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TIETOA TYÖSTÄ

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ABSTRACT

This research report describes the development and implementation of an HF tool and the outputs of this process during the research project HUMTOOL (Applying an HF tool to learn about and to analyse the human contribution to nuclear safety) in 2015-2017.

Both international and national regulation and guidelines have set the principles for utilising human factors (HF) in the safety management of the nuclear industry. In this study, we define HF as individual, work, group and organisational factors that may weaken or strengthen safety, efficiency and well-being at work. To make the concept of HF concrete we use an 'HF tool' as a framework, to define the HF, and to determine which issues to focus on when aiming to increase awareness and competence of HF as a part of nuclear safety management, especially in operational event (OE) reporting and investigation.

In this research report, we summarise the development phases of the HF tool and evaluate the user experiences of the HF tool. We also ponder possibilities for nuclear actors (power plants, regulator, project organisation) to implement the HF tool, and identify areas in which the HF tool needs further development. We utilise findings of workshops and interviews conducted in 2015 and 2016 as background material. Mainly, this report summarises the work done in 2017, which produced research material comprising the intervention material and group interviews collected in five workshops with different nuclear actors, two NPPs, one NPP project and a regulator. To provide a solid basis for the HF tool, we also present the origin and theoretical background of the HF tool, made for Finnish air traffic management in the 2000's, to be utilised in the future development of the tool.

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1. INTRODUCTION

1.1. Human contribution in nuclear safety

The mastery of human factors (HF) is known to be necessary expertise, while the human contribution to safety incidents and accidents has already been recognised for a long time (Dekker, 2002; Reason, 1997; 2008). Learning about and analysing HF is crucial, especially in complex and safety-critical fields, such as the nuclear industry, which has potential for risks and even accidents due to the complexity, dynamicity and uncertainty of the systems (Norros 2004, Vicente 1997).

As a discipline, HF aims to apply knowledge in addressing human capabilities and limitations in the design of systems, and to maintain the efficiency, safety and well-being of those working within them (FAA 2005, Kirwan 2003, Wilson 2000). In this study, we regard HF as individual, work, group and organisational factors that can either support or detract from the functioning of systems, and thus, the safety of the services (Teperi 2012).

Despite long-term, active research in the field of HF, and although system safety models and frameworks have been changing from technical analysis to frameworks of HF, safety culture and system analysis (Hollnagel, 2006; Hale and Hovden, 1998), the emphasis on technological and procedural contributions to safety has dominated, and the human has not been in focus (Hollnagel, 2009; Kirwan, 2003; Teperi, 2012). It can be seen as posing risks, if awareness and competence in recognising and analysing HF as an essential part of the nuclear system safety is ignored or overlooked.

Learning to recognise, understand and analyse the variability of human action at work – does an action occur during normal operations or deviations from those – has been an area of interest in the HF discipline (Norros, 2004; Hollnagel, 2014). Also, nuclear safety guidelines have recommended incorporating systematic methods in the management system in order to identify and manage human and organisational factors affecting safety. According to the guidelines, on one hand, personnel's individual competence in the identification and management of HF and potential errors should be developed, and on the other hand, areas for safety culture improvement should be identified in connection with operational events[1] (OEs) (YVL A3, 303, 311, 315, 319-320). At best, OEs could provide learning material for the system, especially safety management.

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[1] Operational events, OE; such developments, failures, flaws and problems that are of relevance in terms of nuclear or radiation safety. (YVL A10, 104)

It is also recommended in the safety-critical areas that safety-significant OEs be investigated and further steps be taken in order to define corrective and preventive actions. Lessons learnt from the OEs (operating experience feedback) are crucial in preventing accidents and other events in future work (YVL A10; 101, 102; Dekker, 2007).

However, practical, user-friendly tools for the implementation of these recommendations may be missing. Most investigation or analysis techniques are designed for larger accident or case investigations, and they are intended for use by investigation experts (e.g., AcciMap or BowTie-method used by Accident Investigation Board of Finland; FRAM presented in 2009 by Leonhardt et al.). Furthermore, such techniques are time consuming and require strong input in training (Teperi et al, 2015).

In this HUMTOOL-project, the starting point has been that while operative personnel are not professionals of human contribution, they would nevertheless benefit from using a tool by which they could improve their understanding of and skill in identifying the HF contributing in their work and in OEs. They would also learn to analyse and learn straight from OEs, as a part of their everyday work. And finally, the concrete tool would help the organisation to define, by analyzing OEs, which are the appropriate corrective actions.

1.2. The HF tool as a concrete tool to apply HF thinking

In the HUMTOOL- research project, we chose an HF tool to serve as a concrete tool for learning about and analysing human contribution in the nuclear industry, especially from the safety point of view. This was chosen because there user experiences of the HF tool had already been collected from another safety-critical field, aviation.

In aviation, the HF tool was designed in 2003; it was first used in HF-trainings for air traffic controllers and later also became a part of incident investigation in the context of airport and air traffic management (ATM) operations. In 2008, the HF tool was implemented in the safety management system of the ATM, especially as a part of the incident reporting system, to discover which factors in one’s own actions or in work or organisational factors (i.e. human factors) weakened or strengthened the safety in the particular case. (Teperi, 2012; Teperi et al. 2015). The operative personnel (air traffic controllers and their chiefs) accepted the use of the HF tool as a part of the incident reporting system and the HF tool has been used since 2008.

The basic idea from the beginning of the use of the HF tool was that both the successes and failures of everyday work must be recognised and analysed. This was an essential and consciously-chosen aspect of the HF tool, to avoid creation or strengthening of blame culture; focusing on HF can easily lead to a focus on individual or error-based aspects which can result in individuals being blamed as guilty for risks at operative events. As is widely known, incidents or accidents are rarely due to violations and intended harm (Dekker, 2002), but rather, they are mostly the results of chains of events, which are more often weaknesses of some parts of the system, for example restrictions in the work processes or system design or lack of mutual information flow among different actors in the system. (Reason, 1997; Rasmussen, 1997). Finding positive aspects, and factors for maintaining safety in everyday work, has been pointed out as an important goal in the framework of a new safety thinking which focuses on factors that maintain and create safety, referred to as 'Safety II' and resilience (Hollnagel, 2006; 2014), and would also enhance an open reporting culture, as personnel recognise that reporting OEs would not result in blaming (Teperi, Puro, Lappalainen, 2017; Dekker, 2007).

Originally, when designing the HF tool for Finavia at the beginning of the 2000's, ideas of solution-based frameworks, which were regarded as modern thinking in work psychology at that time, also had an effect on choosing this aspect as a core idea of the tool. This aspect had not been raised previously by accident or incident investigations, and as such it can be regarded as quite an innovative way to model human action in safety. This perspective has also been visualised in Finavia incident investigation procedures since 2006 and also used in later developments of the HF tool (Teperi, 2014).

By analysing the positive and negative causal factors of the incidents at their work, the operative ATM personnel learnt to analyse the background factors of the incidents, and better understood the human contribution in occurrences and incidents emerging in their own work, including the human contributions of their own actions (Teperi et al., 2015), which is regarded as one important characteristic of a professional-level expert (Klein, 1998). The benefits of the HF tool were its visuality, user-friendliness and the congruence of its contents with existing HF tools such as HERA-Janus method and HFCAS, which had been used in aviation earlier. (Teperi el al., 2015).

The HF tool has also been modified and tested in other safety-critical fields such as maritime, aviation maintenance and railway. When tested with eight Finnish maritime organisations (Teperi, Puro, Lappalainen, 2017) we noticed that the HF tool offered potential for creating more positive safety culture, while reporting successes would decrease the risk of blame culture. In aviation maintenance, an HF framework offered by an HF tool supported understanding the safety-critical nature of operative aviation maintenance work. It also helped to recognise not only individual characteristics or errors, but also factors related to work processes, work group and organisation, and to formulise corrective actions for improving mastery of safety criticality at all organisational levels, including top and middle management, HR, OSH and safety/quality (Muukka, Teperi, Asikainen, Paajanen, 2017; Teperi, Asikainen, Ala-Laurinaho, Valtonen, Paajanen, 2018). In railway, the HF tool has served as a tool for better understanding not only of the technical issues or individual errors in the system, but for having a more holistic view of human actions in safety. It also enabled the use of this understanding to facilitate the improvement of safety culture by adding HF thinking to safety training contents and incident analysis as a part of the safety management of the organisation (Teperi, 2018).

2. AIMS

The HUMTOOL research project in 2015-2018 aims, as a whole, to study the appropriateness and use of the HF tool in nuclear safety management, especially as an investigation method in operative event (OE) analysis of the nuclear industry. Furthermore, we evaluate the implementation process of the HF tool - its effects on safety thinking and practices, as well as supporting and hindering factors of the implementation process.

In this research report, we focus on the following issues:

- How has the **HF tool developed during the HUMTOOL project** (and also before that so as to make the theoretical basis of the HF tool as solid as possible)
- **How do key persons of the nuclear industry (e.g. NPP safety experts, supervisors, other personnel) consider the HF tool** and the new parts added to it in 2017; are they useful and usable, and what kinds of uses could the HF tool have?
- How **should the HF tool be further improved**, to serve nuclear actors' needs?

On the basis of this research report, we seek to discover what are the supporting and hindering factors of the HF tool implementation process – this would be primarily a HUMTOOL goal for 2018 and the conclusion of the whole project.

3. THEORETICAL BACKGROUND OF THE HF TOOL

In the following chapter, we describe the theoretical background of the original HF tool designed for the ATM, as we consider (despite of all the limitations of the presentation) that this work could serve as background material and utilise future HF development in other safety-critical areas. For this report, we made small modifications for the nuclear focus; a more proper review of nuclear-related HF would be future work.

The contents of the HF tool are constructed by several theories, especially the frameworks of work and organisational psychology, learning at work, organisational learning and cognitive engineering (Teperi, 2012). Furthermore, the original HF tool modified for ATM included some aviation and ATM specific HF, raised by classic accidents at the field such as the Tenerife runway accident in 1977 described by Weick (1993) and by international ATM guidelines such as ICAO, 1989; 1991; 1993 and Eurocontrol, 2008; Teperi, 2012). In these, for example, communication failures or group dynamics were focused on as sources of vulnerability in the operations, but also as resources for maintaining both individual and shared situational awareness during the flight and ATM operations. The theoretical background is described in more detail as follows (this was not published earlier because of the space restrictions in the already-published scientific articles regarding the HF tool use in ATM, nuclear and maritime).

Based on the theoretical background mentioned above, the HF tool consists of four basic levels (not meaning hierarchical levels), which all have an effect on success and safety of the operations: individual, work, group and organisational levels (e.g. Vicente, 1997).

The reason that these levels were included in the tool was that, traditionally, the HF framework has been mistakenly mixed with human error- scope, although individual- and error-based aspects of HF have been only one of the development phases of HF as a discipline, in which, for example, errors at work were classified by their origin or purpose to slips, lapses, errors, mistakes and violations (Reason, 1997; Rasmussen, 1997). The other levels of human action (work, group, organisation) were included in the tool, to show that risks with different variations and severity (near-misses, incidents, accidents) happen because of several background factors not only in individuals' actions, but also in work environments (ergonomics), team and group work and in the organisation. Thus, the HF tool aims to represent a system theoretical model (Leveson, 2011).

Each level includes items that give detailed information of that level (e.g. items 1.-12. at the individual level) – these are numbered from 1 to 47 with the following logic:

I Individual factors and actions, items 1-12*

II Work characteristics, items 20-29

III Group/team factors, items 30-36*

IV Organisational factors, items 40-47*

In total, the HF tool includes 37 items revealing the aspects of human behaviour that can emerge as risks or resources in the complex system (obs. *, not all the numbers/items are used, while at the beginning of designing the HF tool, some empty space /'items' were left, to allow for improvement of the tool afterwards).

The basics of each of the four levels and their details are defined as follows. The numbers in parenthesis at the start of each item are to help the reader to perceive the picture (Figure 1).

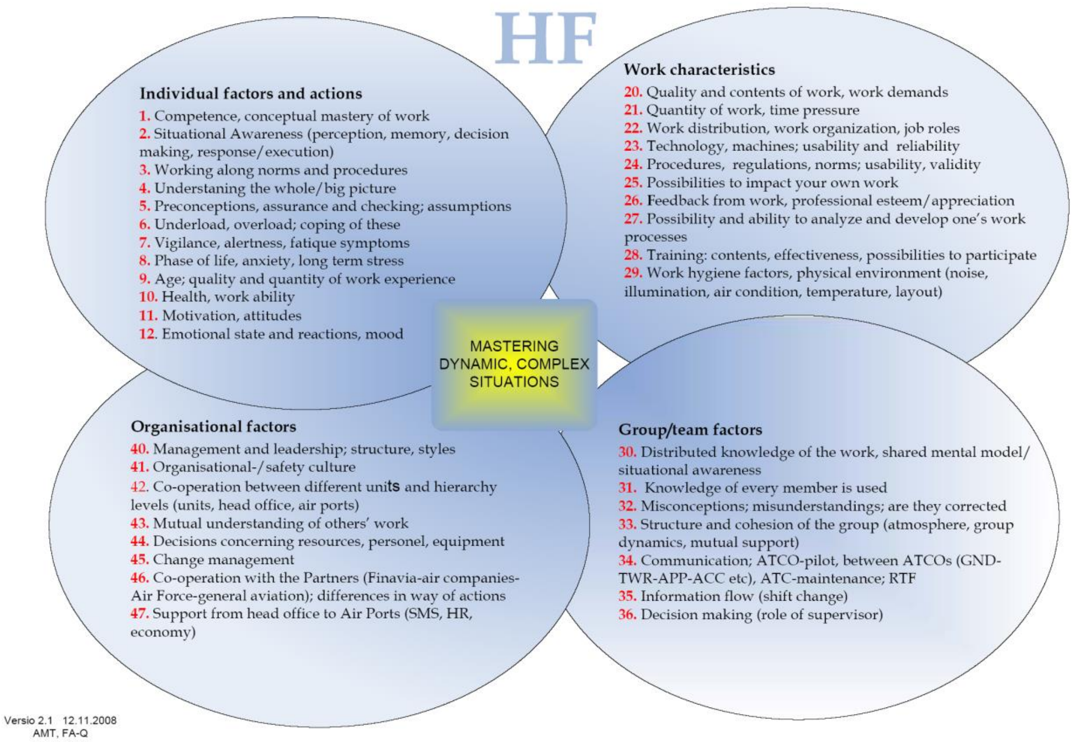

Figure 1. The original HF tool for ATM with four levels (individual, work, group/team and organizational factors) and items included in these levels.

Short definitions or descriptions of each level and item included in the HF tool are given as follows (figure 1).

3.1. Level I - Individual factors and actions

1. Competence is a driving force behind safety systems (Reason, 2008). In high-reliability domains, poor performance may result in high costs and ultimately loss of life (Cox and Sharples, 2007). One way to operationalise competence in scientific studies has been by use of the idea of a 'conceptual mastery of work', which means a person's theoretical understanding of the work process that he/she is working with, including things like what is happening, why, which tools are used, how the operation is run and how the process is corrected if there is a breakdown (Leppänen, 1993). High conceptual mastery of work is related to the wellbeing, job satisfaction and development orientation of workers (Leppänen et al., 1997).

2. Situational Awareness, (SA), including perception, memory, decision making, execution, is defined as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1999). It is essential in hazardous domains, but difficult to acquire and maintain (Reason, 2008). Several ATC-related aircraft accidents and incidents have contained attention slips and errors in judgement (Danaher, 1980; Billings and Reynard, 1984). Dekker (2002) has pointed out that using only the SA conception poses the risk of simplifying the complexity of cases.

3. Working along strict safety requirements, norms and procedures is a prerequisite for safe and efficient ATM processes (e.g. ICAO, 2001; 2005), and is also a firm basis for working in the other safety-critical domains (in nuclear, see for example IAEA, 1998).

4. Understanding the whole/having 'a picture'. The theoretical construct for this phenomenon is a mental model, an internal presentation of the system the people are dealing with. People form internal, mental models of themselves, and of the things and people with whom they interact. They help humans to predict, explain and understand the environment and interaction around them. The mental model may be specific to a given situation (e.g. certain type of traffic) or more globally to the entire task domain (e.g. entire flight sector). They may include abstractions concerning operating guidelines or functional relationships. The models are neither complete nor accurate, but guide human behaviour (Endsley, 1999; Norman, 1986).

5. Foresight is formed in proper learning from the lessons of experience or active processing of 'faint signals'. Assuring the state of one's own SA is a basic premise in safety-critical domains in order to prevent use of wrong preconceptions during the operative working (Endsley, 1999; Reason, 2008).

6. Workload (and coping with it) has been a causal factor in accidents and a source of stress in ATC. Sources of overload can be mental (e.g. number of aircraft under control) or physical demands (Costa, 1995). Underload (e.g. insufficient workload) can cause boredom, complacency, degraded conflict detection and the operator losing awareness of the system's true state. (Metzger and Parasuraman, 2005). See also item 21.

7. Vigilance refers to the ability of an observer to maintain attention over long, uninterrupted periods. The rapid drop occurs when a person is performing a monitoring type of task, inducing a slowing in reaction times or an increase in error rates during task monitoring. (Glendon and Clarke, 2016; Sawin and Scerbo, 1995) The effects of fatigue on persons performing (e.g. lowered attention, higher risk taking, increased error rate) have been a concern, and they have contributed to aviation mishaps. (NTSB, 2007; Roske-Hofstrand, 1995). Working times, e.g. unbroken duty periods, shift and night work, can affect wellbeing in ATC (Costa, 1999).

8. Phase of life, anxiety and long-term stress are essential components which can affect well-being and safety. Stress is a normal reaction to a demanding situation. There are individual differences with respect to stress reactions; what one perceives as stressful, may be a challenge for another. Beyond a certain point, individuals under stress perform less than optimally and stress can adversely affect quality and safety (Glendon and Clarke, 2016). Both employers' and employees' duties to ensure safety and health at work are emphasised in international and national legislation (e.g. OSHA, 1970; Työturvallisuuslaki 2002). To reflect one's own stress (or burnout) level, several measures are available, for example professionals have used the Maslach Burnout Inventory, to estimate the three dimensions of work-based burnout, exhaustion, cynicism and lack of professional efficacy. (Toppinen-Tanner, 2011). To evaluate the effects of the phase of life, Holmes and Rahe (1967) studied whether or not stress contributes to illness and defined a stress scale, which is a list of 43 stressful life events that can contribute to illness.

9. Aging affects a variety of cognitive abilities that are critical to performance in safety-critical work. Visual function, memory, hearing and the ability to understand spoken information decline with age (Ilmarinen and Bonsdorff, 2015; Costa, 1999), but the quality and quantity of work experience also affect performance.

10. Health, work ability. Work ability is defined as the balance between human resources and the demands and characteristics of work. It has a complex structure also including factors outside the working life (Ilmarinen et al. 2005; Ilmarinen and Bonsdorff 2015)

11. Motivation is the willingness to exert high levels of effort toward goals (Robbins, 1996). It is an essential component of commitment and thus one origin of good safety practices (Reason, 2008). Attitudes are evaluative statements or judgements concerning objects, people or events, and they may be revealed as opinions, feelings or a certain way of behaving (Robbins, 1996). In safety-critical operations, e.g. overconfidence or risk taking may emerge which create a state of risk to the safety of the services.

12. Emotional reactions; a temporary state of mind. Emotion is fundamental to nearly all aspects of work behaviour (Briner, 1999). Emotional reactions in ATC work can arise due to a feeling of loss of control, fear of consequences of errors, or relations with supervisors and colleagues. Critical incidents can cause stress; critical incident stress management is recommended at work places which may suffer from work-related risks, near misses or incidents (Leonhardt and Vogt, 2006).

3.2. Level II - Work characteristics

20. Quality of work, work content and work demands affect how a person experiences task significance and autonomy at work, and these can affect performance and well-being (Glendon and Clarke, 2016). According to the job characteristics model, these impact critical psychological states such as experienced responsibility for outcomes at work, and thus work motivation (Hackman and Oldham, 1976).

21. Quantity of work and time pressure (also named "hurry-up syndrome" in aviation) are found to be related to operational errors (Schroeder et al, 2006) and stress in ATC (Costa, 1995). Operator's performance can be degraded by a need to rush tasks because of the pressure to keep on schedule, delays due to weather, peak traffic hours etc.

22. Work distribution, work organisation and clarity of job roles, such as role ambiguity, can be sources of stress in ATC work (Costa, 1995). In ATC, work positions can be manned by groups or individuals; both can have risks (see more information at items 1.-12., 30-36.)

23. Technology, machines; usability, reliability. The ATC system can suffer disruptions as a result of limitations and reliability of equipment (e.g. radar system, radiotelephone quality, equipment layout). Degraded modes occur when operators struggle to maintain levels of service even though key elements of their infrastructure have failed (Johnson et al., 2009).

When equipment failures occur, system safety relies on the skills of controllers, pilots and engineers and safety is maintained by reducing the number of aircraft in the air. (Costa, 1995). Automation in ATC (e.g. the move towards free flight, i.e. pilot-mediated ATC) may increase efficiency, but it has also raised questions about adequate human control over automated systems. Technology can build on human strengths and compensate for human vulnerabilities, but at the same time, mistrust of automation and complacency may emerge. Several studies have dealt with this phenomenon (e.g. Kirwan, 2001; Wickens et al, 1997; Metzger and Parasuraman, 2005).

24. Procedures, regulations and norms are stated to achieve an interoperable global ATM system that meets agreed levels of safety and efficiency (ICAO 2001, 2005). In some cases, operators face conflicting goals and may have to bend the rules to maintain safety (Dekker, 2002). (at the individual level, this issue is focused on in item 3)

25. Possibilities to impact your own work. Lack of control over work process can cause stress and lack of work motivation (Glendon and Clarke, 2016; Hackman and Oldham, 1976, see also item 20). User involvement and participative planning in system design is essential (Wilson and Russell, 2003).

26. Feedback from work; in well-designed and organised work, people can get feedback straight from the work by seeing the result or output (Hackman and Oldham, 1976).

27. Possibility and ability to analyse and develop one's work processes (Leppänen et al., 2008; Boreham, 2002) is a way to develop competence, work mastery and well-being at work, but also a prerequisite of maintaining a high safety level (Norros, 2004; Klein, 1998; (Weick and Sutcliffe, 2003)

28. Training: contents, effectiveness, possibilities to participate. It is crucial how the workplace affords opportunities for individuals to engage in workplace learning and training activities and if an active learning culture and supportive workplace climate exist. (Billett, 2001, 2004; Eraut, 2004).

29. Work hygiene factors, physical environment (noise, illumination, air condition, temperature, layout) have been recognised as work motivation factors (Robbins, 1996) and can be relevant sources of stress at work (Costa, 1995).

3.3. Level III - Group/team factors

30. Team SA is the shared understanding of a situation among team members at one point in time; this is facilitated by team processes (e.g. mission objective, team capabilities) and behaviours (e.g. assertiveness, leadership) (Salas et al. 1995). Shared mental models refer to cognitive processes associated with teamwork, meaning knowledge that is shared among team members. This enable members to anticipate others' behaviour and information requirements in critical situations, e.g. when communication is limited. (Salas et al., 1995; Paris et al., 2000; also Hutchins, 1995 distributed knowledge).

31. Knowledge of every member is used. ATC relies on the performance and skills of teams rather than on the performance of individuals; no individual is able to totally control a system operation, e.g. mutual performance monitoring is needed. (Cox et al. 2007; Salas et al., 2001; Paris et al., 2000). See for power structures items 32. and 33.

32. Misconceptions; misunderstandings; whether they are corrected. In some serious aviation mishaps, power status or situational constraints of the crew have inhibited fluent information exchange and correction of unclear communication (Weick 1993). Crew Resource Management (CRM) training has been applied, to support crew performance. CRM focuses on non-technical skills, such as team work and error management (Helmreich et al. 1999), and it has enhanced learning and promoted desired behavioural changes at several safety-critical domains (Salas et al., 2001). The majority of empirical team studies have focused on military command and aircrews (Salas et al., 1995). See also item 34.

33. Structure and cohesion of the group (atmosphere, group dynamics, mutual support). The effective sphere of the team impacts on team performance through social facilitation, group conformity, mutual trust and collective efficacy (Annett and Stanton, 2000; Paris et al., 2000).

34. Communication; between ATCO-pilot or between different ATCO roles (GND-TWR-APP-ACC[2]), ATC-airport operations; radiophraseology (RTF). Similar call-signs, loss of communication, frequency change, nonstandard phraseology, blocked transmission and radio interference have been the most frequent communication risks in ATM; several proposals to improve these have been put forth (Eurocontrol, 2006). (also item 32.)

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[2]Tower control unit (TWR) provides ATC services to flights that are landing/taking off/other traffic that is on the active runway(s). Approach control unit (APP) provides ATC services to arriving, departing and over-flying flights within the airspace in the vicinity of an aerodrome. Area control centre (ACC) provides ATC services to en-route traffic in control areas under its jurisdiction. Ground (GND) unit takes care of ground movements of the vehicles and aircrafts.

35. Information flow at the work unit, also including information transmission during shift handovers. Shift handovers should be proceduralised to ensure adequate communication and shared SA regarding local conditions (Reason, 2008).

36. Decision making in a group (e.g. role of supervisor) demands recognising the problem and the need for action, and assessing the risks included in these (Williams, 2007). Both analytical and intuitive decision making are needed (Paris et al., 2000). The latter type of decision making, intuitive, is prevalent in real-world settings characterised by, e.g. limits on time, information and resources (Klein, 1998).

3.4. Level IV - Organizational factors

40. Management and leadership; structure, styles. In safety-critical domains, leaders, especially middle management, play a pivotal role in promoting team performance and safety (Kunzle et al., 2009; Lu and Yang, 2010). Flin (2006), states that earlier accounts of air disasters revealed an erosion of managerial resilience.

41. Organizational-/safety culture is defined as safety-related values, attitudes, beliefs, risk perceptions and behaviour of all employees (Lee and Harrison, 2000). Organizational structures, conflicts and culture can constrain opportunities for learning and improving the ways of acting at work in ATC and other complex systems (Owen et al.2009; Weick and Sutcliffe, 2003). Poor safety culture is often linked to the causes of major accidents and incidents (Johnson et al., 2009).

42. Co-operation between different units and hierarchy levels (units, head office, airports). Organizations or work places are collective activity systems which transform through stepwise cycles of expansive learning (Engeström, 2000). New forms of work organization include interdependency between multiple producers, as well as clients and users, and require negotiated 'knotworking', joint cognitive processes and networked expertise across boundaries (Engeström, 2000; 2004; Hollnagel, 2003; Hakkarainen et al., 2004). Conflicting interests in an organization are a source of organizational failure (Perrow, 2007; Rasmussen, 1997).

43. Mutual understanding of others' work. Work process knowledge is defined as an expanded understanding of work roles in parts of the organisation other than the employee's, also including an awareness of the interdependency of the activities in different sections and an understanding of the system as a whole (Boreham, 2002).

44. Decisions concerning resources, personnel, equipment. Executive failure is a situation where top management makes deliberate, knowing choices that harm the organization and its environment, because they have other interests in mind which would be threatened by an effective safety culture (Perrow, 2007; e.g. Milestone and Enron cases at court).

45. Change management (e.g. in personnel or systems). Changes in ATC can result in a variety of changes in how controllers coordinate their activities, communicate, and perform their tasks. The effects of these changes need to be anticipated before they are made (Bonaceto et al., 2005). Participative planning and a positive organizational climate support change (Arvidsson et al., 2006).

46. Co-operation with the partners (in aviation context: air navigation services-airlines-air force-general aviation). There may emerge differences in ways of action and subcultures of the different stakeholders which still have a common work object, safety and efficiency of the services. (Westrum and Adamski, 1999).

47. Support from head office to airports (SMS, HR, economy), see also items 33, 42. When safety improves, the solutions used to improve the safety record should not be further optimised in organisational decision making, usually driven by economic goals (Johnson and Kilner, 2010; Perrow, 2007; Ek et al., 2007; Amalberti, 2001).

3.5. The core of the HF figure (the rectangle in the middle of the HF tool)

The core of the HF tool is named "the mastering of dynamic and complex situations". The theory behind the core refers to the CDU framework, that focuses on complexity (C), dynamicity (D) and uncertainty (U) of the systems of actions (Norros, 2004; Vicente, 1999).

The core of the HF tool aims to summarise the (conceptually overlapping) levels and items that cause complexity, dynamicity and uncertainty in the safety-critical system (here, originally, the ATC system). For example, in the ATC system, several factors contribute to complexity, e.g. combination of high traffic volume, traffic mix, weather and runway/taxiway configuration conditions (Koros et al., 2003). ATC is also a dynamic system in which the state of the system changes both autonomously and as a consequence of manipulations (Manning and Stein, 2005; Cox et al., 2007). Uncertainty in the ATC is sometimes characterised by multiple, ill-defined goals that conflict with each other (e.g. efficiency vs. safety; Ek et al., 2007; Dijkstra, 2006). Few things can be controlled in decision-making, and many key variables and their interactions are not fully understood and are difficult to measure (Klein, 1998; Manning and Stein, 2005).

3.6. Reasons for using the HF tool and HF tool use in the ATC

The HF tool was originally established for the ATC safety management system as a part of the reporting system run by the safety and quality unit. ATC chiefs and operators were asked to analyse incidents in their own units using the HF tool.

The HF tool was created not only for finding the background factors of operative incidents or near-misses, but *to reach some essential aims in regard of improving safety management and safety culture, and there were three of them*:

Firstly, there was an interest in developing deeper understanding, awareness and improved analysing skills of the managers and operators related to safety issues in the organisation. It has been found that this kind of analytic, reflective and investigative role develops the whole system and should be included especially in the work of complex systems, where multiple factors may cause complexity, uncertainty and dynamicity, also affecting the safety of the services (Klein, 1998; Weick and Sutcliffe, 2003; Norros, 2004). Reflecting is also highlighted as an important aspect in the field of workplace learning (Eraut, 2004).

Secondly, ATC operators (air traffic controllers) had large scale HF–training as part of their basic and refresher trainings (Teperi, 2015). But there had not been systematic and accurate HF training for the managers of the organisation (HF training of ATM personnel was in focus because of international guidelines). This was a bit paradoxical, as managers have a crucial role in developing safety culture (Flin, 2006), and applying HF thinking has been regarded as a good tool to facilitate that (Teperi et al., 2017; Teperi and Puro, 2017), but in this organisation, the managers' views concerning HF were fragmented and still developing (Teperi and Leppänen, 2010). Using the HF tool for supervisors was a way to learn about HF and to commit them to this new thinking.

Thirdly, it was important to collect and code occurrence/incident data to discover background factors for the incidents. Development of safety relies on the accurate identification of the factors that can contribute to a risk of accidents (Dekker, 2002; 2007), and to find the right corrective actions to be executed. Collecting and analysing data, using the HF tool, provided the possibility of obtaining this information and maintaining the comparability of findings over time.

To fulfil the above aims, the use of the HF figure was trained in 2008 (in a brief session) as a part of a broader SMS training for 70 managers of the organization (airport managers, chiefs of airport operations, ATC and technicians). Air traffic controllers had already been trained in use of the HF tool. A check list type, 'pocket size', laminated copy of the HF tool was delivered to the managers and to operators and they were asked to use the HF figure to analyse each incident report. They were asked to mark with a minus on the report sheet those HF factors that were causal factors in the incident (e.g. items –2, -23, -34, -46 of the HF figure). Also, they were asked to analyse the positive factors, meaning factors that maintained safety and prevented the situation from becoming worse, and to mark these with a plus on the report sheet (e.g. +3, +9, +35). (see figure 1 in 2.2).

The noted HF were collected on the database of incidents. The results were summarised in the monthly and annual reports of incidents delivered to personnel, supervisors, middle and top management and the board of the organization.

Coding of the data was first manual (reports were on paper), but in 2009, the HF figure was modified as an electronic form, at the same time as when the reporting system became electronic (eCOORS, electronic Confidental Occurrence Reporting System).

During the use of the HF figure, the safety and quality unit could follow the narrative descriptions covering the cases, in order to understand the circumstances and environment of an incident. Thus, it was possible to use data created in the natural settings (ref. NDM studies; Klein, 1998), even though it was not possible to include the descriptions in the published studies, in order to maintain the confidentiality of the reporting system and single reports.

4. DEVELOPING THE HF TOOL FOR THE NUCLEAR INDUSTRY – MATERIAL AND METHODS

4.1. Modifying and testing the HF tool in the nuclear industry (2015-2016)

Based on the ATC experience, the HF tool was modified for the purposes of nuclear safety in the HUMTOOL project in 2015, and is presented below (Figure 2).

Figure 2. HF tool modified for purposes of nuclear safety in this project (originally applied in ATM; Teperi, 2012; Teperi et al., 2015)

The first nuclear version of the HF tool was modified with the HF-experts of two NPPs at the first workshop (one HF-expert from each NPP; Table 1). We then tested and evaluated 'the nuclear HF tool' at the second workshop in September 2015 with ten experts from two NPPs, in addition to 21 interviews in NPP1 and NPP2 conducted after the workshop. The main findings are summarised as follows (results are described in more detail in the published scientific article Teperi, Puro and Ratilainen, 2017),

Study participants named both strengths and weaknesses of the use of the new HF tool in interviews after the workshop.

The most-mentioned and essential strengths of the use of the HF tool were, that the HF tool

1) broadens OE investigators' understanding and helps raise issues that would not otherwise be raised
2) is clear, simple, understandable, concrete and easy to use ('You can quickly learn how to use it; each item is understandable and unambiguous ')
3) gives a positive perspective to whole investigation of OE
4) classifications (of the tool) are clear with detailed items

Meanwhile, study participants mentioned some weaknesses of the use of the new HF tool, listed below:

1) Takes more time and feels difficult to use (at least at the beginning)
2) Some items are difficult to understand
3) HF tool is missing something
4) Risk of losing the scope of analysing technical factors.

Furthermore, study participants' views regarding the HF tool's future use were requested both in the interviews (2015) and during workshop 2 (2015). Interviewees mentioned 16 different ways of using the HF tool in the future. The most often mentioned suggestion was that of using the HF tool as a tool for different phases of OE investigation, namely reporting, data collection and defining corrective actions.

The results also revealed that the successes and positive points of handling OE were recognised through the new tool. The testers told, that this aspect helped them to talk more broadly about the case, while previously, the discussion around operative events had been more focused on negative aspects and items that had failed.

At the third workshop of the project (held in November 2016) the HF tool contents were refreshed and further practiced with the participants, also by using a maritime case (Herald of Free Enterprise- case; the HF tool use also described in Teperi and Puro, 2017). At the workshop, an 'HF tool-clinique' was also held, to make some items of the tool more accurate, and some of the items were slightly changed. At the workshop, NPPs also told about the decision of using AcciMap in future investigations.

To sum up, in 2015-2016, the following actions were done in the HUMTOOL research project, also including actions that are not reported in this report but in a scientific article published earlier (time collected, material, basic question or finding, Table 1):

Table 1. Actions in the HUMTOOL project in 2015-2016 (workshop numbered from WS1-WS3, to clarify the workshops held during the whole HUMTOOL project in 2015-2017

Time	Workshop number	Material	Main findings in 2015-2016
4/2015 6-8/2015 8/2015 9/2015 11/2015	WS1 WS2	- workshop to modify HF tool for nuclear purposes - safety documentation analysis regarding current HF guidelines and current practices (e.g. YVL guide, guidelines at each NPP). - group interview at regulator - workshop to train and test HF tool; intervention material - individual interviews at NPP1, n=12 - individual interviews at NPP2, n=8	-currently, conceptions regarding HF are individual and error based which may hinder the awareness and improvements at the organisational and system level of nuclear industry* - need to concretise the conception of HF.* - in NPPs, several human performance tools have been implemented, but none of them highlight human success factors* - HF tool was regarded as easy-to-use, and it was considered a useful tool especially at OE analysis, reporting and training*
11/2016	WS3	-workshop with NPP1 and NPP2, to further evaluate the HF tool and its use	- need to clarify part of the HF tool items - need to have more detailed supportive material handling HF tool items

*results published in Teperi, Puro and Ratilainen, 2017.

Based on the findings made above, we summarised the main weaknesses and solutions for those in HF tool improvement (Table 2).

Table 2. The most important development needs of the HF tool, and the solutions for them based on the first testing findings in 2015-2016

Development needs (weaknesses) of the HF tool	**Solutions for the needs**
Takes more time and feels difficult to use (at least at the beginning)	More user training of HF tool and introduction to human factors Support in using the HF tool in OE investigation A fan of support questions (=the HF fan)
Some items are difficult to understand	Development of HF tool items together with OE investigation team in workshop 3, clarifying the difficult items and fine-tuning wording and phrases. Developing a fan of support questions
HF tool is missing something	Including the society level of HF as tool in HF map version
Risk of losing the scope of analysing technical factors	Items (especially item nro 23) will be modified in such a way that technical issues will be more focused (Workshop 4)
An idea of merge the HF tool and AcciMap (participants proposed this in WS3)	Developing the HF map
Need of support questions for HF tool items (WS3 proposal)	Developing the HF fan
Some detail changes to some HF tool items (WS3 proposal)	Fine-tuning of wording and phrases of the HF tool
HF tool does not guide to corrective actions	Include corrective actions line up in HF map

Based on the findings above, we determined that broader awareness of the conception of HF, and the concrete means to put it into practice would support the implementation of HF related issues in nuclear safety in such. Also, the HF tool itself would need some improvement, in order to be implemented properly.

4.2. Rethinking and developing the HF tool (2017)

Study participants had mentioned many different ways of using the HF tool in the future in earlier workshops (Workshops and interviews in 2015-2016). Nevertheless, they had not used the tool in OE investigation or in different safety operations. Study participants had named several weaknesses and support needs in using the HF tool, which was the starting point for further development process of the HF tool in 2017. The following actions were then taken, based on earlier findings.

4.2.1. Need for support material for using the HF tool – A fan of support questions

The need for support material of HF tool was revealed many times and especially, the study participants had asked support questions concerning HF tool items or for detailed examples of different items.

A fan of support questions was developed in early 2017 (named the HF fan). The HF fan included 1-6 support questions for each HF tool item and tight instructions for use. The detailed material was based on theoretical background of the HF tool (presented in this research report in chapter 1.3.) which was also used as a background at the HF basic training, put into action at workshops in 2015 (HF-basic training; Teperi 2015).

For example, the item number 20 (Quality and contents of work; work demands) has three support questions:

- Was the duty interesting, meaningful and varied enough?
- Was the challenge of the working situation appropriate in relation to one's know-how?
- Was the duty too routinely or too rarely repeated?

4.2.2. Developing the HF map: integration of AcciMap and HF tool

In the earlier workshop (in 2016) study participants had proposed integration of their currently-used OE investigation method AcciMap and the new method HF tool. They argued, that they are competent in using the AcciMap method and, furthermore that it is useful and familiar. On the other hand, AcciMap was missing the best features of the HF tool – positive perspective and HF perspective.

In the HF tool developing process (Figure 3), the first phases were to modify an ATM version of the HF tool to a nuclear version of the HF tool, and three timelines, grey, green and red timeline were added to the use of the HF tool, to analyse the neutral events of the OE (grey timeline), as well as the successes (green timeline) and the failures and errors (red timeline) of the case (timelines are more detailed described in Teperi and Puro, 2017 and Teperi, Puro, Ratilainen, 2017).

In 2017, this analysing method was replaced by the HF map diagram. The core idea of the AcciMap technique was included in the HF map: the HF map is a multi-layered causal diagram and various causes of incident/OE will be arranged to diagram. The most immediate causes are shown at the bottom (lower sections) of the diagram and every cause of the incident will be modelled in the same diagram at different levels.

Sectors of the HF map are named according to modified levels of the HF tool – they were named (from bottom to top): 1) Neutral timeline (events), 2) Individual actions and factors, 3) Work actions, work characteristics, technics, 3) Group/team level actions 4) Organisational level actions 5) System level (authorities, stakeholders).

Unlike in the AcciMap diagram, the HF map diagram is constructed from both positive factors of incident and negative causes of incident. Identified HF (both positive and negative) behind an incident are represented in the HF map diagram with green plus (+) or red minus (-) signs and numbers of HF tool item.

An actions-line was included in the HF map diagram in order to instruct determinate corrective and preventive actions and put them into practice.

The first user's experiences of the HF map and the HF fan were collected in group discussions after workshops in NPP1 and NPP2 and with the safety authority in 2017. Further development of the tools (HF map and HF fan) will be done together with participant organisations in 2018.

The development process of the nuclear version of HF tool is summarised in Figure 3.

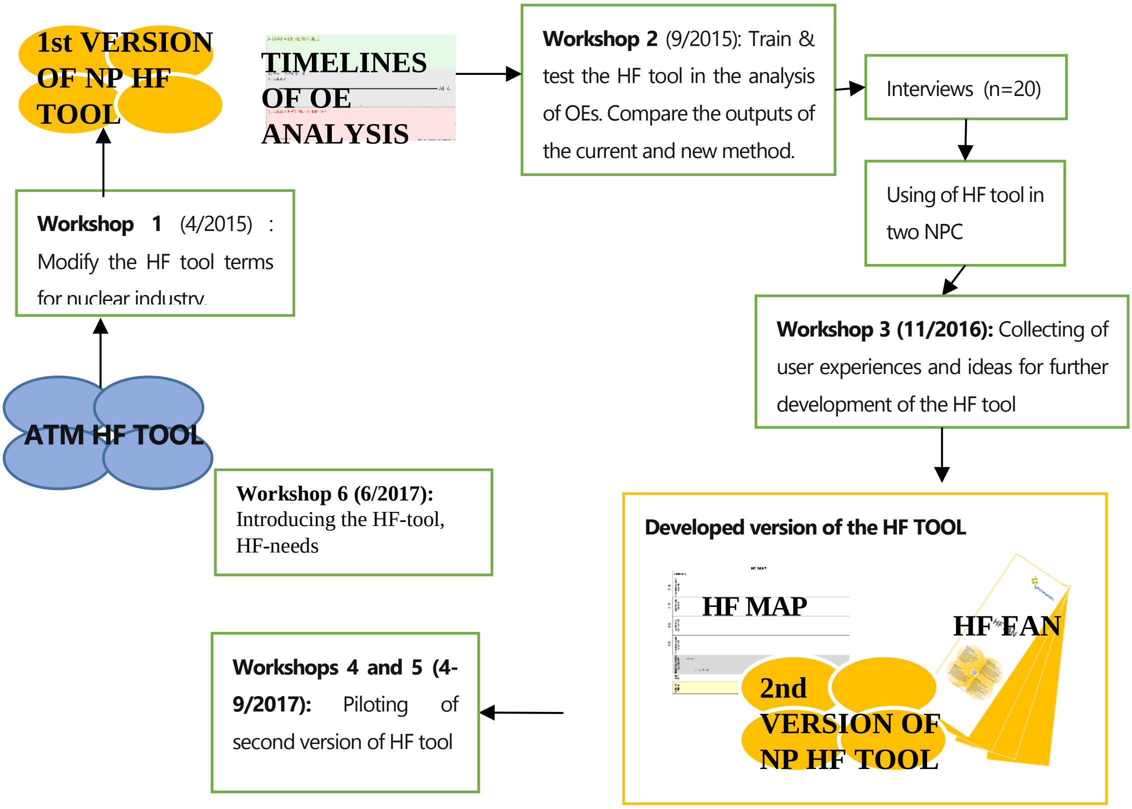

Figure 3. The development process of the nuclear version of the HF tool.

4.3. Testing and implementing the improved HF tool – interventions in 2017

Next, we focus on research actions in 2017 which were the further actions (developments, implementations) based on the needs revealed in 2015-2016. We continued research with two NPPs which had been participating from the beginning of the project.

We also increased and broadened the participants' scope by inviting the authority (Radiation and Nuclear Safety Authority) partner and a nuclear project organisation (also called NPP3 later in this report) to the project. We wanted to strengthen the participation, have more views for the development and implementation of the HF tool and, as such, have a more systemic view of the HF implementation as a part of safety management at the nuclear industry level.

The stakeholders in 2017 were four together, namely two NPPs, one NPP project and a regulator with which we held workshops (Table 3).

Through analysing the material of the workshops (intervention material, i.e. testing the HF tool in OE analysis; interviews) we evaluated the users' needs, experiences and possibilities for applying the HF tool in the nuclear industry, as well as supporting and hindering factors in the implementation process. Possibilities to use the HF tool in the whole Finnish nuclear sector, by different stakeholders, were studied.

We also started to validate and test the HF tool, and recognised HF needs of NPPs.

In 2017, the following workshops were conducted, and the following more specific questions were studied (workshop numbered from WS4-WS7; Table 3)

Table 3. Workshop with the nuclear stakeholder, time, material and issues studied.

Time	WS	Material	Issues evaluated in this research report (2017)
4/2017	WS4	-group discussions/interviews of NPP1	- HF needs of the nuclear key actors
6/2017	WS5	-group discussions/interviews of NPP project	- dissemination of the current results to an authority and NPP project
9/2017	WS6	-group discussions/interviews of regulator	- HF tool developments based on recognised HF needs of the organizations; user support.
9/2017	WS7	- group discussions/interviews of NPP2	- successfulness of the implementation process of the HF tool.

As we wanted to apply nuclear system thinking in practice, we also held a few other workshops with other SAFIR –partners (research project MAPS and other work packages at the CORE research project this HUMTOOL project), to have more joint discussions about the nuclear research topics, and with MAPS, we also decided upon further co-operation. Material from these workshops and meetings are not used as a research material, but more for project background information.

4.3.1. Investigative workshops with NPP1 (4/2017) and NPP2 (9/2017)

Two workshops in 2017 were one-day workshops (6.5 hours), held by two members of the HUMTOOL research group (coded as WS4 and WS7 in Table 3). The investigation workshop was held in NPP1 in 04/2017 and seven safety experts participated. The second investigative workshop was held in NPP2 in 09/2017 and ten safety experts from the NPP2 participated. Some of the experts in both workshops had participated in one or more HUMTOOL-workshops earlier (held in 2015 and/or 2016) and some were not familiar with the project or the tools used.

The HF tool and the HF fan were sent to the participants beforehand, and they were asked to use them when collecting data/interviewing participants and etc. in the OE investigation process. The HF map was introduced in workshops before the analysing sessions.

The aim of the workshops was to train the participants and to test the HF map and the HF fan in analysis of OEs in genuine situations in NPP. The secondary aim of the workshops was to support and spar NPPs and safety experts in OE investigation teams in HF thinking and using the HF tool (including its new techniques, HF map and HF fan) in OE investigation. Before using the HF map, its structure, content and basic ideas were explained to the participants with an example case from maritime (accident of Herald of Free Enterprise).

After introductions, the participants were divided into two subgroups and asked to conduct the OE analysis using the HF tool and its fan and the HF map. The participants were encouraged to ask help from the researchers whenever needed. When both subgroups had done the neutral timeline of the HF map, the timelines were opened and analysed all together before continuing the analysis of OEs. After the investigation sessions groups presented their results (HF maps) to each other, and the results of both group were compared and differences were discussed. The discussions were recorded and the written material and notes that they produced were collected (HF map presentations in A3 size paper or in digital form).

After the investigations of OEs, two researchers conducted a group interview (39 and 48 minutes) for participants, in order to collect first user experiences and further development needs of the HF tool. The group discussions were recorded and transcribed.

Detailed themes of the interviews were:

A. Using the HF tool and the HF fan in collecting the data
    1. How did you use the HF tool and the HF fan in the data collecting process?
    2. If you used them, how did you find using them? Did they add the value to the investigation process? Was it easier to use the HF tool with the HF fan than without it? Do you have some proposal for further development of the tools or some kind of feedback?
    3. If you used the HF fan in conducting the interviews, did you get any feedback about it? What kind of feedback?
    4. Now that you have explored the HF fan, how do you think it could be utilised in the data collecting of OEs?

B. Evaluation of the workshop
5. What thoughts did today's workshop awaken in you? What similarities or differences did working in the workshop have compared to normal OE investigation?
6. How did you find the integration of AcciMap and the HF tool?
    a. What was good? What was bad?
    b. Did the HF tool bring additional value to AcciMap? Did different issues emerge?
    c. Would HF map be utilisable in future?
7. Using the HF fan in the workshop: How did you utilise it? What kind of experiences did you have?

C. Further steps of the HUMTOOL project
8. Has the use of the HF tool affected your own conception of safety management and HF as a part of it?
9. What possibilities and obstacles do you see in utilising the HF tool (the tool, the HF fan, the HF map) in your own organisation?
    9B. What conditions should there be in the use of the HF tool (the tool, the HF fan, the HF map) and in the promotion of HF in your organisation?
10. What are your hopes and thoughts for the HUMTOOL project in the future?

4.3.2. Investigative workshop with the Safety Authority (9/2017)

Eleven participants from different units of the Radiation and Nuclear Safety Authority (STUK) (e.g. radiation, risks, operations, reactor) participated in the one-day workshop held on 4th September 2017 (coded as WS6 in Table 3).

As with the NPP1 and NPP2 workshop procedures, we asked the participants prior to the workshop to select a case which they could analyse during the day with the HF tool. The HF tool and the HF fan were sent to the participants beforehand. We decided to analyse only one case, and more properly, rather than taking two cases under analysis.

Most of the participants (except for 2-3 persons) had participated in the FIOH workshop with HF tool theory and practice sessions a year before (11-12/2016) as a training service (not as a part of HUMTOOL/SAFIR-project), which had a similar kind of structure and content compared to the sessions held within the HUMTOOL project at NPP1 and NPP2. Thus, participants in the regulator organization had a similar kind of a situation with regard to the prior mental model of the HF tool and its use, compared to the NPP1 and NPP2 participants.

In the regulator –workshop, the participants analysed the case that had been investigated by the NPP itself. The information that they had from the case, came from the investigation report at hand, but also from their 'tacit knowledge' regarding the case (some of the participants had handled the case somehow as a part of their basic task and work role, from which they had some further information).

4.3.3. Introducing the HF tool for an NPP project (NPP3, 6/2017)

Workshop 5 in 2017 was a half-day workshop (3 hours), held by three members of the research group. An introduction workshop was held in NPP3 in 06/2017 and five safety experts participated. The whole workshop was recorded and transcribed (WS5 in Table 3).

The first aim of the workshop was to collect information about HF and their management in the NPP project. The second aim was to introduce the HF tool, the HF fan and the HF map to the NPP safety, quality and HR experts and to discover the use possibilities of the HF tool in the NPP.

After the introduction of the participants, the researchers started a first group interview about HF and their management in order to get an idea of the current state of the NPP concerning this sector. The more detailed interview questions (section A) are presented below.

A. HF and their management

1. How do you define HF? What comes to mind concerning the word/concept?
2. How do HF show up in your work?
3. How do you take this sector into consideration (what techniques, applications) in your own organisation?
4. Have you had training about this sector in your organisation? What kind, when?
5. Have you had initiatives, projects concerning the topic at your workplace?
6. How would you estimate power plant - authority collaboration in the HF field? The strengths and weaknesses of the collaboration?
7. What type of operational events have occurred in the NPP project? Do certain types of events repeat themselves?

8. How are operational events are reported (internally, outwardly) and investigated/analysed? How the information is utilised?

The second group interview was started by introducing the HF tool, the HF fan and the HF map to the participants starting from the historical development phases of the HF discipline and thinking, and also including the transition of safety thinking from Safety I to Safety II (see also Introduction in this report). The HF map was introduced by explaining its structure, content and basic ideas with one example case from maritime (accident of Herald of Free Enterprise). Copies of the HF tool and the HF fan were given to the participants.

The group discussion concerned the use of the HF tool in the nuclear project organisation. The goal was to find out the needs in the company's HF knowledge and know-how as well as the use potential of the HF tool in the company. The more detailed interview questions (section B) are presented below.

B. The use possibilities of the HF tool

9. Is the introduced HF tool already familiar to you?
10. Is a similar tool already in use?
11. What kind of use could the HF tool have in your operation?
12. What kind of knowledge and know-how needs do you have in the field of HF?

4.3.4. Additional meetings to facilitate SAFIR- co-operation

In addition to research activities, HUMTOOL organised two separate workshops, to uncover synergy values among SAFIR2018-projects. The material of these workshops is not used as research material or data, but the findings will be utilised in the future development of the HF tool.

HUMTOOL- and MAPS-project[3] teams organised a joint meeting/workshop. The topic of the meeting was an HF view on safety management principles for managing complex projects and exploring the applicability of the HF tool in complex projects.

Topics of the workshop included

[3] MAPS = Management principles and safety culture in complex projects lead by Gotcheva, N.; details in: http://safir2018.vtt.fi/docs/Annual_plan_2015_apps_signed.pdf

- presentation of the HUMTOOL project
- mechanisms for governance of inter-organisational project networks (MAPS)
- mutual reflections concerning the two research projects
- discussion about uses of the HF tool in the nuclear industry network and system.

We agreed on co-operation and joint outputs to add value for SAFIR in 2017-2018 which include drafting a joint manuscript with the working title 'Facilitating network/collaborative safety culture by applying the HF tool' – the idea is to include those areas in the HF tool that it is currently missing (network- and context aspects). The purpose is also to evaluate, whether implementation of the HF tool is more efficient, while utilising project management and system thinking points of views, and by the participation of different nuclear stakeholders in the implementation (SAFIR2018 Reference Group meeting on 9th October 2018; MAPS and HUMTOOL project status reports).

HUMTOOL also organised a joint workshop with other work packages of CORE research project (work packages 1, 2 and 6), to find ways to co-operate between project work packages.

5. RESULTS

5.1. Results of the Workshops with NPP1 and NPP2

5.1.1. The use of the HF tool

The NPPs had not used either the HF tool or the HF fan in collecting data of the OEs which were investigated in the workshops, but both NPPs had used the HF tool independently in OE investigations after the earlier workshops of this research project:

- NPP1 had used the HF tool in theme investigation of seven separate OEs. They had used the HF tool to identify common characteristics (both positive and negative issues) in the background of OEs. They found that:
    - some of the HF tool items were impossible to deal with in theme investigation, because they had not been handled in an original OE investigation process (regarding the cases included in the theme investigation) and they did not re-interview anyone in the theme investigation process.
    - using the HF tool had helped to structure the theme investigation. They brainstormed in the workshop that it could be useful to draw a big, common timeline in theme investigation and analyse whether there are any factors which have an influence on another OE.
- NPP2 had used the HF tool in two separate incident investigations (the first case was an OE and another case was a near miss in occupational safety).
    - The positive perspective was highlighted as the most important additional value of using the HF tool in OE investigation –*"Actually, it is the only investigation method that can express positive factors."*
    - User experience of the HF tool in another case was also positive. Using the HF tool had helped the parties to understand that it is not only the individual's actions which have influenced an occurred situation. - *"I noticed, when we started to study the background of the situation with different parties, …they [meaning participants of OE] started to open up in a different way."*

In the workshop of NPP1, the participants analysed one unfinished (investigation not yet finalised) OE case. In the workshop of NPP2 they re-analysed two cases, which had been investigated earlier by an OE investigation team using a different analysis method. Participants worked in subgroups, and after the investigation of cases, the subgroups presented the results of their investigation to each other and discussed similarities and differences.

The analysis of the case with the HF tool and a joint discussion after the analysis revealed interesting questions, ambiguities and differences, especially the following:

- Participants asked which factors in the OE should be marked by 'positive' (HF +)? Are issues which are "normal action" and conducted along the norms, also marked as positive?
- In some details, subgroups had thought/meant the same issues/causes, but used different items (numbers) of the HF tool. "*We just marked it by a different number. We meant the same issues.*"
- Participants asked and discussed, whether the "Corrective actions -line" of the HF map is interrelated with a time line or identified causes. The researchers clarified that it is interrelated with causes regardless of the implementation time of the corrective measures.
- There were some quite small differences in the results of the investigations of subgroups, i.e. both subgroups had discussed/thought about the same issues, but had written it down under different words.
- The HF map charts seemed quite the same and subgroups discovered the same causes/characteristics behind OEs. However, there were also differences (for example the starting and ending points of the timeline, which HF tool items had been identified).

5.1.2. User's experiences of the HF tool

User experiences and further development needs of the tools (HF tool, HF fan and HF map) were collected in the group interviews of the workshop. Participants' views were based on the use of tools in the workshop, in earlier workshops (in 2015 and 2016) and independently. Users' experiences of the HF tool are presented in table 4.

Table 4. Users' experiences of the original HF tool and the new tools linked to it

User's experiences	***Examples of conceptions***
HF tool gives additional value to investigation	• *"Actually, it is the only investigation method that can express positive factors."* • *"Helps in understanding the human factors behind OEs/incidents"* • *"The HF tool and the tools linked to it expressed issues (motivation, attitudes, group dynamics) which had not traditionally concerned OE investigation."* • *"Well, we looked issues from sides different from those usedtraditionally."* • *"The HF tool helped the participants in an incident to understand that it is not only the action of individuals, but the action of group and familiar practices…as well. And then we started thinking about it more broadly."*
HF tool is a systematic checklist of human factors to investigate and helps systematic and consistent reporting	• *"Systematics are good. If you go through this HF tool, all different aspects of human and organisational factors should be treated. Go through as a check-list, "is there this item or this item..."* • *"With the HF tool, all the different aspects have to be gone through and the next phase is that you can document them for reporting. And if you read the report after year or after a couple of years, and there is documented what the HF tool has gone through, you know, that they [HF tool items] have been considered."* • *"Evaluation of the HF does not depend on who has evaluated it if the HF tool is used."* • *"With this tool, we catch HF quite easily."*
Using HF tool requires training	• *"When I looked the HF Tool some time after the earlier workshops, I did not figure out how to use it. Now when we have used it together again, it helps me forward and I can train using it."* • *"It [HF tool] is 'somewhat overwhelming' at first. I guess that after a couple of training times, I could get more out of it."* • *"You should assimilate the issues [HF, tools] first, and then you can really utilise it."* • *"I should have a better understanding of the HF tool, in order to utilise it without 'searching'. If you have this understanding, you can find the right items easily."* • *"According to my first impression it is quite a good tool. But it is just so that you can't slap those kind of läystäke down in front of anybody. You should assimilate it first yourself, and then you can use it."*
HF tool cannot fully replace other investigation method	• *"The best would be if you could analyse OE with two different methods – analyse, for example, technicalities with one method and part of OE with another method."* • *"There could be work distribution in an investigation situation; one investigator could investigate technical issues and the other HF issues.*

	It is not good, if you say after 45 minutes of interviewing, "now we will also look at these questions of HF…"
Lack of technical issues of HF tool	• *"Some combination of the HF tool and technical investigation tools could give a good result."* • *"We have plenty of technical issues too…accordingly, we will need to have a lot of time and resources in order to use another tool alongside this tool. In technical issues, we do not get to a deep enough level with the HF tool. "* • *"In practice, this HF tool covers only the HF issues."*
Some detail changes to some HF tool items	• *"The new HF tool item is needed."* • *"Technical issues should be highlighted more clearly in the HF tool items."* • *"Some re-wording of HF tool items is needed."*
The organisation culture does not support using the HF tool	• *"It would be not received well, if you go with this HF tool to a sixty-something year-old person, who has performed forty years of electrical work here, and ask: 'How did you sleep?' "* • *"It is not easy to analyse HF issues if you are facing people who do not understand why you are asking those things."*

According to study participants, the HF tool gives additional value to OE investigation and is useful as a check-list of HF. They experienced that using the HF tool helped consider HF issues systematically and independent of the evaluator. Participants highlighted that using the tools requires training and that users have to assimilate it themselves before using it. The lack of technical issues was highlighted in users' experiences and participants saw that the HF tool (and tools linked or added to it) cannot fully replace other investigation methods. In addition, participants proposed some detailed changes to the HF tool items. According to study participants, the organisation culture does not fully support analysing HF factors – as one of the interviewees described it- *"If you still face that wall"*.

Additionally one workshop participant raised his/her concern that the HF tool must not be used "blindly": *"You should not get blindly going through these questions of the HF tool. You will always end up at the conclusion that it was the leader's fault."*

5.1.3. User's experiences of the HF fan

Workshop participants informed that they used support questions to check or make certain of the meaning of the HF tool items. Participants considered the HF fan to be very useful and valuable:

- *"They [the support questions of HF fan] look very good."*
- "*We used them all the time."*
- *"Those support questions better 'interpret what some words in the HF tool items mean."*

However, participants did not experience the support questions as novel and they have largely understood items of the HF tool correctly – *"when I looked at the support questions of the HF fan, I mentioned that I had asked/thought about the same issues."*

Participants described that they could use the support questions when they interview participants of OE situations and collect data. However, according to participants' views, it is not possible to *"go interview anybody with this HF fan in hand" although they can ask/use these questions*.

Participants also recognised the risk of delimitation when using the HF fan - *"we cannot answer only the support questions of each item and then move on to the next item"*.

Participants highlighted the difficulties in determining the proper corrective actions relating to HF issues, and asked whether the next version of the HF fan could help in this phase of OE investigation.

5.1.4. User's experiences of the HF map

Workshop participants used the HF map (a combination of the HF tool timelines and AcciMap-chart) for the first time in the workshops. Researchers included questions of user experiences in group interviews in the end of the workshops and the resulting comments are summarised in Table 5 below.

Table 5. User's experiences of the HF map

User experience	Examples of conceptions
Really good outcomes after hard work	• *"Outcome/output is really good, although working with it was hard."*
The tool (earlier three timelines, currently the HF map) has evolved forward	• *"The HF map is a step forward of the tool"* • *"Sections of the diagram are good in pointing out where the problem is. The vertical dimension is important."* • *"When we used only the HF tool earlier, items were unconnected to each other. Now in the timelines of the HF map they acquire a totally new meaning."* • *"I really liked it. The HF map clarifies the wholeness – which led to what."*
Usability of ppt.-template and	• *"Good to use, but the usability of the ppt.-template should develop. There were difficulties in drawing the HF map in a digital form."*

readability of the HF map	• *"Drawing the HF map takes too much time, outcome is easily a 'jungle of arrows'.* • *"The outcome of the HF map modelling should be clear and easy to read."*
Actions-line is very useful	• *"Targeting corrective actions is a really good feature of the HF map. You can mark very easily why some measures should be done."* • *"The actions-line should also be included in the AcciMap-diagram."*
Changing the mindset of modelling incident requires training (-problem of fixing to earlier timelines)	• *"I only started to write down HF+ and HF- items as we did previously in using the HF tool. And then I realised, that "Aaaa – I can write them down in the same way as in the AcciMap-diagram."* • *"Technical issues were left unrecorded in the HF map modelling, however."*
Some detail changes to the HF map	• *"The highest level could be 'operation outside NPP'."* • *"Our own AcciMap template has technical issues and working conditions as their own categories and in the HF map they were divided into two sections. It is only changing my own mindset."*

According to interviewees' views, the tool has evolved forward and *"hard work with the HF map leads to really good outputs"*. Participants mentioned the actions-line as an especially good feature of the HF map. Usability of the HF map template and some detail changes concerning naming of sectors were mentioned as further development needs of the HF map.

Additionally, one participant pointed out difficulties in using the HF map in theme investigation, when there is no timeline of a specific case.

5.2. Investigation workshop with regulator (9/2017)

5.2.1. Pre-familiarity of the HF tool and the authority's role in OE investigation

Workshop participants had selected the case, but had not analysed it before the workshop. The HF tool and the HF fan were delivered beforehand to the participants and there was a possibility for pre-familiarisation with the tools. Some of the participants knew the HF tool, because their client NPP had used it in OE investigation reporting.

The OE investigation is not included in the authorities' usual work duties or responsibilities. As an authority, they oversee and monitor the quality of OE investigation of NPPs, but do not usually investigate single OE cases themselves. One participant told in the interview that the OE investigation experience in the workshop was very profitable for him/her, and now he/she can better understand the challenges and difficulties of the OE investigation and reporting process. *"When you try to consider it yourself in this way, you notice how complex it is to investigate OE - - - perhaps this increases a little bit our understanding of why it is so difficult to make those reports."*

5.2.2. User's experiences of the HF tool, HF fan and HF map

The use of the HF tool in the workshops raised the following questions and user's experiences.

New investigation methods, their implementation and training in the nuclear domain were positively received by the workshop participants.

- *"It probably brings added value. The key factor is that using an investigation method generates discussion, broadens your own thinking and ensures that all things will be pondered/examined."*
- *"Development of investigation methods is positive, because there is quite a narrow selection of investigation methods available in the Finnish nuclear domain.*

The concept of the HF tool was seen as useful, but was not seen as suitable for an authority in its current form; the tool would need some further modification and consideration. *"We should find our own way to use this tool."* Participants also highlighted the importance of being aware of tools which are used by NPPs.

According to a participant, using the HF tools gives added value for OE investigation and safety management:

- Use of the HF tool raised several further questions for further examination, which have to be clarified during the investigation.
- It was seen as important that the HF tool acts "as a mindmap" or "mindset" and reminds us that there are many factors at different levels included in HF, not only individual actions and characteristics.
- The HF tool points out that HF like well-being at work, fluency in work etc. are also safety factors in safety-critical domains.
- Classifying the causes, summarising information and monitoring trends were also mentioned as important features and possibilities of the HF tool. *"You would have information from all cases - - - and then you could summarise them yearly and observe whether there are many hits in this level/these items."*

The HF fan and the HF map were considered by the participants to be useful tools:

- According to participants, they relied particularly upon the HF fan when they investigated the OE case. They told that the HF fan helped to identify the right items from the HF tool but, in some cases, they have understood the HF tool item differently than the way in which the support questions of an item clarified it. Items are broader in the topic level than in support questions. *"In some cases, we guessed 'that could be the right item', but when we read the questions, we realised that this HF tool item meant something else, because the question was formulated in this way."*
- Different levels of the HF map diagram were considered especially useful by participants - *"we easily found factors in the individual level and then the upper empty levels of the diagram took our attention to the upper levels of the diagram."*

Participants identified the need to emphasise technical issues and contextual aspects of HF in the HF tool items.

- Participants proposed a hybrid investigation method which covers both technical problems and HF.
- *"Well, technical issues would be better included in this method."*
- *"Some items were worded such that you could understand them more as psychological than contextual issues... "*
- One participant highlighted, that HF are not only psychology but also technical aspects and that contextual technical factors are included in HF. He/she observed that it is necessary to clarify this, for example, in the introduction or training of the method.

Participants asked which factors in the OE should be marked as 'positive' (HF +); are the issues which are conducted along the norms also marked as positive? The researchers guided the participants to mark as positive 'all the actions and factors that maintain safety'; referring to Safety-II thinking in the theoretical background of the tool. The use of the HF tool raised the point that the same factors may be both positive and negative (e.g. item number 32, group communication).

A picture of the whole case is needed at the final stage of investigation:

- Does the HF tool give a picture of the whole case, at the final stage?
- Participants felt that analysis with the HF tool needs one phase more. "*It would be important to constitute an overall picture/synthesis of all identified causes and factors."* They also observed that more specific instructions are needed the last phase of analysis; "*How do you get an overall picture and identify which factors were essential factors of a case? How should you summarise the event?"*

Participants identified some challenges and training needs for using the HF tool:

- Which expertise/know-how is needed in order to use the HF tool and investigate HF issues in the OE investigation process? One participant noted that, as a nuclear engineer, he/she is not experienced in dealing with HF issues of OE and has no kind of education/training for that.
- It is a challenge to get from engineering -thinking and technical details to HF-thinking and really reach the deeper level.
- Some HF issues may be speculative; can these kinds of issues be mentioned in the analysis?
- Different small groups can conclude upon different kinds of items; should there be voting at the end of an analysis session to determine which items are finally chosen for the final analysis?

Participants wondered whether the HF tool may be lacking in some respects:

- Is the habit or risk of 'cutting the corners' or a pressure to conduct tasks more efficiently included in the HF tool? Should it be an independent item in the HF tool? Researchers provided guidance that item number 3 is intended for this phenomenon (working along norms).
- How about delays in starting a particular task? (If, for example, sometimes demanding bureaucracy needs to be addressed before the task can be started.)
- Is there an item for focusing on the 'we have been aware of the problem, but nothing has been done about it' –phenomena, when corrective actions have not been done?

These findings can be used as material for coming improvements of the HF tool, especially if the same issues are also raised at other workshops with the other participants, and the issues are more general.

5.3. Introducing the HF tool for NPP project

In this report, we examine only the results of part B interviews (see Materials and methods, chapter 4.3.3). Part A material is not analysed, but rather used more as background material and information used for perceiving what kinds of conceptions study subjects have regarding HF. A similar kind of analysis was made from the results of NPP1 and NPP2 in 2016 and included in a scientific article.

5.3.1. Familiarity with the HF tool and use of similar tools

The first part (questions 9. and 10.) of the group interview section B considered the familiarity of the HF tool and asked whether some similar tool is used in the organisation. Some of the participants had heard of the HF tool before, but weren't very familiar with it. The participants didn't recognise any similar type of tool, at least not as extensive as the HF tool, which would be in use in their organisation.

5.3.2. The use of the HF tool

The second part (question 11.) was about the possibilities for using the HF tool in the operation of a participant's particular organisation. A large number of different targets of use came up in the conversation.

Construction work and design of the new NPP could have quite different needs and ways of using the HF tool, and use of the tool could be easier in the construction work. For example, the investigation of an incident could use the HF tool to gather information about what happened and how people should have behaved in the situation. On the other hand, the HF tool could be used when predicting possible deviations beforehand. When something is noticed in the designing work, this tool could be used to determine whether everything in the concept processes and systems is in condition.

Inspecting the design could use the HF tool to ensure the quality of the work and to design documentation. The HF tool could be used to investigate what went wrong if a design error manages to advance all the way to the implementation. In addition, HF aspects could be brought to designing the use of the NPP especially because of the cultural and methodological differences between different operators working on the same project.

Considering the whole NPP project, it could be interesting to utilise the HF tool to investigate and understand why some document analysis process took for example five months' time instead of the planned two months and to perceive the long chains of aspects that can be behind such delays.

One possible use of the HF tool is to find out whether people found instructions and working methods suitable and possible to follow in a deviation situation. The NPP project company has an extensive system of instructions but the case-specific application of those remains subject to the experts' own conceptions. The HF tool could be used to investigate some challenging documents or a whole complex of issues which are unfinished or difficult to solve.

The HF tool could also be utilised in personnel administration/HR. The NPP project company desires that personnel feel well and the company is interested in asking about and following this factor at both the team and individual levels. If flaws are detected, the HF tool could be used to prevent them from escalating. In addition, the HF tool could assist supervisors as a tool for performance development discussions (PDDs). It contains many aspects that would be useful for supervisors.

One possible use of the HF tool could be to investigate effects that are presumed to be results of the matrix organisation in order to determine whether those effects could arise from something else.

In conclusion, the participants felt that they would need to identify some concrete issues to which the HF tool should be applied. One clear case could be a rejecting decision from the authority on some design proposal. The normal work of the project consists of finishing documents to improve the construction permit of the new NPP. The HF tool is found to be difficult to use in this kind of work. The participants continue to recognise suitable targets for HF tool use and to discuss about it inside their organisation.

5.3.3. Needs for HF knowledge and know-how

The last part (question 12.) of the interview considered the organisation's needs for knowledge and know-how in the field of HF. The participants recognised that basic training of HF is lacking. There has been a three-lecture series about safety culture in the organisation which introduced HF aspects but which mainly concentrated on safety culture. It is felt that more concrete HF training is needed.

6. SUMMARY AND CONCLUSIONS

In this research report, we have focused on the following issues: 1) How has the HF tool developed during the HUMTOOL project (and also before that; what is its theoretical basis), 2) How do key persons in the nuclear industry (e.g. NPP safety experts, supervisors, authority) consider the HF tool; is it useful and usable, and what kind of uses could it have as a part of the safety management of the organisations? and 3) How should the HF tool be improved, to serve nuclear actors' needs?

These issues are handled as follows:

1) **How has the HF tool developed during the HUMTOOL project (and also before that; what is its theoretical basis)?**

In this report, we described the origin and theoretical basis of the HF tool as it has evolved since 2003 when the HF tool was first taken into use in Finnish ATM (Teperi et al., 2015) and which use has been disseminated to other safety-critical areas (e.g. Teperi et al., 2017 maritime; Teperi, 2018 railway).

In the nuclear context, the HF tool has been continuously improving during the HUMTOOL-project in 2015-2017. The main development phases have been the use of the three-coloured timeline to describe the chain of events as well as the positive and negative contributing factors in the case under investigation, adding supportive questions as an HF fan, and integrating the HF tool with the AcciMap-method, which is widely recognised and an established method for accident investigation (Rasmussen and Svedung, 2000).

The core idea of HF tool development has been the joint and participative improvement process by researchers and users in nuclear organisations. The users themselves have given ideas on how to use and improve the HF tool; both NPPs had used the HF tool independently after the first workshops in 2015-2016.

In this sense, the HF tool has emerged as a flexible, 'resilient' tool which has the potential to face and meet the development needs of the users. But it can also be interpreted that using and pondering the HF tool has served to commit nuclear actors to approaching safety thinking from a new angle, the human contribution view, in a traditional, technically-driven, functional environment.

2) **How do key persons of the nuclear industry (e.g. NPP safety experts, supervisors, authority) consider the HF tool and its new parts added in 2017; are they useful and usable, and what kind of uses could the HF tool have?**

An important finding was that participants experienced the HF tool acting "as a mindset" which reminds us that there are many factors at different levels included in HF –not only individual actions and characteristics. This was originally one of the main goals in the HF tools.

Study subjects regarded the new parts of the HF tool (the HF fan and HF map) as valuable, felt that they advance the philosophy of the HF tool and noticed that the parts added to the HF tool were made based on their own needs. As one of the participants said, *'It's hard work, but with a good result'*.

The HF fan was experienced as a good support. Some observed that it was not a novelty, which can be seen as a good signal that HF items could describe the contents and basic ideas of issues quite clearly. Others saw that their own interpretation of the HF tool items could change, after reading the HF fan support questions.

Study participants envisioned several different kinds of uses for the HF tool, especially for the NPP project organisation. Using the HF tool in HR processes such as personal development discussions, and designing and constructing the new NPP were seen as valuable potential uses, but use of the HF tool in documentation preparation, e.g. for construction licenses, was deemed to not be useful.

It must be noted, that the HF tool has not been applied in a similar way thus far in the nuclear industry, compared to ATC. In ATC, the HF tool was used by operators (air traffic controllers and chiefs) themselves, after each incident happening and reporting. The original goals of using the HF tool (described in chapter 3.6) were to educate and to commit operative personnel (who are not HF- or investigation professionals) to HF as a new way of thinking about safety, to learn to analyse and holistically understand background factors of incidents (not from an individual and error based aspect, which risks blame culture), and to determine the right corrective actions for safety improvements. In the nuclear industry, through this project, the HF tool has been applied by safety and authority experts, who already act as 'semi-professionals' or 'professionals' for incident analysis and who can thus also facilitate use of the tool in the organisation.

In any case, a question may be raised as to whether the nuclear operators should also be committed to HF tool use, to improve the safety culture in general?

3) How should the HF tool be improved, so as to serve nuclear actors' needs?

Thus far, the HF tool has been improved based on the users' feedback, as described above.

However, it was still a quite widely-raised criticism that the HF tool lacks technical aspects. In this aspect, the HF tool would not replace other earlier-used investigation methods or it should be broadened with the addition of technical and contextual aspects. This is now further pondered.

It must be remarked, that HF is supposed and designed to be used to analyse and learn about the human contribution to safety, not technical aspects, which already is a tight part of the nuclear industry system design. On the other hand, these factors cannot be separated from each other in the real operative environment. The future development of the HF tool should take this issue into account.

A finding that must be regarded as important is that, currently, the HF tool lacks contextuality and industry level characteristics (although some items of the HF tool refer to this at the system level). This point must be focused on in future work and this has already begun in the co-operation with the MAPS-project, which is focusing on the complexity of nuclear projects.

Also, an important development need identified is the need to create an overall picture/synthesis of all identified causes and factors at the end of the analysis session. More specific instructions will be needed at the last phase of analysis in the future.

Additionally, some new items could be added to the nuclear version of the HF tool, for example pressure and delays were mentioned as options for new additions. This is possible while the HF tool has the potential for modifications.

Nuclear organisations were eager to co-operate with the HF tool development and participated actively in all the workshops during 2015-2017. This is a sign of the need for competence of this kind of work in the field; for example, investigation trainings have been rare and the HUMTOOL project met this need. Over time, there have been several new participants at the NPPs and authority workshops; the pros of this are that the HF tool is disseminated to a broader audience and the HF awareness is raised, but a con of this from the project point of view is that the coaching of the new members for the project starts each time 'from the beginning'.

The culture of the nuclear industry does not necessarily support raising up the HF items. In certain cases, it was felt to be too sensitive an endeavour to interview operators by use of the HF fan. On the other hand, some felt that using the HF tool in the investigation caused people to participate in a new way.

Study subjects did not have similar tools in use beforehand, they had heard some information about the HF tool earlier, but were not very familiar with that. There was also need for a proper HF training. It would be useful for all investigators to attend HF training, to give attention also to this aspect, to show competence this aspect in interviews during investigation processes and to discover deeper contents and phenomena. It was commented that thus far, investigations have focused on the technical writing of the investigation report or describing the case in a technically detailed way, 'what happened' instead of 'why it happened'.

It would also be useful for the objects of HF-oriented investigations to attend HF training, to develop an understanding of why this kind of process is included in the safety management procedures of the company, thereby discouraging the development of an opposing atmosphere for the investigators seeking to use the new tools.

In the future, HF tool use has to still be clarified: why is the HF tool used, how is it used, by whom is it used and with which competence is it used in the nuclear industry. Also, the hindering and supporting factors of HF tool use are included in the scope of the HUMTOOL project in 2018.

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This research report describes the development and implementation of an HF tool and the outputs of this process during the research project HUMTOOL (Applying an HF tool to learn about and to analyse the human contribution to nuclear safety) in 2015-2017.

In this research report, we summarise the development phases of the HF tool and evaluate the user experiences of the HF tool. We also ponder possibilities for nuclear actors (power plants, regulator, project organisation) to implement the HF tool, and identify areas in which the HF tool needs further development. We utilise findings of workshops and interviews conducted in 2015 and 2016 as background material. Mainly, this report summarises the work done in 2017, which produced research material comprising the intervention material and group interviews collected in five workshops with different nuclear actors, two NPPs, one NPP project and a regulator. To provide a solid basis for the HF tool, we also present the origin and theoretical background of the HF tool, made for Finnish air traffic management in the 2000's, to be utilised in the future development of the tool.

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