SMR Staffing Solutions: Human Factors Integration

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Abstract

Rolls-Royce is designing a Small Modular Reactor (SMR) for deployment on the grid by 2030. The reactor design is led by market requirement, based on Pressurised Water Reactor (PWR) technology and is designed to have a power output of between 400-450 MWe.

A challenge for SMR designs is the consideration of staffing requirements for operation and management of the SMR in a power station context, including consideration of multiple modules on a single site, or multiple SMR sites in a fleet solution.

A process is required for the assessment and specification of staffing for SMR designs to provide an optimised staffing solution to deliver safe operation whilst controlling costs.

Systematic consideration of Human Factors throughout design development, using a structured Human Factors Integration (HFI) process, is being adopted as a capability to address the definition and demonstration of robust and cost effective staffing solutions for SMR designs and power stations.

The HFI process draws upon established Human Factors analysis methods to ensure that all Human Factors issues in the design are identified and addressed. A range of HFI methods is available to support the design process, and these methods can be organised into a predictive capability for the assessment and specification of staffing requirements for the SMR power station solution.

Application of the HFI framework early in design allows early consideration of staffing solutions and the ability to optimise the use of engineering delivery of plant functions, and to evaluate multiple staffing options to meet design requirements.

1. Introduction

Rolls-Royce is currently in the concept phase of the Small Modular Reactor (SMR) design process. The design of the SMR is requirements led and a set of key design principles and assessment criteria have been defined for the project to direct the design decision making and the progression of the design architecture and solutions.

A key requirement in designing the SMR is to ensure that Human Factors issues have been considered throughout the design process, in order to demonstrate that it can be operated safely at all lifecycle stages.

2. Overview of UK Small Modular Reactor (SMR)

Worldwide, electricity generation is being challenged to decarbonise so that commitments on limiting global warming can be supported. In the UK, studies, for example by the Energy

Technologies Institute (UK scenarios for a low carbon energy system transition, 2015), identify that a mixed portfolio of nuclear, renewable and gas generation technologies is the most viable option economically and technically to deliver this.

For nuclear generation, the UK has been pursuing a policy of attracting multiple international reactor vendors to build new large nuclear plants. However, financing is proving to be a key challenge.

Small Modular Reactors (SMR) offer a complementary capability to the programme of large nuclear plants by providing additional diversity to the energy mix and further flexibility and security for the electricity grid in the future. In addition, SMRs inherently offer more flexibility than large scale reactors, opening up potential for load following or Combined Heat and Power (CHP) applications.

Rolls-Royce has established the key requirements that impact most on the technology choices available to a reactor vendor against the needs of the end-user/other stakeholders (governmental, industrial, and operational). These requirements and objectives have driven the characteristics of the UK SMR design and include:

1. Highest power for lowest cost;
2. Enhanced passive safety;
3. Proliferation resistant;
4. Regulatory compliance;
5. Proven technologies;
6. Design for manufacture / construction;
7. Design for operation e.g. enhanced access for maintenance and refuel;
8. Compact modular design;
9. Design to gain volume economies;
10. Whole power station standardisation / modularisation;
11. Design with account for public perception;
12. Compatibility with existing infrastructure.

Overall, the design is being driven to provide certainty of cost (<£5000 per kWe installed capacity), certainty of delivery (<4 years from first nuclear concrete to commissioned for nth of a kind (NOAK)) and affordability (LCOE between £60-£70 per MWhr NOAK).

From these requirements, a three loop, close-coupled, pressurised water reactor provides a power output at circa 400-450 MWe from 1200-1350 MWth using industry standard UO2 fuel. Coolant is circulated via three centrifugal Reactor Coolant Pumps (RCPs) to three corresponding vertical u-tube Steam Generators (SGs). The design includes multiple active and passive safety systems, each with substantial internal redundancy.

The reactor is located in Nuclear Island adjacent to Turbine Island with the Cooling Water Pump House following. These facilities are protected by a robust hazard shield. Support buildings and those containing auxiliary services are situated within a berm that sweeps around the site and provides further protection from external hazards, e.g. tsunami or aircraft impact. A conceptual view of the Rolls-Royce SMR is shown in Figure 1.

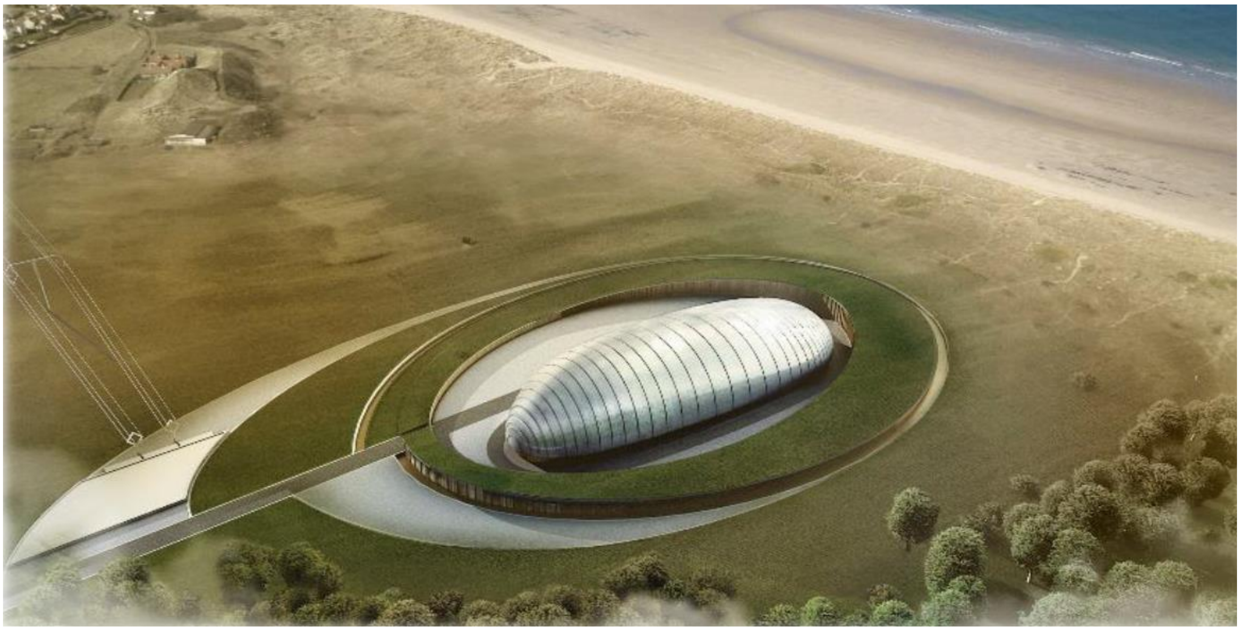

Figure 1: Conceptual View of Rolls-Royce SMR

3. SMR Staffing

A challenge for SMR designs is the consideration of staffing requirements for operation and management of the SMR in a power station context. Staffing must be considered for a single SMR module power station to ensure sufficient resources are provided for safe operation. However, the potential for multiple modules on a single site, or multiple SMR sites in a fleet solution, must also be addressed to ensure that staffing costs do not impact on the economic viability of SMR designs.

4. Reducing Staffing Requirements

Reducing staffing requirements can be achieved by various means, including task elimination, task simplification and increased use of engineering automation or passive systems. However, it must be demonstrated that plant functions can be delivered safely by the resulting staffing solution, and that the staffing solution can be maintained.

Task elimination can result from provision of passive systems, with no requirement for active management or control input from people. In addition, task elimination may also be achieved by provision of remote operation or surveillance of equipment from the control room, which removes the requirement for local operation by another person.

Task simplification may be achieved by reducing the complexity of plant operations, and therefore reducing the number of process steps required to deliver plant functions.

Engineered automation of plant functions can be used to eliminate or simplify the tasks normally assigned to people in the design solution. However, the requirement for monitoring of correct operation of automated systems must be considered to ensure operator situational awareness.

5. Staffing Specification

Specification of a staffing solution for a SMR power station includes definition of the number of personnel to be provided, and the skills, qualification etc. associated with their different roles in order to ensure sufficient trained people are available for safe operation. A process is required for the assessment and specification of staffing for SMR designs to provide an optimised staffing solution to deliver safe operation whilst controlling costs.

Rolls-Royce has adopted a structured Human Factors Integration (HFI) process to ensure the systematic consideration of Human Factors throughout design development, including the definition and demonstration of robust and cost effective staffing solutions for SMR designs and power stations. The UK Office for Nuclear Regulation (ONR) provides guidance to its inspectors on expectations for HFI in a specific Technical Assessors Guide (TAG) (ONR, 2017, NS-TAST-GD-058-Revision 3).

6. Human Factors Integration

Human Factors Integration is achieved and managed from the earliest stages of SMR design development through application of a Human Factors Integration Plan (HFIP). The purpose of the HFIP is to be the coordinating document for all HFI activities in the project, defining how the Human Factors Engineering activities necessary for successful delivery of the design will be conducted. The HFIP is used to ensure a consistent and robust approach to the application of Human Factors principles across the project. The HFIP defines the scope and programme of HFI activities, the resources required to deliver HFI, and strategy for HFI delivery, including identification of standards and methods.

A range of established HFI methods is available to support the design process. These methods include task analysis, description of the target audience, Allocation of Function (AoF) and Operational Sequence Diagrams (OSD). Descriptions of these methods are available from Kirwan and Ainsworth (1992) and Stanton et al (2013).

7. Human Factors Methods for Staffing

The fundamental approach to HFI is the application of task analysis methods to provide representation and analysis of human-system interactions. A Hierarchical Task Analysis (HTA) can be established in the earliest concept design phase, even with very limited design detail and maturity. HTA allows the decomposition of a high level goal into a series of sub-goals, tasks and activities to be completed by the human element of a system. A numbered hierarchy is used to provide a unique identifier for each goal, sub-goal, activity and task. The structure of the HTA allows early identification of the breadth of expected human-system interactions, in terms of the goals to be achieved, across a range of design options. Investigation and development of task detail in the HTA is achieved by construction of a Tabular Task Analysis (TTA) from the HTA numbered hierarchy.

The TTA provides a mechanism for allocating tasks and activities to personnel, identifying design support required for task delivery, and for investigating the potential for human error and error recovery. The TTA also allows task information, such as estimated task duration, to be added to the task description.

In order to provide a baseline for Human Factors analyses, a Target Audience Description (TAD) is generated at the start of the design process. The TAD provides a structured description of the skills, knowledge, physical, psychological and physiological capabilities and capacities of available personnel. The TAD is also used to capture initial assumptions on the number of personnel by drawing on knowledge of existing staffing solutions for nuclear power stations.

AoF is used to assign those tasks required to meet system goals to either humans or engineered elements of the system, based on their respective strengths and weaknesses. As a result of this analysis, tasks for which humans are known to have poor levels of reliability are assigned to the engineered elements of the system, and tasks at which humans show better performance are not automated in order to improve overall system performance. AoF is considered in parallel with the task analysis, and is developed and updated as task detail increases as the design solution matures.

The functions, and resulting activities, assigned to humans in the design can be represented and analysed in OSD (example in Figure 2). The OSD allows investigation of the number of people required to deliver activities and functions over time to ensure safe power station operation.

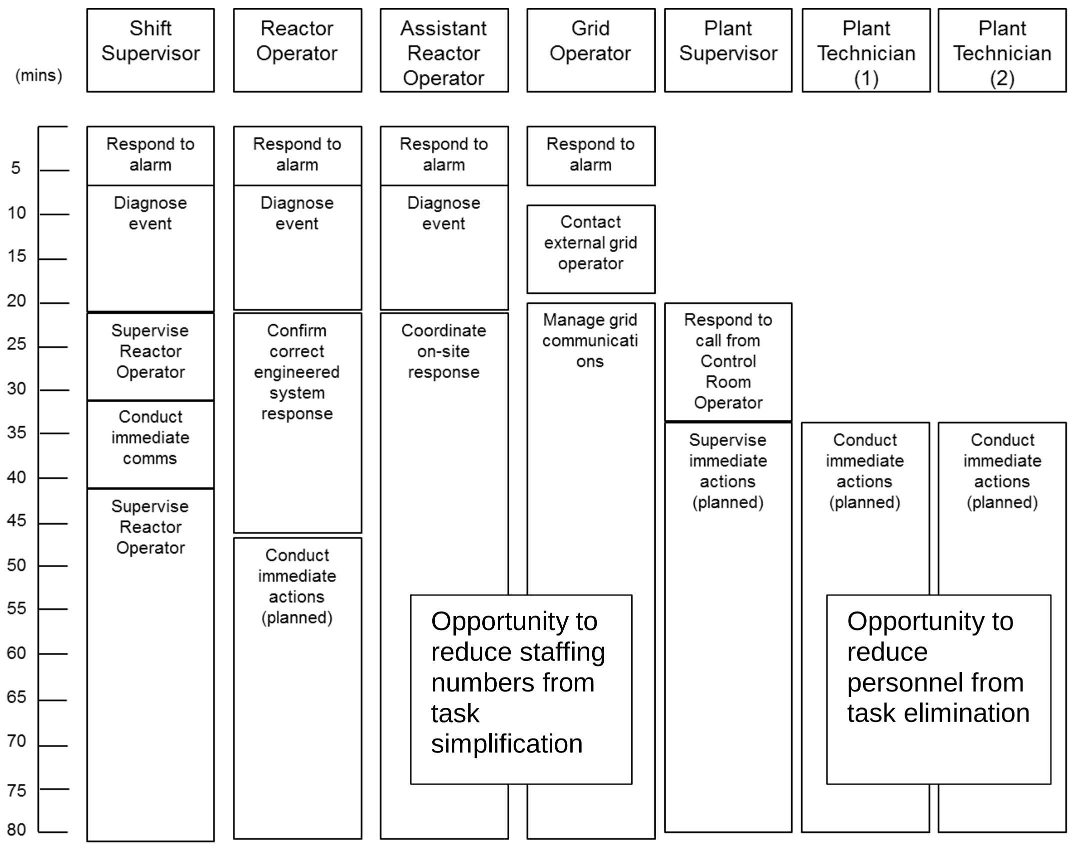

Figure 2: Example OSD for Response to an Event

An OSD is a flow diagram linking various task operations in the order in which they are normally carried out. It is a representational technique by which data can be organised for presentation and subsequent analysis. An OSD predominantly represents a linear flow and is conventionally drawn from top to bottom. The OSD in Figure 2 shows examples of opportunities to reduce staffing numbers by task elimination or task simplification.

Iteration of analyses to address the addition of design and task detail supports design development and is used to explore and inform design decisions. These methods can be organised into a predictive capability for the assessment and specification of staffing requirements for the SMR and power station design.

8. Staffing for Multiple Reactor Units

The application of analysis methods to support investigation and definition of staffing requirements has been described in the context of a single reactor power station. However, the analysis methods are also applicable to the assessment of multiple reactor units on a single power station site, or multiple power station sites operated as a fleet solution.

The HTA/TTA and OSD methods allow for the visual representation of tasks and activities allocated to personnel against time to be reviewed in the context of multiple reactor units. For example, where an operator is monitoring two reactor units, a monitoring activity for each unit can be shown in parallel against the same person. In this example, the workload on the operator, and the ability to maintain situational awareness across multiple units, become key considerations when assessing this staffing option.

Workload in this context is concerned with human capability for processing information (such as from displays, alarms, documentation and communications), holding items in memory, making decisions and performing tasks. Excess workload can result in a degradation of human performance, such that the time required for task completion is increased, or the potential for human error is increased. It should also be noted that underload can also lead to human performance issues such as boredom, loss of situation awareness and reduced alertness.

Situational Awareness can be described as the ability to identify, process, and comprehend the critical elements of information about what is happening to the environment, process or system being controlled and monitored. In simple terms, situational awareness is the ability of a person to know what is happening around them.

Allocation of parallel activities to a single person has the potential to increase workload on that person, and affect their situational awareness, by presenting competing demands for attention in the same time period. Application of HTA/TTA and OSD methods is used to represent task allocation and identify potential periods of high workload, and to highlight periods of operation where there is sufficient time available to respond to an event, such that parallel monitoring can be accommodated (effectively the extended time allows for monitoring and response tasks to be considered as series activities).

The HFI methods are equally applicable to operations conducted outside of the control room, and the methods can be used to inform the optimum balance between remote operation from the control room and manual operation of equipment local to the plant.

There are also opportunities for staffing reduction for each SMR installation in a fleet solution by sharing personnel across power station sites in the fleet. For example, it may be possible to utilise a single maintenance team across multiple sites by staggering the maintenance schedules for each site. There may also be opportunities to utilise personnel from one site to provide remote support to another site by provision of remote surveillance or provision of communication links between sites.

Representation of design options to share personnel between sites, or to provide support remotely between sites, is also possible using the HFI methods described in this paper by including allocation of tasks to personnel from remote sites in the OSD.

9. Sustainable Staffing

The staffing solution derived for the SMR design in a power station context must also be demonstrated to be sustainable over the life cycle of the power station. The ability to recruit, train, retain and support sufficient personnel with the correct level of skills, knowledge and experience to support safe operation must be addressed as part of the overall design solution for the SMR.

A key element of providing a sustainable staffing solution is to understand the training requirements to support operation of the design solution.

Training Need Analysis (TNA) is the process of identifying and addressing the gap between existing employee training and the level of training needed to deliver the role associated with a new design. TNA is the first stage in the training process and involves a procedure to determine a recommended training solution for progression to detailed training design.

TNA can be used as part of the system development process to explore the relationship between the design of the system and the training required. Early consideration of the design of training to deliver personnel with the required skills and abilities allows early decisions to be made on the requirements for training infrastructure and facilities, which may be provided at each power station site, or can be shared between sites in a dedicated training facility.

10. Conclusion

Rolls-Royce has adopted a structured Human Factors Integration (HFI) process to ensure the Systematic consideration of Human Factors throughout design development, including the definition and demonstration of robust and cost effective staffing solutions for SMR designs and power stations. The HFI process utilises a set of established Human Factors methods to consider the allocation of tasks to the human element of the system design, to provide descriptions of human activities using task analysis, and to investigate a range of staffing solutions using Operational Sequence Diagrams (OSD).

The application of analysis methods to support investigation and definition of staffing requirements has been described in the context of both a single reactor power station, and in the assessment of multiple reactor units on a single power station site, or multiple power station sites operated as a fleet solution. Key considerations of operator workload and situational awareness have been identified as measures for the assessment of staffing solutions.

The ability to recruit, train, retain and support sufficient personnel with the correct level of skills, knowledge and experience to support safe operation has been identified as part of the overall design solution for the SMR. A Training Needs Analysis (TNA) process has been identified as part of the system development process to explore the relationship between the design of the system and the training required.

Iteration of analyses will be used to address the addition of design and task detail to support design development and to explore and inform design decisions. The HFI methods described in this paper can be organised into a predictive capability for the assessment and specification of staffing requirements for the SMR and power station design, which allows staffing costs to be managed whilst maintaining safe operation through life.

11. References

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