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# Categories of measures to guide choice of human factors methods for nuclear power plant control room evaluation

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ABSTRACT

Safe operation is a central objective for nuclear power plants that must be supported by the entity managing the operation, the control room system. Safe operation is dependent on how technology is used, so it is important to take human factors issues into consideration. During design or modification of the control room system, its ability to support safe operation must be assessed to ensure that safety-critical discrepancies are eliminated before implementation. Methods are a necessary tool in human factors evaluation, and there are many to choose from. One prerequisite for evaluation is knowing what to evaluate, and this knowledge determines which methods are most suitable. The purpose of this paper is to identify categories of measures that can guide the choice of evaluation methods for assessing nuclear power plant control room systems. Measures targeted by human factors evaluation methods were compared with aspects that contribute to safe operation and measures proposed and used by other researchers. The conclusion of this paper is that measures targeted by human factors evaluation methods can be grouped into six categories: system performance, task performance, teamwork, use of resources, user experience, and identification of design discrepancies. These six categories can guide the choice of human factors evaluation methods to assess socio-technical systems. Methods providing data from all six categories of measures are needed to fully assess a nuclear power plant control room system.

## 1. Introduction

Safe operation is a central objective for high-risk industries such as nuclear power plants. Nuclear safety, as defined by the International Atomic Energy Agency, is "*the achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards*"(International Atomic Energy Agency, 2007, pp. 133). In this definition, the word "radiation" can be excluded to create a definition of safety for nuclear power plants that includes other hazards than radiation. However, safety is not the only objective of a nuclear power plant, the production of electricity is the fundamental reason for the plant's existence. Safe operation thus relates to the production of electricity without exposing workers, the public or the environment to undue hazards.

A nuclear power plant can be viewed as a socio-technical system, an open system where three mutually interdependent elements – technological subsystem, personnel subsystem, and work system design (Hendrick and Kleiner, 2001) – interact with one another and the external environment to jointly contribute to safe operation of the plant. Operation of the plant is managed from a central control room, a socio-technical system in itself made up of interdependent elements such as operator interfaces (technological subsystem), operators (personnel subsystem), and work routines (work system design). The control room exercises central control and monitoring, as well as administrative responsibilities (International Standard Organisation, 2000), with the purpose of achieving proper operating conditions, preventing accidents or mitigating accident consequences.

The discipline of human factors is defined as "*the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance*" (International Ergonomics Association, 2016). Consideration of human factors, according to the International Nuclear Safety Advisory Group (1999), is one of the underlying principles of nuclear safety. Viewing the control room system as a socio-technical system corresponds to the rationale behind this statement. Joint optimisation of the elements in the nuclear power plant control room system, including interactions between humans and other elements of the system, plays an important part in the achievement of safe operation. For example, designing the operator interface (technological subsystem) to present needed information in an understandable manner

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aids the shift team's (personnel subsystem) decision-making regarding safety-critical issues.

Due to the control room system's operational significance all changes have the potential to impact safety (Norros and Nuutinen, 2005). In nuclear as well as in other industries with major accident potential, there are strong incentives for addressing safety during the design process. Hale et al. (2007) mainly attribute this interest in safety in design to "*a logical conclusion that systems development begin with design and so design offers the earliest, and hopefully the cheapest place to intervene and get it right*" (ibid., p. 308). The advantage of avoiding design errors is supported by reviews of accident and incident data suggesting that 20–50% of accidents and incidents have their root causes in design (Kinnersley and Roelen, 2007; Taylor, 2007). To minimise error making and enhance error detection and correction, designers should be trained and informed and provided with the correct tools (Hale et al., 2007).

Evaluation methods are one set of such tools. To evaluate a new or modified control room system during the plant development process, one integral activity is to manage the impact on safety. If design is the place to intervene and get it right, as Hale et al. (2007) put it, then evaluation is the way to know where to intervene. The human factors domain offers a multitude of different methods for assessing a system, and in a development project methods relevant for the control room system evaluation in question have to be selected. Types of data obtained by different techniques are one decision criterion for incorporating human performance evaluation in design provided in a guide for the evaluation nuclear power generating stations by the Institute of Electrical and Electronics Engineers (1999). However, using types of obtained data as a criterion for method choice requires knowing which data is relevant for the system being evaluated. In a review of methods related to assessing human performance in nuclear power plant control room simulations, Le Blanc et al. (2010) highlight the challenge of establishing the types of data or combinations of data needed to claim that human performance is acceptable. This challenge and the need to address it is also acknowledged by O'Hara and Fleger (2015), as one result of their research into identifying aspects of integrated system validation (an activity performed before a design for a new or modified control room is implemented to assess whether it supports safe operation) that need to be updated, along with the available technical basis for supporting this update.

One path toward choosing suitable evaluation methods for control room evaluation lies in identifying measures that are relevant for assessing the control room system's ability to support safe operation. The word measure is here used to denote something that is registered in an evaluation with the purpose of indicating a quality in the system to be evaluated. A suitable starting point for this is to identify what contributes to safe operation. Simonsen and Osvalder (2015) studied aspects of the nuclear power plant control room system that contribute to safe operation. The purpose of the study was to build a foundation for evaluation measures. Five overall themes of aspects contributing to safe operation were identified in the collected data: *situations*, *functions*, *tasks*, *characteristics* and *structural elements*. As part of a framework meant to "*develop a coherent set of performance indicators and measures for integrated system validation*", among other things, Braarud and Rø Eitrheim (2013, pp. 4) developed a model of nuclear power plant control room work that "*covers the control room functionalities, their possible physical representations and the support for safe and effective performance of the tasks by the team*" (ibid, pp. 17). They proposed that current models of control room work did not consider the physical representations, couplings to cognitive support, discrimination between individual and team demands, and relation to the current situation and process state (normal operation, disturbances, accidents). They therefore wished to suggest their own model. They describe their model as consisting of four main components: *team*, *cognitive dimensions*, *tools*, and *situation*. The cognitive dimensions component in turn is divided into *team cognition*, *situation understanding*, *mission*, and *control and verification*. The model by Braarud and Rø Eitrheim (2013) is explained in more detail in the discussion chapter. By exploring what contributes to safe operation in the context of nuclear power plant control rooms, these two sources provide a foundation for identifying measures relevant for assessing the control room system's ability to support safe operation.

Others take one step further and suggest suitable measures for nuclear power plant control room evaluation. Savioja (2014) concludes that evaluation methodologies tend to simplify and generalise the operating work. She presents a framework for finding measures to comprehensively assess systems usability in nuclear power plant control rooms. The framework, presented as a 3 × 3-matrix, evaluates the *instrumental*, *psychological* and *communicative* functions of a control room system in use (the 'tool' in Savioja's terminology) from the different perspectives of *performance*, *way of acting* and *user experience*. The three perspectives and three tool functions in the framework create nine so-called "*general classes of systems usability indicators*" (Savioja, 2014, pp. 87). The systems usability framework of Savioja (2014) is explained in more detail in the discussion chapter.

Measures for evaluating nuclear power plant control rooms are also proposed in a human factors engineering program review model, called NUREG-0711, issued by the United States Nuclear Regulatory Commission to provide their staff with a review methodology for plant modifications or newly-built plants (United States Nuclear Regulatory Commission, 2012). This review model is used by other parties in other countries as well, as guidance for planning and performing human factors activities in development projects. Integrated system validation is the major summative evaluation activity proposed in NUREG-0711. Five so-called performance measures for integrated system validation are suggested: *plant performance*; *primary and secondary task performance*; *situation awareness*; *workload*; and *anthropometry and physiology*.

As stated above, one path toward choosing suitable evaluation methods for control room evaluation lies in identifying relevant measures. Models and studies describing nuclear power plant control room systems and suggesting measures for evaluation are not in apparent agreement with each other. The purpose of this paper is to identify categories of measures that can guide the choice of evaluation methods for assessing nuclear power plant control room systems. A category of measures is a term used here to denote a group of measures that target the same quality of the system to be measured. This was achieved by comparing measures targeted by existing evaluation methods with the models and studies described above as well as with measures utilised in empirical nuclear power plant control room evaluations.

## 2. Method

In this paper, relevant categories of measures were identified through two main steps: discerning categories of measures and assessing these categories' relevance in control room system evaluation.

In the first step, measures targeted by existing human factors evaluation methods were compiled and analysed. An evaluation method was defined as a method that collects data and supports the process of making a judgement about something. One example of how a method might support this process is the determination of acceptance criteria. Some methods provided assessment criteria (such as method-specific scales with pass/fail levels), others collected measures that in themselves contain a judgement and thereby assessment criteria (such as errors). Some evaluation methods allowed the determination of assessment criteria through baseline assessment, i.e. performing an evaluation before the system has been changed and comparing the result from the evaluation of the changed system to this. Methods from two textbooks (Stanton et al., 2005; Wilson, 2005) with extensive compilations of human factors evaluation methods from different sources, research traditions, and time periods were assembled. Initially, a list of 162 methods was complied. On closer examination, methods not considered to be evaluation methods were excluded, as well as methods