenance.**

One study participant commented on the needs of NPP maintenance as follows:

'The items now planned for allocation are exactly the day-to-day tasks of maintenance... After all, these things have been going on for many tens of years, but in terms of continuous improvement, they are exactly the jobs we should develop'.

Another kick-off/introductory workshop was held with the participating NPPs, a regulator, and safety experts from another NPP representing another company (n=12). Here, we also introduced CWPA. In the group discussions, the participants evaluated the overall situation, current use, and benefits of using the PD approach in the nuclear industry in general and in their own NPPs.

Implementation of CWPA in three sets of workshops

After orientation, three different sets of WPA workshops were conducted (Figure 3). Each set included two workshops, described in more detailed in Table 1.

The first set of CWPA consisted of two workshops, (Figure 3) and was conducted in the spring of 2020. It focused on **assemblers' and supervisors' work in solving fault repair.** The CWPA consisted of five intensive analysis sessions, each lasting two hours, and had altogether 13 study participants.

At first, three electrician and automation mechanics/assembler pairs selected a disturbance case that they wanted to analyse (Workshop 1). They then modelled the phases and tasks and possible problems and challenges in the process and identified smooth and efficient work methods. Development ideas were also collected and discussed (Method described in Appendix 1).

After this, two groups of supervisors and experts added their relevant tasks to the process descriptions of each case, with comments and development ideas. In this way, both the assemblers' and supervisors' views of the processes were combined with the process illustrations. As a result of the analysis, 13 different development ideas were proposed, concerning, for example, digitalization (digital pictures and documents), work environment (better lighting in dark places/spaces) and information sharing (development ideas to improve work order forms and spare part ordering procedures.

A summarizing, disseminating, and evaluating workshop (Workshop 2) was conducted a week later, with the assemblers, supervisors, and experts who had participated in the analysis process, but also members from management and HR and safety experts, totalling 15 participants. We discussed the results of the process analysis and development ideas that arose from it.

Three ideas were selected for further planning, and preliminary plans for these were agreed on. The participants also reflected on and evaluated the CWPA method. The needs and target for the next modelling (second set of CWPA) were decided.

The second set of CWPA focused **on collaboration between the main departments of engineering, operations, and maintenance during modifications. It focused on the planning processes of the modifications, especially from the perspective of the managers' and engineers' work.**

This phase included two workshops (Figure 3) and was conducted in the autumn of 2020. The specific case was a compressor change/replacement and the scheduling and planning phase of the replacement work. Nine engineers and managers representing the different departments participated in the workshop (maintenance engineers, planning engineers, project managers, team managers, asset manager).

First, the representatives of each department modelled the phases and tasks of their own planning process on a timeline and presented the processes to each other. The processes were illustrated as parallel processes on the timeline (Workshop 3). The participants identified strengths and good practices, and disturbances or needs for development. They also pointed out connections between processes and needs for information and noted interconnections and collaboration (arrows), including different kinds of planning and review meetings (Figure 4). Finally, development proposals were listed, and after discussion, these were grouped into solution areas, and preliminary plans were initiated.

A summarizing, disseminating, and evaluating workshop was held as on online meeting a month later (Workshop 4). The participants (n=16) were managers from different departments and activities, supervisors, development managers, and engineers.

The third set of CWPA concerned the **component health reporting** and the **System health reporting** processes in the lifecycle management of NPP. This case consisted of expert knowledge work with intensive information gathering and knowledge creation.

The analysis focused on how to help the reporting process produce good quality knowledge and reports for the use of both annual planning and long-term investments, and for overall sustainable life cycle management.

The participants in this phase were the maintenance (n=4), engineering (n=5), and development (n=1) units, ten in total (Workshop 5). They modelled the component health reporting and the system health reporting processes in parallel on the timeline as groups, after which they presented the process to each other.

A summarizing, disseminating, and evaluating workshop was held as an online meeting (Workshop 6).

To sum up, the CPWA in 2019–2021 (Table 1) consisted of the following actions:

Table 1. Actions in CWPA in 2019–2021 (workshops numbered WS1–WS7), aims of each action, data collected, and number of participants in each action

Time	Action/ Work-shop	Aim of action/workshop	Collected material (study participants)
6/2019	Interviews	-preliminary overview and data collection to determine needs and current state of NPP maintenance	-individual interviews in NPPs (n=9)
9/2019	Kick-off in NPP	-orientation/kick-off meeting in NPP -introduction of method -summary of interview findings -selection of work processes for WPA to be analysed in following phase	-notes and minutes of workshops (n=9)
9/2019	Kick-off for nuclear actors	-orientation of project for other nuclear actors (regulator, other NPP experts) -introduction of method -summary and discussion of interview findings - current uses and benefits of PD	-notes, group discussions with whiteboard presentations (n=12)
First set of CWPA			
2/2020	WS1	**-modelling four fault repairs;** forms for development plans (Appendix 2)	-intervention material; recorded discussions; illustrations of process (n=13, six assemblers, seven supervisors)
3/2020	WS2	-summary, evaluation, and conclusions of WS1	-recorded discussions (n=15)

Second set of CWPA			
10/2020	WS3	-**modelling modifications: case scheduling and planning replacement work of a compressor** -collaboration between engineering, operations and maintenance departments to form a unified view of modification processes	-intervention material; recorded discussions; illustrations of process analysis (photos); development plans (forms) n=9 (engineers, managers)
11/2020	WS4	-summary, evaluation, and conclusions of WS3	-recorded discussions; development plans (n=16, engineers, managers, supervisors, developers, leaders)
Third set of CWPA			
9/2021	WS5	-**modelling component health and system health reporting processes** for lifecycle management of NPP -focus on how to help reporting process produce good quality knowledge and reports, for the use of annual planning, long-term investments, and life cycle management	-intervention material; recorded discussions; illustrations of process analysis (photos); development plans (forms) (n=10)
10/2021	WS6	-summary, evaluation, and conclusions of workshop WS5	- notes on discussion (n=13)
Total	9 actions		Partly same people in each workshop or interview

3.1.4. Results of applying CWPA

Interviews revealed needs and exact targets for CWPA

We conducted interviews to gain a preliminary understanding of maintenance activities and to outline potential targets for participative process modelling and development.

From the maintenance perspective, notable changes had occurred in the organization and in work in recent years. Co-operation negotiations in 2015, resulting in redundancies, and the prolonged completion of the third reactor had affected employees' moods in the facility. The effects of the general shift in the engineering labour market towards shorter employment contracts could also be seen in plant operations, as it had increased the demand for training. However, all this affected the work of the managers and officials more than that of the mechanics: daily mechanical work had changed relatively little over the last years.

A change in the organizational culture from face-to-face and phone communication to more mediated communication such as e-mailing and service tickets could be identified, as well as a shift from formerly very close and personal communication towards more formal co-operation. Safety work had a greater, more visible role in operations, and a new intensity could be identified in the orientation to development. Different leadership and expert positions and roles were seen to form a relatively complex structure of leadership and technical expertise. The relations between the operative personnel and their closest supervisors were portrayed as very close and interaction and collaboration as very frequent – but opposite examples could also be found, as some experts' tasks were highly autonomous. Technical expertise appeared to be highly valued, and technically strong leading experts were highly appreciated. Collaboration within the maintenance department that involved operative staff in writing work instructions was praised as an excellent example of participative action. The leadership culture had moved in a more modern, human-centred direction, making the current top management appear highly approachable.

When asked about tasks or features of maintenance that could be suitable for closer examination and development, the interviewees highlighted ad-hoc repairs, unexpected malfunctions, and situations that require collaboration across organizational units. A recent organizational change, in which technical support was divided into a separate function, was portrayed as an ongoing process which highlighted the need to develop cross-functional communication and collaboration. Technical expertise was partly centralized into a separate function and required modifications to maintenance work processes.

Similarly, the documentation of maintenance project plans, inaccurate repair requests, difficulties acquiring spare parts, and collaboration between units were potential targets for improvement. Recurring problems, to which finding a more solid overall solution would be welcome, were also brought up. The more common nuclear safety challenges of loose particles and protection against radiation were also frequently mentioned.

First set of CWPA – results from Workshops 1 and 2

Altogether 13 assemblers and experts participated in Workshop 1 to model four typical faults requiring repairs, which were:

- Flow of ventilation air stack impossible to measure
- Inadvertent start-up of pump during periodical test of 327 system
- Failure of pump in 321 system (imagined problem: 'if it failed, what would we do?')
- Excessive earthing current of generator rotor –> change of coal ring gasket raised shaft voltage of generator [1]

Based on the modelling, the participants raised the most important areas that needed development and proposed 13 development ideas to improve work. In Workshop 2, three ideas were selected for further planning, for which the participants made development plans, structured as forms (Appendix 2). These forms focused on concrete actions, with ten steps for how to proceed with the corrective measure in practice.

The development plans included the following proposals:

- Pictures and documents should be digitalized (guidelines, procedures)
- Better, safer lighting is needed in some dark places (work environment)
- Work order forms need to be improved (information sharing)
- Ideas for spare parts and ordering procedures (work processes)

The following lessons were learnt from using the CWPA method:

- Motivating and relevant cases need to be selected for the analysis, to enable learning and developing
- Using the method requires time, resources and motivation; workplace culture needs to develop the view that it is acceptable to prioritize participation in developing work in workshops

[1] terminology may be plant specific and may vary in different countries

- Useful, valid targets for CWPA could be:
    - A phase of a process that often requires reworking and maintenance, or often has faults, defects, or disturbances
    - A major disturbance that could be used as a shared learning case for several different occupational groups, hierarchical levels, experts, etc.
    - A process that is to be renewed: a case in which a major new machine, system or equipment is installed – the issues that require attention and the kind of training required for using the new system should be jointly evaluated. Anticipating and recognizing the differences between old and new work methods can make a change visible and more concrete.

Concerning the selection of the participants for the CWPA method, they should:

- work with the case in practice
- have the best expertise and knowledge of the case; they should know what and how it happened, why certain choices were made, and what kind of challenges were encountered
- be motivated and committed to participating in the often demanding and laborious learning process

Regarding the utilization of CWPA for learning:

- A participative process for further planning and implementing the ideas should be arranged,
- Those who presented the idea should also participate in planning and implementing them.

Second set of CWPA – results of Workshops 3 and 4

Altogether 13 engineers and managers participated in Workshop 3 to model modifications, specifically the scheduling and planning of the replacement of a compressor. Collaboration between the engineering, operations and maintenance departments was our specific focus, to understand how they formed a unified view of modification processes despite organizational structures and working as separate units.

As with Workshops 1 and 2, the second set of CWPA revealed areas of work that needed development, but the participants also learnt lessons related to the method itself.

The modelling revealed that some things worked well while others, such as collaboration, needed development. The strengths were well-functioning project organization, for example, meetings to maintain situation awareness and personnel competence. On the other hand, many of the (collaboration) problems concerned subcontractor delays; late proposals or guidance; insufficient or late plans; delays with devices, spare parts, or materials; late improvement suggestions, or overload of tasks. These were seen as needing further development.

All the participants recognized a need to improve shared situation awareness and to adequately understand the overall process in the units. The participants made several suggestions for improvements, one of which was a more stable structure for collaborating across functions: they proposed that a structure of four review meetings would help collaboration in the future. They suggested a series of meetings, which would have the following steps:

1. Pre-job briefing, in the initial phase, to plan how the process will be conducted
    - all relevant actors (including component specialist) to participate[2]
    - all actors must commit to the plan
2. Design review, two review meetings,
    - following up whether the process is proceeding according to plan
    - taking corrective measures when needed
3. Preliminary review of the plant modification documentation
    - quality check for amending and minimizing errors
4. Pre-job briefing of work planning and control
    - starting work scheduling across the functions

One lesson learnt from using the CWPA method was the importance of positive learning. Workshops 3 and 4 specifically focused on creating a positive atmosphere. The participants were first asked to name the strengths and successes of the process and collaboration, i.e., before discussing possible challenges or problems. After this, it was easier to move on to the more negative issues of collaboration. Typically, disturbances, problems, and risks had been discussed before cases of success, and this had affected the work atmosphere, causing the risk of tension in communication across functions.

[2] According to STUK's SSC classification: structures, systems, components

Third set of CWPA – results from Workshops 5 and 6

Ten people (managers, experts) participated in Workshop 5 to model the component health and system health reporting processes. The study participants considered these processes relevant: although data are gathered throughout the year, the reporting process itself is very intensive. It is highly relevant for high-quality planning processes, and a successful reporting phase ensures that preventive maintenance, investments, and revisions/outages are realized as safely and smoothly as possible. The reporting phase takes from a few weeks to a month, and about 120 people prepare one or several reports. The scope of the reporting processes is broad; 3000 components and 200 systems of the NPP are described and evaluated in the reports. The system and component health reports include data on the results of disturbances and revisions, for example, collected to build a comprehensive view of the situation, as well as the maintenance and development needs of the equipment, components, and systems. The reporting process is annual and uses the knowledge obtained the previous year (e.g., revision results). It is repeated in mainly the same way each year but is slightly modified on the basis of the lessons learnt from the preceding year. The big picture (the final report) is formed by a complex, collaborative process, which uses and summarizes numerous information sources.

Data sources and their quality were discussed at the workshop, as were the needs for shared analysis and interpretation of the judgements. The experts regarded this phase of the maintenance as essential insurance that the plant would function properly. As experts, they felt that they were responsible for the ongoing processes at the plant.

The modelling of the reporting process revealed that the following needs for development:

- the goals and reasons for the component and system health reports, as well as their differences need to be clarified; in some cases (components/systems), reports are quite similar, and work some overlaps
- the original data must be sound: the development proposals concerned, for example, improvements to disturbance reports, and updating and clarifying disturbance codes
- spare part lists and priorities, and accurate knowledge of the stock level of spare parts must be ensured, as they are essential for future maintenance and investment plans
- some data gathering could be automated, and data/IT systems integrated

- reporting needs to be organized; the most beneficial timeframe needs to be redefined, especially in the system health report (due to revision pressure in the springtime).

The conclusion of the workshop was that the bigger picture of the reporting process needs clarification. The wider discussion stressed the need to rethink and define the basic task and role of the reporting process. The study participants felt that the reason for doing this work must be emphasized, to assure the quality of the work and to mitigate errors and flaws in the process.

The general need for more collaboration in writing component and system health reports was raised. There should be more platforms for the different partners of the maintenance functions to collect data and make interpretations together.

Summary of CWPA results:

The collaborative analysis of the work processes revealed several areas of work that needed development. This indicates that as a method, the CWPA can externalize work process knowledge and everyday needs in work processes.

The process of conducting CWPA also revealed some aspects of the method itself that needed development and possibilities to improve its use. These results are useful not only for researchers, but also for experts or supervisors at the plant, as they enable them to further apply CWPA in the future on their own. Knowledge about CWPA is also needed to see the benefits, as well as the limitations and prerequisites for conducting the method in the real world. Table 2 summarizes the results of the maintenance work processes and the CWPA method.

Table 2. Results showing the aspects of the modelled maintenance work processes that need developing and the use of the CWPA method. Time when workshops held, main results of the method and the work itself.

		Main results	
Time	Work-shop or action	Aspects of work that need developing	CWPA method
6/2019	Inter-views	- changes in NPP organization and maintenance work; new ways of organizing work; competence management is challenged	- a way to commit to the research, to start using the PD method, and to recognize topical needs for accurate PD application
9/2019	kick-off	- need to improve procedures and co-operation in fault repairs -> theme for WS1	- work process analysis used previously, but not with aim of collaborative learning
2/2020	WS1	- good practices exist for fault repairs, but further development is needed through collaboration and information sharing among supervisors, experts, and assemblers in several phases of the process	- importance of selecting a relevant case for modelling beforehand
3/2020	WS2	- collaboration and information sharing among engineering, operations and maintenance units during modifications needs improvement	- motivating and relevant cases need to be selected for the analysis; selected participants must actually work with the case; enough time needs to be reserved for preparing development plans
10/2020	WS3	- strengths are well-functioning project organization with mutual support; weaknesses are subcontractor delays, late proposals or guidance, plans lacking information, work overload - development proposals concerned securing accurate information for all partners	- good practice is to first go through positive aspects, things that are working well and successes, after which it is easier to proceed to more negative or critical issues of work processes and to deal with their weaknesses

11/2020	WS4	- in the process of planning and scheduling modifications, shared situation awareness across different activities needs improving	- follow-up in teams, 'informing nature'
9/2021	WS5	- reporting process is regarded as vague, and its basic task/aim, expectations, measures, and required collaboration during the process have to be clarified (motivation for reporter)	- method helped verbalize thoughts and needed actions ('I've thought about this, this has bothered me, but I've had no initiative to proceed with it")
10/2021	WS6		WPA offered a forum, structure, time, and space for experts from different functions to collaboratively discuss and see the decision-making that typically takes place at the upper level of the organization. It also helped define the implementation of practical measures.

One interesting finding was that the preliminary interviews were a good way to find 'sore points' or tensions. These could be further elaborated using CWPA, during which different cases are targeted to address topical needs. Using CWPA strengthened the preliminary intuition of the study participants, and the external expert facilitated the process of making these issues more visible and concrete, also supporting collaboration in handling difficult issues. The structure and organization of the method as a series of workshops helped all the necessary parties participate in the work, thus all the development points were identified together. During the method, a continuum was reached which resembled the basics of organizational development, such as ideas of process consultation and a stepwise process facilitated by an external expert and consultant/researcher. At the same time, the collaborative work made the meaning of shared situational awareness more concrete.

To conclude,

- CWPA offered a resource (= forum, structure, time, and space) for collaborative discussion among maintenance experts, for recognizing and verifying topical areas that needed development, and for progressing as part of overall NPP planning and development (especially the implementation of ED).
- CWPA offered a forum and structure in which experts could voice their views on decision-making, which typically happens in the upper levels of the organization
- CWPA modelled the implementation path of the practical measures that would be needed in the near future (not yet the final stage, but as a facilitating part of the organizational process).

3.2. Video-based learning

3.2.1. Theoretical background of the method

The idea of using video to develop expertise in the nuclear domain draws from a strong line of research conducted at Électricité de France (EDF) by Lahlou (2010) and others (Le Bellu & Lahlou, 2010; Fauquet-Alekhine et al. 2018). We aim to transfer this line of research to Finland and expand it by using prominent Finnish research traditions. This relates to the way in which researchers can facilitate video-observation sessions with the workers. The development and implementation of the method synthesize the established lines of study, such as work on interpretive practice (Norros, 2004; Savioja, et al., 2014; Norros, 2018; Wahlström et al., 2017, 2018), the use of a first-person camera for uncovering tacit knowledge line work developed at EDF (Lahlou, 2010), and workplace learning according to the 'change laboratory' tradition, with its expansive learning concept in Finland (Engeström, 2001).

3.2.2. Method

We have introduced the method of video-based collaborative reflection to the maintenance personnel in the NPP. The idea is that learning takes place as the workers observe their own work practices in the video recording. Watching the events that take place during the activities allows the workers to discuss what could be done differently and what they did correctly. The facilitator asks questions and guides the discussion.

The video-viewing session is designed to match its main purpose. The session may begin with a discussion on work performance based on the group's recollection of the activity. After this, task performance can be re-evaluated on the basis of the video and discussed further.

Identifying the activity to be recorded is the first and most crucial step of the video-based method. The reason for choosing a certain activity for training and development purposes should be clear, and thus the safety-critical nature of the activity is a good starting point. The activity should consist of (critical) events that take place over a reasonably short time, so that it is possible to make video-recordings that do not take too long to watch, depending on how much time is available to use for developmental activity. Furthermore, there should be a enough communicative and/or physical activity to be video-recorded.

We suggest that the video-based method includes the following steps:

- Identifying a safety-critical activity that can be video-recorded
- Setting up a work team
- Making the video recordings
- A brief analysis of the recordings
- Editing the videos
- Designing developmental sessions
- Realizing the developmental sessions
- Follow-up and reporting

3.2.3. Implementation

This section presents an example of the implementation of the video-based method. The primary purpose of the sessions was to test the method and collect feedback from the NPP workers.

Creation of video material

Maintenance worker's heavy lifting activities were recorded during the annual outage by the nuclear power plant's video development personnel. The selected case was the lifting of a reactor shield unit, as it is one of the critical tasks during the outage, and accidents during this task could have serious consequences.

The video camera was positioned so that all the lifting crew members in the crane control room were visible, and their faces were towards the camera. The camera microphone recorded any speech. The researchers watched the collected material and created a video compilation of six excerpts representing activities that were interesting for the research. The criteria for selecting the clips were that they contained a certain amount of discussion among the heavy-lifting crew, for example, problem-solving, asking questions, contradictions, confusion about task performance, and suggestions for improvement. The clip lengths varied from approximately 40 seconds to two-and-a-half minutes. Subtitles were added to the final selected clips as the audio quality was not always good. In addition, a minute-long time-lapse video was created from the material recorded in the nuclear reactor hall, showing the movements of the reactor shield unit. The video compilation was used in two video sessions with the maintenance workers who were involved in the heavy lifting activities.

First test session

The first test session was prepared after the lifting operations, meaning that the video session was held with the people involved in the lifting task soon after the lifting and outage. The session materials included the selection of video clips and a list of questions and themes for discussion. The agenda was divided into two parts: the first part focused on the discussion based on the individuals' and groups' recollection of the lifting task, *without* the video material. In the second phase, the video clips were shown to promote further discussion. The session was held in the NPP's training facilities and lasted one hour. The researchers facilitated the discussion.

Second test session

After the first session, it was agreed with the NPP personnel that the next session would be held **before** the lifting tasks began. The second test session was thus held for the maintenance workers (supervisor level) directly before the outage and its heavy lifting activities. The participants were also involved in the development of the training. The session's agenda was again divided into two parts: the first part consisted of discussion without the video clips and the latter part was supported by the video material. However, the time-lapse video was shown during the first part. The six video clips were the same as those in the first session. In the interview, certain themes guided the questions, for example, questions related to good work practices and uncertainties related to the lifting activities. In addition to encouraging self-reflection, the interview included questions on the developing the method for maintenance workers' training, for example, how and in what situations the method could be used.

3.2.4. Main results

We have learned that the video-based method has a number of useful purposes in maintenance activities. These purposes include at least the following:

- In **before-task operations,** the video session takes place just before the work, and prepares workers for the forthcoming task.
- **After-task operations** are for reviewing the group's work directly after the performance.
- **The after-incident video-review** can be especially useful for discussing why something went wrong and how to prevent it from happening again.
- The video method can also be used for **training new people.**
- **Developing procedures.**

According to the NPP workers, all five purposes were relevant in the maintenance context. The before-task session could provide refresher training for experienced workers, and could also be part of training for new workers, which was seen as an especially relevant purpose for the method. Using the method to review specific incidents would provide an effective way to evaluate the causes of an incident. This type of session would possibly be more limited to a certain critical event, and the video material would thus be easier to prepare. The more general after-task video session could potentially encourage more sharing of good practices and organizational learning through collaborative reflection, and support post-job review practices.

It is evident that video material can stimulate discussion and reflection in a group. During the test sessions, the video material helped the participants recall important issues and revealed which activities' performance could be improved. The discussion also revealed some contradictions between the participants' comments. The attitude towards the method was positive in general. It is noteworthy that filming people during their work and watching the material together in a group is a novel approach, and has not previously been accepted in NPPs (in Finland).

Careful selection of a suitable task for the video recordings is important. The task should be complex, communicative, involve physical activities, and have safety-critical relevance. Furthermore, careful selection of video material is essential for successful implementation of the method. The responsible person or team should at least have time and sufficient competence to make choices. Competence in video-editing would be needed as well. However, these selections and the related work depend on the purpose of the video session: if the aim is to watch one specific critical event, the editing should not be very laborious.

Technical and organizational challenges and conditions for implementation

The method was further evaluated together with the NPP's video development team. The following general and specific challenges, requirements and conditions were identified in relation to the implementation of the video method in the heavy lifting task (Tables 3 and 4).

Table 3. Technical challenges:

Suitable equipment in general	The camera overheated and went off a few times. The audio quality was not always good. Proper equipment should be acquired, which suits the work environment.
Camera angles and positions	Combining the video footage from the crane control room (lifting crew) and that from the reactor hall (movements of the lifted object) would bring more context to the video material. Currently, synchronizing the footage is challenging. Furthermore, seeing the user interfaces/control panels that are being used would also be useful.
Video-editing competence	Sufficient competence is required for editing the video material. Subtitles are required if audio quality is poor. A specific person or team for video-editing is recommended. It is also important to decide who will select the video excerpts.

Table 4. Organizational challenges:

Consent	Permission is always required for filming in the NPP. People's privacy must be carefully considered, consent requested, and people should be removed from the footage if they so desire.
Ownership and responsibility	A person in the NPP should be appointed to be responsible for the method.
Usefulness	The usefulness of a new method must always be proven if it is to be officially recognized in the NPP. The method is proven useful, for example, if: 1) the use of method results in a clear, beneficial change in the chosen activity 2) (several) relevant people in the NPP consider it beneficial 3) research results support the use of the method 4) the use of the method produces good results in other NPPs.
Processes and procedure	Processes and procedures are required for using the method in the NPP.
Schedule	The schedule of, for example, the annual outage can be challenging and might require an on-duty person for video recording (this concerns the appointed responsible person). Automation of the recording process could be considered.

According to the NPP personnel, the most significant challenges were related to the responsibilities and usefulness of the method, and to the selection and editing of the actual video material.

In sum, the NPP personnel concluded that the video-based method provides a clearly new way to prepare for work and to learn from previous activities. The method provides viewpoints that possibly cannot be acquired anywhere else. To be recognized as an official method in the NPP it needs to be included in the power plant's existing guidelines and procedures.

3.3. Meeting-based human performance tools

3.3.1. Background

Human performance (HU) tools are a diverse set of good work practices or error-reduction techniques that originate from various industrial contexts. They are usually applied in the operational context by shop-floor workers (especially maintenance and control room workers). The most commonly used HU tools are pre-job briefings, post-job reviews, the STAR principle (self-checking), peer checking, independent verification, and clear communication (Oedewald et al., 2015).

Meeting-based HU tools (pre-job briefings and post-job reviews) involve holding meetings with task participants to prepare for the task or to reflect on it after it has been completed.

Pre-job briefings are held before the task is performed. According to the DoE Human Performance Improvement Handbook, their function is to review tasks, roles and responsibilities, critical steps, hazards, safety precautions, and operating experience (DoE, 2009, p. 34). Post-job reviews, on the other hand, are held after the task has been completed, and their primary function is to serve as a self-assessment to collect feedback and lessons learned (DoE, 2009, p. 54). In this way, meeting-based HU tools are temporally connected to each other: what has been examined in previous pre-job briefings and post-job reviews is relevant for future pre-job briefings when preparing to perform a task again.

The application of meeting-based HU tools is usually graded according to the demands and safety significance of the task (e.g., see DoE, 2009, pp. 34–35). In their most extensive variations, the meetings are often documented in some way, usually by the supervisor or manager responsible for the task. This documentation can serve many purposes. For example, it can serve as a vehicle for organizational learning. Organizational learning occurs when lessons learned by individuals or specific teams are disseminated and utilized by the organization, as opposed to only by those who were involved in creating the lessons (e.g., Argote, 2013). Therefore, the documentation produced by the meeting-based HU tools could be considered ‘organizational memory’, which facilitates organizational learning. However, it is unclear whether the content of the information produced by meeting-based HU tools is sufficiently informative for organizational learning and whether it is really used for this purpose. Since the potential end-users of this information can be very diverse and have different needs and interests, the way in which the person responsible for the task prepares the documentation can also benefit from participatory development.

In this case study, we ask the following research questions:

- What is naturally documented in pre-job briefings and post-job reviews and what is not?
- What should be documented?
- How can we facilitate the generation and use of documented information?

3.3.2. Methods

The case study was conducted in a Finnish nuclear power company.

The data collection method at this stage of the case study was a review of the company's procedure for performing pre-job briefings and post-job reviews, and a review of the records produced during them.

In this company, pre-job briefings and post-job reviews are graded on four different levels, Levels 1 and 2 are verbal and Levels 3 and 4 are written. On Level 3, feedback is written in an open text field in the work permit system, and on Level 4, minutes are also taken in the meetings.

For this case study, we reviewed all the Level 3 and 4 pre-job briefings and post-job review feedback fields in the work permit system for 2020 (n=1372). The total number of pre-job briefings (Level 1–4) held in 2020 was 3796.

Some of the work permit system feedback referred explicitly to the minutes of the meetings. We used these minutes as an additional data source (n=12).

We conducted thematic analysis to identify the themes that emerged from all the feedback comments in the work permit system and the minutes of the meetings. We used a similar theme structure for both data sources. We also reviewed the procedure for pre-job briefings and post-job reviews (what was expected) and compared it to the themes that emerged in the feedback and the minutes of the meetings (what we observed).

3.3.3. Preliminary results

Procedure

The company has a procedure for conducting pre-job briefings and post-job reviews: it has four levels of pre-job briefings, described by a four-field (event probability * severity of consequences). The documentation requirements are defined for each level: Levels 1 and 2 are verbal and do not require documentation, Level 3 requires documentation in the open text fields of the work permit system, and Level 4 additionally requires minutes to be taken in the meeting. In addition, for Level 4 pre-job briefings, a risk assessment is conducted before the meeting. Post-job reviews must be documented at least when there is a documentation requirement for a pre-job briefing, either in the work permit system, in separate minutes, or as a final project report.

The procedure states that pre-job briefings and post-job reviews are mandatory.

The procedure also sets goals for pre-job briefings and post-job reviews and defines the themes to be discussed. The general goal of pre-job briefings is to instruct workers prior to starting work. The themes expected to be covered by pre-job briefings include:

- Purpose, scope, and type of work
- Training/required competence
- Documents, permits
- Work methods
- Previous experiences
- Risks and their mitigation (including occupational and industrial safety, nuclear and plant safety, radiation safety, environmental safety, and production-related risks)
- What to do in irregular situations
- Responsibilities and contact persons

The general goal of post-job reviews is to learn lessons for similar tasks in the future. The themes expected to be covered include:

- Successes, observations, and potential for improvement
- Further actions
- Needs for documentation and reporting

Overall, the instructions for conducting the post-job reviews (half a page) were much shorter than those for the pre-job briefings (8 pages).

Open feedback in work permit system

A total of 825 pre-job briefing feedback fields were filled in (60% of all Level 3 and 4 pre-job briefings). Their extensiveness varied rather considerably (mean length was 11.1 words, standard deviation 11.4 words). There appeared to be no clear relation between work content and the length of the feedback. However, there were great differences between the organizational units (of the co-ordinating work manager) in terms of how often they had filled in the open text feedback field. Some units had filled in all or almost all their Level 3 and 4 pre-job briefing feedback fields, while others had filled in very few or none.

The total number of filled-in post-job review feedback fields was 78 (6%). Almost all the post-job review feedback related to a change in pre-job briefing level (e.g., from 2 to 3), and was not actual feedback. However, some respondents seemed to write post-job reflections in the pre-job briefing field. Overall, this means a very limited amount of information was available from the post-job review feedback fields for analysis. Consequently, only the analyses of pre-job briefing feedback are presented below.

Table 5 presents the overall results of the thematic analysis. Risk identification and mitigation measures were the most common themes.

Confined spaces and chemicals were the most often identified risks. COVID-19 was quite a prevalent risk, but 89% of the mentions of it were in the responses of only one team. Other identified risks included electric shocks, falling, radiation and contamination, fire, release of energies, other working groups, and asbestos. Plant safety (nuclear safety) risks were not separately reported, but foreign material risks did come up in some comments. Overall, the most typically reported identified risks seemed to relate to occupational safety.

The most commonly reported risk mitigation measure referred to various types of personal protective equipment (PPE). Special work process considerations were also often mentioned (procedures, practices, or work methods). Other mentioned risk mitigation measures included reviewing working conditions, warnings or work site markings, applying cautious approaches, explicitly forbidding something, co-ordinating with others, preparing for emergency situations, and the presence of safety officials.

Description of the participants was another very common theme. Usually the participants' names, disciplines, or contractors were listed. Sometimes a general reference was made to the working groups holding the pre-job briefings. A list of participants was the only content in 15% of the feedback comments.

Interfaces to other stakeholders (units or to contractors) were usually related to the participants in pre-job briefings who should be contacted or involved before, during or after performing a task, or awareness of the activities of other groups. In some cases, pre-job briefings were held by contractors.

Feedback that referred to familiarization with work usually stated that work had been reviewed (without being specific about the work). A few feedback comments described the actual work contents or phases in detail.

Documentation of operating experience was rare in the feedback. The respondents made references to similar or related jobs but did not describe detailed operating experience.

Four responses were categorized as 'lessons learned or feedback'. It was unclear whether they were intentionally documented as pre-job briefing feedback.

Some of the comments were not thematically classified; these were either unrelated to work or comments with no evident content (Table 5).

Table 5. Overview of emergent themes, example quotes, and approximate prevalence of themes

Pre-job briefing themes	Example quotes (translated from Finnish)	Prevalence
Risk identification	'The basement is treated as a confined space.' 'Chemical hazards were reviewed in the pre-job briefing: alkali, acid and contaminated water.' 'Electricity room, be careful.' 'In addition to the task performance review, COVID-19 risks were identified and mitigation measures were evaluated' 'Acknowledge the radiation on top of the reactor cover.'	45%
Risk mitigation measures	'Work is done in high places. Harnesses must be worn at all times.' 'Wear a visor and rubber gloves.' 'Task phases and work practices in confined spaces were reviewed in the pre-job briefing.' 'No one goes in the container. Put a prohibition sign on the lid.' 'Consider other working groups while performing the task.'	43%

	'Verified the location of emergency shower and exit routes.' 'Radiation safety officer is present at all times.' 'Risk of foreign parts, apply protective measures so that nothing falls.'	
Participants	'Participants were from engineering, radiation protection, inspection and cleaning.'	36%
Interfaces to other stakeholders	'Contact control room before and after work.'	24%
General confirmation of meeting held	'Pre-job briefings were held.'	24%
Familiarization with work	'Tasks were reviewed.'	17%
Reference to minutes of meetings	'See attached minutes of the meeting.'	9%
Work context and background	'Last year, the container was opened and there was no need for cleaning. Therefore, now only a visual inspection is conducted.'	4%
Reference to work content or permit	'Work was performed according to the work permit [code].'	2%
Confirmation or description of work done	'Work ok.'	2%
Not classified		2%
Operating experience	'Similar task was performed during previous outages.'	1%

Lessons learned or feedback	'We suggest building curved scaffolding for working inside the pressure vessel.'	<1%
TOTAL filled-in pre-job briefing feedback fields		825

Table 6 shows the comparison of the themes that emerged in the work permit system's feedback comments and the expected themes for pre-job briefings. The feedback relatively fully covered the purpose, scope and type of work, work methods and identification of industrial safety, radiation safety, and environmental safety. These are also core tasks in pre-job briefings. The need for training, documents or permits, preparation for emergencies, responsibilities, and contact persons were less commonly documented. However, apart from preparation for emergencies, documentation of these themes might not be particularly relevant. Previous experiences, nuclear and plant safety and production risks were also rarely documented. Based on the feedback, it was unclear whether operating experience was examined in pre-job briefings, and if it was, what its content was and where the experience had been gained. Nuclear and plant safety are an important part of work in nuclear power plants. Even though foreign material risks and mitigation measures were sometimes mentioned, this theme was quite rare. It is worth further examining why nuclear and plant safety issues are not naturally documented.

Table 6. Comparison of expected and reported themes

Expected (procedure)	**Reported (in feedback comments of work permit system)**
Purpose, scope, and type of work	Familiarization /preparation with work was a common theme
Training/required competence	Competence assurance was sometimes mentioned (risk mitigation measures)
Documents, permits	Procedures or permits were sometimes referred to
Work methods	Special work process considerations were a common theme
Previous experience	Operating experience was rarely reported
Occupational, industrial, radiation, and environmental safety	Occupational safety risks and mitigation measures were the most common themes
Nuclear and plant safety	Nuclear and plant safety risks were not highlighted, apart from risks of foreign material and related actions
Production risks	Production risks were not highlighted
What to do in irregular situations	Emergency practices were sometimes highlighted (risk mitigation measures)
Responsibilities and contact persons	Responsibilities were not often reported, but interfaces with other units or contractors were reported

Minutes of meetings

We reviewed the minutes of twelve meetings (ten from pre-job briefings and two from post-job reviews). These meetings were held by three different co-ordinating supervisors and in two different maintenance disciplines. Both post-job review minutes were related to a corresponding pre-job briefing, which was also available for analysis. Ten of the meetings were held either completely or partially remotely (including both post-job reviews).

The minutes of the pre-job briefings were not identically structured and they varied in how extensively they were prepared. The most important topics were covered in all the pre-job briefing minutes: work description and background, training documents and permits, risks and mitigation, responsibilities and contact persons, and operating in irregular situations.

Almost all (90%) minutes had a structure (subchapters) for risk identification and mitigation measures. Risks were structured as either high-level (work-specific issues, and occupational, plant, environmental, and production risks), or detailed (up to 14 specific risks, ranging from confined spaces, fire, slipping, to loose parts and radiation, etc.). Plant safety risks (40%) and loose parts (70%) were covered more often in the minutes than in the work permit system feedback.

Like in the work permit system feedback, PPE was the most often mentioned risk mitigation measure. However, preparation for emergencies was more often (100%) mentioned in the minutes than in the work permit feedback (4%).

Previous experience was referred to in almost all the minutes (90%). These references were either short statements or detailed descriptions of the experience and how it may affect the current task. However, it was unclear how the previous experience had been gained: whether it was through discussion during a pre-job briefing, a review of previous documentation, or something else.

Some pre-job briefing minutes also mentioned other HU tools or referred to conducting a post-job review.

Table 3 compares the themes that emerged from the pre-job briefing minutes and the expected themes of the pre-job briefings. Overall, the pre-job briefing minutes template seems to ensure that all relevant topics are documented (Table 7).

Table 7. Comparison of expected and reported themes

Expected (procedure)	**Reported (pre-job briefing minutes)**
Purpose, scope, and type of work	Described in all the minutes
Training/required competence	Review of competences was a very common risk mitigation measure, covered in almost all the minutes
Documents, permits	Review of procedures or permits was a very common risk mitigation measure, covered in all the minutes
Work methods	Special work process considerations were a common theme
Previous experience	Previous experience was discussed in almost all the minutes
Occupational, industrial, radiation, and environmental safety	Different types of risks were covered; very extensively in some of the minutes
Nuclear and plant safety	Plant safety risks were structurally included and covered in most of the minutes
Production risks	Production risks were structurally included in half of the minutes
What to do in irregular situations	Preparation for emergencies was reviewed in all the minutes
Responsibilities and contact persons	Responsibilities and contact persons were included in all the minutes

The two post-job review minutes were prepared by the same co-ordinating manager and were related to similar tasks. Both the post-job review minutes followed a similar document structure (subchapters) to that of their corresponding pre-job briefing minutes: instead of describing work plans and anticipated risks (pre-job briefing), the post-job review minutes described realized work, risks, and experiences (including good practices and suggestions) (Table 8).

Table 8. Comparison of corresponding pre-job briefings minutes and post-job review minutes

Theme	Pre-job briefing minutes (n=2)	Post-job review minutes (n=2)
Work description / background	Descriptions of planned schedule	Descriptions of realized schedule
Training, documents and permits	Reference to risk assessment form Reference to work permits, procedures and training materials Description of previous experience and special requirements	Reference to work permits and procedures (repeated from pre-job briefing minutes) Other topics discussed in pre-job briefing minutes were sometimes included in the structure of the minutes but had no content ('Nothing special')
Risks and mitigation	Work specific issues Occupational, plant, and environmental safety and production risks and mitigation measures	Risks discussed in pre-job briefing minutes were included in the structure of the minutes but had no content
Responsibilities and contacts	Table of names and phone numbers	Statement that responsibilities and contacts realized as planned
Operation in irregular situations	Description of what to do in irregular situations	Description of issues observed at work site and corrective measures
Reference to post-job review	Reference to post-job review to be conducted by the co-ordinating supervisor	Notion of good practice and suggestions for improvement

3.3.4. Summary

The results of the case study suggest that documenting meeting-based HU tools can be useful for at least three purposes.

First, documentation provides a paper trail that shows that pre-job briefings and post-job reviews have been held according to expectations (also documented). This helps in monitoring their implementation and development. However, the purpose of the documentation may merely be to adhere to rules if workers feel it is otherwise not useful, and this may reduce its quality. Considering that 40% of the 2020 Level 3 and 4 pre-job briefings had no filled in work permit system's feedback fields, and that there was no post-job review feedback, there may be some need for improvement in this area.

Second, documentation can serve as encouragement to systematically conduct pre-job briefings and post-job reviews, and to reflect on work performance in teams. Document templates, guidance, and open fields in the work permit system may help structure and motivate reflection, which may otherwise be difficult to do or to remember. The pre-job briefing minutes templates seemed to be useful for ensuring that all the relevant topics were covered – as well as topics that did not naturally emerge in work permit system's feedback comments. However, for post-job review feedback, this did not seem to be the case, as there were very few of them: additional help for supporting and structuring the documentation of post-job reviews seems to be needed.

Third, documentation can be seen as storage of information for organizational learning (i.e., organizational memory): the documentation created could or should be used by someone else or sometime later for learning and development. Based on the data reviewed, it is unsure whether documentation really is useful for this purpose. For example, a great deal of the work permit system feedback was rather declarative and as such may have little value for organizational learning.

Since the reviewed documentation primarily highlighted the topics that the co-ordinating work manager felt was important to record, it was not possible to determine which topics were really discussed during the pre-job briefings or post-job reviews. To capture this information, we have planned additional data collection in the form of interviews and focus groups for this case study.

4. CONCLUSION

In this research report, we have focused on three methods as examples of PD and on our findings and the lessons learnt from the methods applied. We have presented some examples of the work and its areas that need developing, based on the information that the three methods offered. The methods we applied were collaborative work process analysis (CWPA); a video-based method for collaborative learning; and the development of HU tools. The case studies were conducted in relation to nuclear maintenance operations.

PD in the nuclear industry was regarded as valuable, but there were also preconditions for its application. Our main conclusions are the following:

- First, the participants valued the discussions in the NPPs, and accepted the method and its evaluation. Applying the methods helped them find new aspects of the work and build a shared understanding of everyday work and its development needs
- Second, the importance of case selection for collective analysis and learning is essential for practical relevance and for motivating participants to join the discussions
- Third, it is important to enhance positive learning to observe and learn strengths and best practices and not only focus on disturbances or other failures.

In this study, we applied and evaluated each method separately, but in the future, they could be used to complement each other. Options could be:

- to use CWPA to obtain a bigger picture of the processes and their interconnections
- to use video-reflection to further analyse specific work phases with critical procedures
- to further apply CWPA and video methods
    - to analyse current HU tools and their use, and
    - to recognize needs to develop new HU tools, or
    - as part of HU procedures.

This potential could be further investigated in future research. In the near future, the research could also more fully clarify the benefits and countermeasures of utilizing PD-based methods in NPPs. Applying PD is somewhat time consuming, and the benefits must be clearly shown. For NPPs, concrete output is an essential criterion.

The drawbacks or disadvantages of PD methods could be that during their application, they may be experienced as an extra task in daily work processes, which increase workload. However, developing work should be regarded as an eminent part of normal daily work. Some methods, such as CWPA in this study, demand a skilful facilitator, and group dynamics may affect work or the output of the group's work: for example, some group members may dominate or underlying tensions between the functions or in the organizational culture may inadvertently be strengthened.

Whether these kinds of methods can be applied in practice is ultimately affected by the organizational and industrial culture. Applying methods with participative orientation may be one way to renew safety culture and make it more open, just and fair, thus making further steps in applying participative development (PD) easier.

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Appendix 1.

Use of the CWPA

The modelling group analysed their work from different viewpoints:

- Picturing the work process (yellow sticky note): shared understanding of the entire process, phases, and main tasks
- Critical phases, problematic tasks, needs for development (red sticky note)
    - critical analysis and discussion on possible short comings, recognizing possible safety-critical tasks, quality assurance
- Ideas, solutions, good practices (green sticky note): Collective, participative idea generation and planning for better productivity, safety, and well-being
- Other viewpoints, for example, collaboration needs (e.g., orange sticky note, other colours),
    - depending on the targets of the development and learning process

Figure 1, Appendix: Example of work process modelling chart.

Appendix 2.

Development plan – forms

Systematic modelling of the work process produced concrete proposals for how to improve the work. These proposals were gathered onto one form, which contained the following items:

1) Aspect to be developed; what must be improved/developed
2) Reasons: Why this aspect must be developed
3) Proposals for practical development measures
4) Benefits and possible drawbacks of realizing development measures
5) Prerequisites for implementing development measures
6) Who makes the decisions?
7) Who is responsible for the measures?
8) Who is the actual implements the measures?
9) Timetable of the measures
10) Follow-up and evaluation of development measures

(Teperi & Leppänen, 2011)