# Adaptive Automation in Control Rooms: Discussing safety challenges in computerized procedures

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**Abstract:** Adaptive Computerized Procedures (ACPs) in nuclear control rooms could significantly affect safety by impacting operator performance. This paper explores how computerized procedures, and their automation can influence system safety and human reliability. ACPs represent a shift from traditional manual operations to dynamic, real-time responsive systems. We highlight the potential advantages and challenges of adaptive automation approaches to computerized procedures, in comparison with other automation approaches and discuss their impact on operator roles and performance, underscoring its relevance for human reliability analysis. We consider how future research could explore diverse approaches to optimize ACP design for reliability, safety, and efficiency**.** Based on this discussion, we advance suggestions for future work, arguing that a multi-method approach will be crucial, encompassing quantitative and experimental approaches (assessing response times and accuracy) as well as more naturalistic and qualitative approaches (such as observations and interviews). We anticipate two possible lanes on future research, one more focused on classical hypothesis testing for assessing the performance and safety implications of specific features of the ACPs, and another lane, focused on thorough analysis of existing ACPs and reviewing current experiences, as well as a synthesis of expected differences between the use of paper, computerized, automated, and adaptive procedures. In conclusion, the integration of ACPs into nuclear control rooms presents the possibility for enhancing human performance and reliability. However, we must explore strategies to optimize their design for best human-system performance outcomes.

**Keywords:** Adaptive computerized procedures; human reliability analysis; automation; nuclear control rooms; digitalization

## 1. INTRODUCTION

Digitalization processes have been a significant topic within nuclear industry. Modernization and digitalization of conventional (analogue panels/boards) control rooms are core research topics in the field, especially in relation to system performance and operator roles and reliability (Fernandes *et al.*, 2015; Hildebrandt & Fernandes, 2016; Liu *et al.*, 2020; Porthin *et al.*, 2020). The digital revolution, with most control rooms today having a hybrid set-up where analogue panels co-exist with computerized systems, is now well established in the industry. New ways of operating are also starting to be considered with either increasingly digital controls or fully digital control systems. Linked to this process, the topic of automation has also been vastly explored within the nuclear industry (e.g. Laitio *et al.*, 2013; Skraaning & Jamieson, 2021). Several questions have been posed and are iteratively being re-defined and answered: What to automate? How to automate it? What is the role of the human as automation becomes more common? Importantly, both the processes of digitalization and automation in the nuclear industry entail clear safety challenges, still with unclear consequences for human performance and overall system reliability.

In the current work we are adopting a human factors systems approach to better understand the potential impact of digital/computerised procedures with integrated automation in achieving operation and safety goals for the plant. We aim to provide an overview of the current and future functionality of procedures, the current practices, and implications, as well as analyse the potential differences, impacts, advantages, and disadvantages that increasing levels of digitalization and automation could have. In the next sections we will focus on presenting a theoretical framework for the presented approach, based on the literature on both procedure use and human-automation interaction. We will then consider current state of practice on computerized procedures, presenting some examples. We further explore the definitions and concepts around digital, computerized, and automated procedures before we dive into the consideration of human reliability analysis techniques. We take lessons learned from other digitalization processes in the control room, as well as human-automation findings to inform the expected impacts of automated computerized procedures in the overall safety and performance of control room operations.

### 1.1 Procedure use in nuclear industry

Nuclear operations are often referred to as "highly procedural", meaning that most tasks have a pre-defined written procedure that the operators follow individually, as a team, and/or while being supervised and peer-checked in their actions (Barnes & Radford, 1987). The use of procedures and the adherence to protocol is often referred to as a source of reliability, standardization, and thus increased safety in nuclear operations. Nonetheless, it is crucial to understand that "following procedures" is not necessarily a simple "pre-programmed" task within the control room (e.g. Peres *et al., 2016)*. It might be tempting to (mistakenly) assume that since work processes are deeply dependent and dictated by pre-defined procedures, that digitalizing and even automating these procedures would be "enough" to reduce errors and safely operate the plants. Several works have shown that there are different layers of interaction, understanding, awareness, and decision making while using procedures (e.g. Massaiu & Holmgren, 2017; Liao & Hildebrandt, 2013).

Within the Halden Project, several studies related to procedures for nuclear power plant operation have been performed along the years. Among those, Massaiu and Holmgren (2017), evaluated how the presence of an experienced technical staff member could complement and/or a digitalized procedure tool could affect the performance of the crews in facing complex emergency situations. The tool was thought to give extra support to operators' decision-making process by showing the high level 'intention' of the procedure and the status in relation to it. A qualitative analysis observed positive effects, for example that 67% of the crew's adaptations (conscious decisions and actions not directed by the procedure's step in effect) had positive consequences, confirming the importance of the operators' engineering expertise for effectively mitigating accidents requiring adaptation. This conclusion hints how new cooperative systems, designed to support the operator's decision making, could tap the operators' expertise in the most effective ways specially in unexpected situations.

### 1.2 Human-automation interaction

Automation and automated procedures are key topics within contemporary discussions on human-machine interaction, being expected to simplify work processes and improve system performance, reliability, and safety. However, we would like to emphasize the relevance of using human-centred approaches to achieve these goals with automated systems. It is crucial to understand and accept the role of the humans as key knowledge holders, decision makers, and ultimate safety barriers when we conceptualize, design, and implement such systems. The needs, skills, capabilities, and limitations of the human operators need to inform the development to make sure the automation can remain aligned with overall plant goals. We argue that a holistic perspective is required to foster the potentials of automation in process control and mitigating any identifiable challenges in the process. A celebrated example of this discussion is Endsley's (2016) *automation conundrum* example where further automation could contribute to more reliable systems but at the same time result in lower situation awareness for the operator as well as induce mistrust in the system and increase the difficulty of hand-over situations when the system modes are changed from autonomous to manual (returning control to the operator).

Within this context, we discuss the task allocation tradition (e.g Parasuraman et al., 2000), where tasks are distributed or rather – divided, between humans and automated systems. This approach as a strong link with the initial conceptualization of automation and artificial intelligence in the 1960's, where it was thought that the machines' roles would be to replace humans, according to the machines' capabilities at any given point. Based on these assumptions, the goal was said to be to "optimize performance" by identifying tasks that the humans excelled at, and tasks that the machines were able to perform more accurately and/or faster. This gave rise in human factors to the famous MABA-MABA paradigms (man-are-better-at, machines-are-better-at; e.g. Swain & Guttman, 1980; Sheridan, 1987), proposing that humans take over creativity, adaptability, and problem-solving tasks, while machines would be responsible for precise, repetitive, and high-speed tasks. The levels of automation framework has also tight links to this approach. And even though these approaches are still popular and possibly the most common in applied contexts today, they have not gone without criticism. For instance, Dekker and Woods (2002) are highly critical of the task allocation approaches and argue that human and automation need to act as a team.

### 1.3 State of practice with computerized procedures

Currently, most of the existing power plants work with paper procedures which are printed and available to the operators. Each operator has a set of prints for themselves where they often take notes, or write down time/action logs when running the procedure. These procedures are mostly seen as of individual use, staying at the operator's desk. Collaboration in procedures is done mostly by reading out-loud or stating the status of the requested actions while the supervisor and other crew members can consult their own copies of the procedures. When field operators are involved, the collaboration occurs mainly via telephone with the shift supervisor, the status overview become more implicit, not being immediately visible to the other crew members.

Contrastingly, new builds and new concepts of control rooms (multi-unit, small modular reactors, micro-reactors) have started discussing contexts where automation is significantly more visible in overall operations, including suggestions for "one-button star-up" or even "unmanned control rooms". Computerized procedures have started to permeate the industry, showing the potential to overcome the limits of paper procedures, from simply reducing the amount of paper, to improving communication and teamwork, to simplifying the recording of relevant notes or logging time required, hopefully leading to better effort estimations. In the literature, there are still scarce examples of the implementation and use of computerized procedures in the nuclear industry. We were able to identify three discrete examples that we will discuss as a basis for the following sections in the paper.

- *Example 1: Partially automated control room procedure system in the N4 reactors*

The N4 reactors are generation II pressurized water reactors. The four existing reactors in France started operating in the late 1990's with a digital control system that includes a partially automated procedure system. Tasset and Labarthe (2000) describe the impacts on safety of the computerized control rooms. The N4 procedure system is an advanced computerized system which can select the emergency procedure to be applied based on plant status and that provides online process info to the operators. The authors identify as one of the major human factors issues the difficulties that the operating crews had in understanding and operating the logic of the computerized procedures. The authors describe this system as a "state-oriented approach to emergency operating procedures" and considerer that the approach was overall successful. Nonetheless, they highlight incongruencies, in situations where "the operating strategy provided by these procedures is not completely adapted to the situation perceived by the operators". This challenge is linked to the Civaux 1 incident in May of 1998 where the operators decided to perform other actions (not required by the ongoing procedure) to optimize performance. This entailed that the operators had to work outside the system prescribed procedure which had an associated time cost/delay. Simultaneously, the authors observe that the operators seemed to show signs of "over-reliance" on the system, accepting its recommendations in case of doubt.

- *Example 2: Turbine automatics in the Nordic power plants.*

As described by Hurlen and collaborators (2021, 2024), at the Nordic plants there is a common automated procedure for running up and down the turbine and linked systems. The procedure is structured in sequences of steps and sub-steps including pre-conditions, required actions, and end conditions. According to the authors *"a typical implementation consisted of around 6 sequences, 15-20 main steps and 50-70 sub-steps*" (Hurlen et al., 2024). In their work the authors have a qualitative approach to exploring the operators' experiences across five different control rooms in two different countries, interviewing and testing with a total of 19 participants. The paper focuses on design improvements to address the identified challenges by the operators. Thereby the authors accept the premise of allocating tasks specifically to the machine and considering the operators a supervisor and checker of the automation's tasks. In this context, they highlight the concepts of transparency and teamwork as crucial topics that require further attention in the system. In a brief experience review presented in this paper, the authors refer that the operators: were apprehensive regarding the system; identified several instances of "unexpected/surprising" behaviour of the system when transitioning from manual to automatic operation; issues on syncing the turbine automatics system with other tasks and procedures in the main control room; challenges with the update of the turbine automatics to match changes in operational procedures; and difficulty understanding what needed to be done if the automatic sequence was interrupted.

- *Example 3: The computerized procedure system at the AP1000 control room*

More recent reactor designs have privileged highly or fully digitalised control systems in the control room. The AP1000 reactor is one of the common examples in literature. Its computerized procedure system is presented as going beyond the digitalization of the paper procedures. As seen in Lipner et. al (2006) or Wen (2010), it is a dynamic system that presents integrated process data, as well as an assessment of the step execution within the procedures. These features are expected to contribute to a "more efficient" procedure execution, as well as "reducing operator workload" by decreasing the monitoring effort outside the procedure and signalling when specific steps need to be performed. In 2018, Taylor et al. present a simulator study where they test the impact of failures of the CPS on operator response. In their study the operators were faced with different failures of the CPS including detecting failures of the: a) automatic step evaluation function; and b) automatic place keeping; as well as c) a total loss of the CPS with the need to revert to paper procedures. The authors described that there were detected inconsistencies in human performance, with the operators always double-checking/self-verifying the procedure steps regardless of the system indication, but even so sometimes failing to detect CPS' wrong indications. Some of the participants also struggled to recall in which step of the procedure they were in the situation where they lost the place keeping function or the overall CPS system, hinting that over-reliance on the systems' automatic features can occur.

These examples can illustrate cases of "history repeated", with more recent implementation of automation in the nuclear industry. There are clear drawbacks in a classical approach to higher levels of automation, where the automation is progressively taking over more tasks from the human, without consideration of the actual needs from the humans in the system. The linear assumption that taking tasks away from the human would allow them to focus better, reducing workload, cannot be taken for granted. Relegating the humans to the position of an uninformed supervisor is not only undesirable (given humans well document difficulty in long-lasting supervisory tasks) as it is unrealistic, especially when quick take-over is to be required. Given the presented theoretical background, our approach towards procedures in nuclear control rooms is to face them as core tools or facilitators of the human work. Procedures are not "how" a plant is operated, they are rather a tool designed to standardize ways of working, act as a safety barrier, and be used as an instrument by the operators do guide their actions and support them in collecting all relevant information required to making further decisions. We are sceptical of approaches that believe procedures to be the ultimate instructions to operate a plant and thus (erroneously) assume that operating tasks would be straightforwardly automated by increased digitalization and sensing, excluding from the process core human tasks that are not scripted such as for example consideration of parallel or simultaneous mitigation paths, knowledge-based information and experience, and core decision-making and situation analysis and diagnostics.

## 2. BACKGROUND ON COMPUTERIZED PROCEDURES IN NUCLEAR INDUSTRY

The IEEE Standard 1786 (IEEE, 2022) identifies operating procedures as tools for giving directions to human operators for safely performing a set of selected tasks, and Computerised Operating Procedure Systems (COPS) as applications that present operating procedures to operators using an electronic visual display, with the goal of facilitating the human operator's elective use of those procedures.

Operating procedures are designed based on the technology of the plant and the operation model. For instance, operators controlling a traditional Pressurised Water Reactor, will have a set of procedures that will be necessarily different from operators controlling a Small Modular Reactors' plant. Alberty and collaborators (2023), proposed levels of automation for nuclear reactor operation and mentioned that procedures will continue to be relevant with automation levels going from 0 (no automation) to level 4 (high automation. For level 5 (full automation), it is argued that humans will be no longer needed, and thus "human-in-the-loop" approaches, where humans are supposed to monitor plant performance and intervene, when necessary, will be no longer needed, and consequently procedures will be obsolete as they are integrated in the logic – in this work we challenge this position. Nonetheless, for most plants today, procedures have an important role in maintaining safety, contributing to resilience and reliable operation. Plants automated at different levels, though, will require different sets of procedures, or even possibly less complex procedure systems as the level of automation increases and human intervention is minimised. The use of procedures might also be different according to the identify state: normal, abnormal, alarm response, emergency, etc. Procedure use is tightly linked with operator control and thus it is possible that their focus can change, for instance emphasizing aspects like testing and diagnosis, or having a more advisory/summarizing role on what is the plant status and current requirements.

Currently procedures are often paper-based and the operators perform the procedure with an individual paper copy. Procedures are however rarely performed by an operator alone – operators may cooperate, often with peer-checking activities ongoing as an extra safety layer. Depending on the procedure, its use can involve cooperation, communication, and supervision, among different operators' tasks. As digitalization progress, COPS can be introduced to improve efficiency and safety of procedure execution, at the same time they can raise new risks and failure modes. The operating procedures, the available technology in the control room, the sensors, and actuators along with consideration of opportunities and human factors, shape the COPS. IEEE-1786 recognises three types of COPS, as defined in the standard:

- *Type 1 systems represent procedure text documents for operational use on a computer-generated visual display.*

Type 1 are presumably the most common COPS today. The use of procedures with this system type is essentially the use of paper procedures. Those systems, with navigational links, can provide a quicker access to procedures, can provide human performance tools like place keeping, and could support the communication among the operators helping to share the progress during execution (by synchronizing actions and requiring the operators to read through and confirm/verify parameters and status as a team). For example, a simulator based empirical comparison with paper-based procedure showed improved performance with COPS for symptom control and reactor check and turbine check (Braarud & Svengren, 2020). Paper procedures are always easily available as a backup media in case of COPS malfunctioning or for operator choice, reducing the introduction of new risk. Type 1 COPS are expected to improve efficiency without meaningful impact on safety.

- *Type 2 systems use dynamic process data for embedded display, to evaluate conditions or procedure logic, or to monitor plant conditions during procedure-defined intervals of applicability. Type 2 COPS cannot issue control commands, but they may provide access to soft control capabilities that exist outside of the COPS.*

Task performance and safety could be improved with Type 2 COPS, by providing automatic processing of procedure step logic, automatic display of process information relevant to procedure steps. New failures mode can occur as shown in Taylor an collaborators (2018), where discrepancies might be difficult to detect especially when the system wrongly shows conditions in agreement with operators' expectations.

- *Type 3 systems include embedded soft controls that may be used to issue control commands to plant equipment. Type 3 systems may include automatic sequences of steps (i.e., procedure-based automation) that are determined to require limited operator oversight, and for which there are procedures and training that would allow the operator to perform the steps manually, if necessary or desired*

Type 3 COPS push even more the scope and boundaries of advantages and risks. The capabilities displayed but this category of systems range broadly. Presenting various levels of automation, autonomy, ability to interact with the operators. ACPs belong to this third group. Applying the levels of automation at a single procedure in Type 3 COPS it is possible to have a mix of procedures at different levels of automation. One solution, as seen in small modular reactors' simulators could be to have a set of completely automated procedures and a set of completely manual procedures.

As an example, in O'Hara et al. (2000) a thorough account of the required considerations regarding computerized procedures in nuclear is given. Meanwhile other types of plants and procedures have been developed, but we argue that this work is still relevant, given the current state of practice in the use of computerized procedures. The authors developed a technical basis for human factors and ergonomics review of the computer-based procedure systems and highlight that there were still gaps in our understanding of these systems. Regardless, it is mentioned that Computerized Procedure Systems (CPS) expand the capabilities of paper-based procedures and the authors concluded from their analysis that CPS could improve and enrich operator performance. Hall and collaborators (2023) in an experiment comparing the three types of computer-based procedures, observed manual-digital in the use of procedures. This could hint that a wider flexibility in assigning tasks to the automation depending on the type of procedure and situation. On the same line are the results of an explorative study using a simple ACPs interfaced with a full-scope simulator (Bisio & Bloch, 2023). The operators appreciated the automatic support in normal conditions, especially for long sequences, but they tended to get back control in more critical sequences. They valued the automation stopping when some disturbances were interfering with the procedure execution, and appreciated the presentation of information about the detected event, while the procedure execution framework provides the context helping the operators to diagnose the event. On the other end the ACPs, given its potential and high flexibility, can impact widely on workflow, communication and teamwork, competence development, and other human performance factors, posing new challenges to the HRA.

## 3. ADAPTIVE AUTOMATION APPROACHES

Adaptive automation refers to systems that dynamically adjust the level and type of automation in response to changing conditions, such as the operator's workload, task complexity, or environmental factors (e.g. Parasuraman et al., 2000; Sheridan & Parasuraman, 2005). The key novelty in these approaches is that they break the previous dichotomy between humans and machines, conceptualizing hybrid teams and raising the possibility that autonomous systems need to know not only information about the process, but also about the humans controlling/supervision the process, in such a way that there is a continuous dialogue between them. This dynamic adjustment aims to optimize human-automation interaction by providing the appropriate level of support at the right time, enhancing overall system performance, safety, and operator well-being.

More recently, authors such as Shneiderman (2020) have, within the context of human-artificial intelligence interaction, re-iterated that high levels of human control are possible to combine with high levels of automation, as well as that the focus needs to be on empowering the humans, not on emulating them.

Within the nuclear context, exploration of adaptive automation approaches has been previously presented (e.g. O'Hara, 2017; O'Hara & Higgins, 2020; Popov et al., 2020). Adaptive automation could be beneficial to maintain the human in-the-loop, allowing exploitation of their expertise and hence improving operation resilience, to reach a good workload balance. Adaptation could also have positive impact on trust in automation. Trust is in continuous evolution and need to be calibrated to avoid the traps of over trust or, at the opposite under-trust. A recently performed study in the Human Technology Organization Project (HTO-Halden Project) labs aimed at gathering the first reaction of operators while working with a simple adaptive CPS (Bisio & Bloch, 2023). The system provided (limited) ability to adapt to minor deviations from the expected situation while executing a standard operation procedure, helping the operators to detect anomalies interfering with the procedure execution. The tool presented an abstract structured overview of the procedure and its execution status, integrated with run rime information from the plant. In an early set of observations, intended mainly as walk-through sessions, a short introduction of the new system was presented to the operator. Later, the operator was left to perform the procedure with the new tool and a paper copy of the same procedure. Most part of the procedure was assigned to the tool for automatic execution. In this condition, most operators, at first tended to use the paper version to verify the behaviour of the system, then, the operators tended to abandon the paper version when they verified that the most relevant information conveyed by the procedure was on the screen, and the tool performed as expected. They used the CPS when requested to intervene to fix anomalies, in a few cases using the paper procedure for contextual details. In other words, they became aware that they were always in control, they could rely on synchronisation points, the automatic execution had a well-defined scope that the operators could control, and that the system was flexible enough to give them time to evaluate the situation and intervene. In a second set of data collection, aimed at evaluating the impact on situation awareness of the same system, we presented the adaptive CPS in equivalent way, but let a group of operators to get acquainted with the system together. When the observation began, as before with a single operator performing the procedure with the help of the adaptive CPS, the paper version of the procedure was not used. The development of trust was not in focus at that time, but this effect deserves more attention. We interpret this difference in the paper procedure use as a quicker building up of trust in the second set of experiments as the adaptive characteristics were experienced earlier. Linked to the concept of trust, Solberg et al. (2022) suggested a conceptual model for how trust evolves in the interaction with AI based decision aids. With a no-strict definition of AI based decision, we could consider an adaptive CPS belonging to this category, with AI enabling more adaptive and cooperative capabilities. The trends observed in the above-mentioned study fit the model. The model can also suggest that an adaptive system could be more likely to bring to a balanced level of trust, contributing, among the other factors, to the perceived control over the system's decisions, while positively supporting operators' attentional capacity.

## 4. HUMAN RELIABILITY ANALYSIS AND ADAPTIVE PROCEDURES

Human Reliability Analysis (HRA) can be overall described as a structured approach to evaluate the likelihood of human errors and their impact on overall system performance. HRA aims to identify, quantify, and mitigate human error to enhance overall system safety and reliability.

Boring *et al.* (2011) discussed Human Reliability Analysis (HRA) for computerized procedures comparing many of the features with paper-based procedures. The main performance shaping factors (PSFs) they discussed were communications, workload and situation awareness, and human-system interface. The failure modes they discussed were related to transfer to backup procedures, degraded computerized procedure functionality, recovery from operator input failures, and failure to follow the computerized procedures. The latter is especially interesting when talking about adaptive procedures, since the most traditional way of doing HRA, by analyzing errors of omission (EOO) from procedures, might not be as relevant in computerized and automated procedures where that might be expected to be handled by the system.

There are two difficulties with application of traditional HRA to adaptive procedures. The first issue relates to the way to model the scenario in PRA/PSA (Probabilistic Risk/Safety Analysis). Will the adaptiveness of procedures challenge the use of event trees in modelling the scenario? This depends on the way in which procedures are adaptive. O'Hara (2017) and O'Hara and Higgins (2020) discuss adaptive automation and adaptive procedures at length. Their concept of "triggering conditions" is a good way into analyzing adaptive procedures. If the triggering conditions and the transfer between the human and the automatic procedure keeps within the modelled scenario, one might foresee that a traditional scenario analysis might be utilized. The difference would be how many events that are acted upon by the human. In a simple solution one may analyze all events to be done by the human, and then use other cases or scenario variants created by the transfer of control between the human and the automatic system. There might be many scenario variants to model or analyze though.

However, the other difficulty might be even more challenging. How do we know the impact on human performance created by the various scenarios, with varying degrees of human activity? Will the situation awareness be significantly different if the human is involved to a large extent, in many procedure steps, than when the human is just monitoring the automatic procedure progress in general? Also, how and to which extent will the workload vary? These issues may be central research questions to investigate in this adaptive procedure project, and that will have a lot of impact on the way to do HRA for these kinds of systems (e.g. Endsley, 2016). Another possibility is to change the way in which HRA is done, and maybe use a slightly different angle of attack, as discussed in Bye (2024).

## 5. DISCUSSION & FUTURE WORK

Through this work it is possible to see that already today, several operational commercial plants have at least some procedures that are computerized and which have some level of automation, expected to either take-over or facilitate tasks that were before performed by the human operators. It is possible to find reports however, of new risks (such as over-compliance), new errors (automation errors), and new risks and errors that are a consequence of the complicated relation between humans and automation in the current frameworks within which human-automation is being planned and designed. We propose that the path towards efficient and safe computerized procedures in process control is to adopt a human-centred approach where the goal is to assure the achievement of generic plant goals, assuming a hybrid team composed by humans and automation. Within this context, we argue that the paradigms of adaptive automation, linked with operator training, and increasingly capable (and intelligent) systems, will offer the best chance of maintaining high levels of performance, reliability, and safety in the control room.

We have presented the well documented challenges in human-automation interaction literature, as well as concrete examples of how these challenges and issues have been present in previous implementations of different automation levels within computerized procedures. A significant part of the human factors literature accounts on limitations and challenges with automated systems that require human supervision or take-over in control, focusing mainly on mitigation strategies for these challenges. Seldomly, have we found a critical approach on the basic assumptions on how the human-automation dyad is expected to interact (one exception is Dekker and Woods, 2002). The concepts of trust, transparency, task allocation, human in the loop, have been useful to better understand and potentially improve already existing systems by using interaction design and human cognition and knowledge. However, we argue that they will not be able to truly contribute to a smooth human-automation interaction because these concepts have mostly accepted the premise that automation will simply “take-over” some degree of tasks and will need to be able to explain itself to the human that may (or not) have decision responsibility over the following steps. Our argument is that these approaches entail a static representation of the control process that does not correspond to the levels of dynamism and uncertainty that are common in complex control systems and that the human operators are trained and experienced in handling. To capture the true nature of the control room work, a flexible and adaptive system will be needed that does not aim to replace the human but rather to optimise the human performance – such a system could be achievable within more recent approaches such as adaptive automation, linking it to the old-school human-machine symbiosis tradition (Licklider, 1960).

Nowadays, the technological development might be able to support at least early prototyping of adaptive automation in the context of procedures in nuclear operations. Outward sensing, especially focused on the assessment of operator status – including for instance fatigue and/or workload assessment – as well as supporting some degree of personalization – accounting for level of experience, operator role, or even preferences – seems feasible and is already available and being piloted in real world contexts (e.g. Cassenti & Veksler, 2018; Romero et al., 2015). Recent tools and systems such as large language models could also be of use in summarizing, combining, and making information more available or more explicit to the operators as a support during procedure usage. The specific concepts of implementation of adaptive automation will be critical for its feasibility and the definition of its safety impacts. Procedures could be adaptive in many different ways, and being adaptive to both plant and human states, needs, and specific task goals. Defining these conditions and how to assess them is the big challenge regarding application of adaptive procedures.

New topics and approaches to human-automation interaction and collaboration are needed in high-risk industries. There are recent efforts to discuss, explore, and propose new methodologies to analyse and promote safety in these new hybrid systems. Specifically for procedure use, Peres & Handricks (2024) present an interesting work focusing on the links between safety climate and procedure use attending to persons, tasks, and contexts. It validates the importance of considering interactions between multiple factors rather than relying solely on individual characteristics, as posited by traditional safety models.

Only through controlled and dedicated testing of new concept of dynamic and flexible human-automation interaction, will we be able to foresee and reflect on the challenges that might result from its implementation. There is only a limited number of iterations that could be predicted based on previous experiences with automation of procedures. Currently we have a working hypothesis that adaptive automation approaches could help mitigate the impact of automation from a human factors and human reliability perspective. However, it is difficult to anticipates the safety challenges it could give rise to.

In this context we plan to explore in the near term what are the requirements, characteristics, and preferences regarding the implementation of computerized and automated procedures. We wich to explore and experiment with concepts in order to be able to prioritize the capabilities of an adaptive procedure system that could enhance procedure use in complex environments. We will contact experienced operators, vendors, and human factors professionals and try to link their views, expectations and needs with the knowledge available in literature on adaptive automation applications in complex systems. In a second stage, we expect to prototype automated procedures for nuclear control (probably focusing on specific procedures for emergency situations) so we can assess operators' performance with the system, controlling its levels of support, adaptiveness, or potential links with state-based assessments. We expect these initial studies, both of qualitative and quantitative nature, will contribute to a better understanding of ACPs in nuclear control. Moreover, we expect to provide recommendations deemed useful for both the design and implementation of the systems, as well as recommendations for assuring safe operation of the plant in joint human-automation teams. Another contribution will be providing preliminary performance data on how operators interact with the ACPs in specific scenarios, and according to the available features.

## 6. CONCLUSION

In this paper we argue for the implementation of human-centred approaches to the integration of automation in the specific case of computerized procedures in nuclear power control. We position ourselves within the classic intelligent augmentation - IA tradition (in opposition to artificial intelligence - AI) arguing towards symbiosis (e.g. Engelbart, 1962; Licklider, 1960) in the man-machine interaction rather than replacement of the human (McCarthy, 1958). Furthermore, we argue that previous implementation of automation systems in nuclear control rooms have traditionally followed a logic of allocation of tasks between man and machine (e.g. Sheridan, 1987) that is closer to AI approaches where the machine/automation is seen as a full replacement of the human either in a single tasks or in a set of tasks. Often there has been an implicit belief that human-automation interaction is a transitional phase between a full human controlled operation and a fully automated operation. We defend the perspective that only through a paradigm where both human and machine are considered essential parts of the system will it be possible to implement successful, safe, reliable, and sustainable automation in complex process control settings. This approach entails that current systems are not seen in a logic of a transitional phase where human act as supervisors while the machines are not (yet) able to do the tasks themselves. Rather, we argue that functional human-automation coordination is the central and final goal for the next generation of control room operations.

Integration of automation in nuclear control rooms is intricately linked to safety risks. While the argument for more automation is usually reduction of human error and workload for the operators, it also introduces challenges related for instance to situational awareness, skill degradation, and system reliability. Balancing automation with human oversight through adaptive automation paradigms, re-designing training, focusing on intuitive interfaces, maintaining robust and updated safety protocols, and designing human-centered systems is essential for optimizing safety in nuclear control rooms and realizing the potential of automation in a resilience, sustainable, and efficient way.

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