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Title

E3S Chapter 18: Human Factors Engineering

Executive Summary

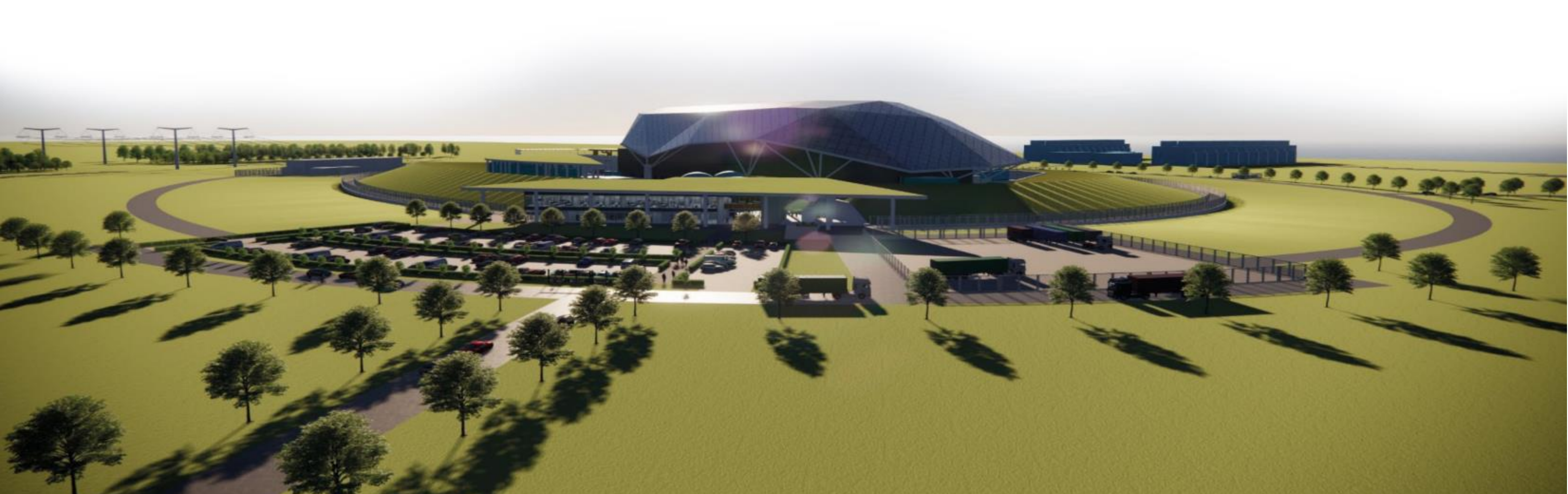
This chapter of the Environment, Safety, Security, and Safeguards (E3S) Case presents the human factors engineering of the Rolls-Royce Small Modular Reactor (RR SMR). Human Factors (HF) applies knowledge of human characteristics to optimise the design of products, equipment, environments, systems, and organisations. HF methods are applied to minimise human errors and enhance human performance for a given design. HF methods are most effective when delivered through early engagement with a design project.

The HF assessments aim to demonstrate the high-level Claim that 'HF is fully integrated into the Rolls-Royce (RR) Small Modular Reactor (SMR) design and substantiation processes, with the aim of minimising harm to personnel or environment and maximising human performance'. The substantiation of this top level and the supporting sub-Claims will develop over the length of the RR SMR programme, as evidence for each becomes available in-line with the design maturity.

This document provides the substantiation of the HF Claims, commensurate with the design definition, with evidence provided in a series of supporting documents.

Within this Preliminary Concept Definition (PCD) phase, and the earlier iterations of PCD, a variety of HF assessments have been completed across the whole scope of RR SMR. The early involvement of HF on the RR SMR programme has provided a foundation for future assessments, through requirements derivation, identification of key standards and design guidance.

Given the early stage of the design development it has not been possible at this time to confirm that all HF Claims have been substantiated as greater design definition is required in addition to some areas of testing. However, the analysis of the current concept provides confidence that it will be possible to substantiate the HF Claims at an appropriate stage in the design and E3S Case, as the design continues to mature and as HF guidance continues to be embedded.



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18.0.1 Introduction to Chapter

Chapter 18 of the Rolls-Royce Small Modular Reactor (RR SMR) Environment, Safety, Security & Safeguards (E3S) Case forms part of the Pre-Construction Safety Report (PCSR), as defined in E3S Case Chapter 1: Introduction, Reference [1].

Chapter 18 presents the overarching summary and entry point to the Human Factors (HF) design and analysis aspects for the RR SMR, as defined at Reference Design (RD) 5 level of design maturity.

18.0.2 Introduction to Human Factors

HF applies knowledge of human characteristics to optimise the design of products, equipment, environments, systems and organisations. HF methods are applied to minimise human errors and enhance human performance for a given design. HF methods are most effective when delivered through early engagement with a design project.

The objectives for HF are:

1. To support the design, in a fully integrated manner, through provision of HF policies, requirements, guidance and support
2. To ensure that HF support to the project is managed and integrated in a way that ensures a consistent approach across the scope of the project, and throughout its duration
3. To ensure that HF issues are considered in the design solution, and to provide appropriate analysis and evidence to support design decisions
4. To ensure that system designs are optimised from a HF perspective, as far as is practicable, to deliver a safe, efficient and effective set of human-system interactions in the design solution.

18.0.3 Scope

The objectives stated in Section 18.0.2 are achieved through the HF programme, which supports the full scope of engineering design and assessment activities across all aspects of the RR SMR power station and factories.

This document content refers to those Structures, Systems and Components (SSCs) which are within the Generic Design Assessment (GDA) scope.

Design/Programme Maturity

RR SMR design information presented in this revision of the PCSR is largely based on the design definition at the end of Preliminary Concept Definition (PCD), which is an interim design stage representing RD5 level of design maturity.

During PCD there has been focus on integrating HF into the programme, developing requirements and guidance to enable the design teams to incorporate HF considerations into their concept. HF have supported the identification of operator actions in line with the concept maturity and have used techniques such as Task Analysis to develop the detail of the operator actions. Initial control facility concepts have been developed, to be defined further in the subsequent design phases alongside the increasing concept maturity.

18.0.4 Claims, Arguments and Evidence Route Map

The HF assessments aim to demonstrate the high-level Claim that 'Human Factors is fully integrated into the RR SMR design and substantiation processes, with the aim of minimising harm to personnel or environment and maximising human performance'.

This Claim is supported by a hierarchy of sub-Claims as shown in Appendix A: Claim, Argument, Evidence Route Map.

The first level of Claims in support of the overall Claim are:

1. Human Factors design requirements are incorporated into the RR SMR
2. The RR SMR design provides the operators with the facilities to enable safe and secure operation
3. Human Factors design requirements and human-based actions are substantiated
4. The RR SMR design is informed by assumptions on the capability of a future licensee from a Human Factors perspective.

The substantiation of these Claims will develop as evidence for each becomes available in-line with the design maturity, which will be documented in the Claims, Arguments, Evidence (CAE) Route Map [2], described further in E3S Case Chapter 1: Introduction, Reference [1].

This document provides the substantiation of these Claims, commensurate with the design definition, with evidence provided in a series of supporting documents. The sections relevant to each Claim are:

1. Claim 1: Sections 18.2
2. Claim 2: Sections 18.3 and 18.4
3. Claim 3: Section 18.5, 18.6, and 18.7
4. Claim 4: Section 18.8.

Section 18.1 provides the Concept of Operations (ConOps) as context to the role of the operator on RR SMR.

18.1 Concept of Operations

18.1.1 Introduction

A ConOps is a set of information describing the characteristics of a proposed system from the viewpoint of an individual who will use that system. ConOps assumptions relating to RR SMR are discussed in this section. These assumptions will be reviewed as the design matures.

18.1.2 Philosophy

The SMR is aiming to reduce the need for operators to manually intervene in power station operations, for any lifecycle mode and mode of operation. Whilst automation can be beneficial to reducing the potential for human error or reducing potential harm to personnel, there is a need for personnel to maintain situational awareness.

An Allocation of Function (AoF) process will support the identification the optimal allocation of activities to person, system, or a combination. The RR SMR concept includes a number of passive safety systems to limit the Claims placed on the operator, and the interface will include features to support the operator in activities assigned to them.

18.1.3 Manufacturing, Construction and Commissioning

Equipment and components for the RR SMR will be manufactured in a number of controlled factory environments. Factory operations are diverse and are expected to include operations such as:

1. Fabrication of items
2. Construction and assembly of components, systems, modules
3. Mechanical handling of equipment
4. Machinery operations
5. Inspections including radiography
6. Work control systems
7. Logistics.

An on-site factory will be available for the construction and assembly of the power station infrastructure, buildings and systems. This will provide a level of weather protection for the operations and personnel inside the on-site factory.

Manufacturing and Construction operations will include automation and remote operations when practicable; however, manual operator actions are still expected for some operations.

The modularised design and the Mechanical, Electrical and Plumbing factory will allow for Factory Acceptance Testing of agreed SSC within a controlled environment off-site. The remainder of the Commissioning (e.g., Cold and Hot Functional testing) will take place on site, with the appropriate controls for the activities. Commissioning activities are expected to be largely manual, although the automated systems will be tested.

18.1.4 Power Operation

Whilst the RR SMR is designed for flexible operations, steady state operation is assumed for the E3S Case. It is expected that there will be only minimal requirement for manual adjustment of reactivity (e.g., to manage fuel burnup).

Fundamentally, the reactor is expected to operate in two distinct modes; Power Operations, and Shutdown Operations to permit Outages and Refuelling periods. These can be divided into six modes of operation, which are largely similar to the modes of operation for existing PWRs:

1. Power Operations
2. Low Power
3. Hot Standby
4. Hot Shutdown
5. Cold Shutdown
6. Refuelling.

Monitoring and control of the RR SMR will be centralised within the Main Control Room (MCR), located within the Reactor Island. From here, operators monitor and control the entire plant.

A detailed list of the Operational Limits and Conditions (OLCs) will be developed for the design to provide the operators with boundaries of operation. These will include parameters such as temperatures, pressures, status of SSC and activity limits, the required acceptance criteria (e.g., limits), and will be detailed in Technical Specifications.

From the MCR, the operators are able to take action to correct identified deviations, however the benign nature of the plant means that no remote operator actions are required within the first 30 minutes of a fault occurring. Passive systems provide the initial protection against the faults identified as design basis initiating events, which challenge control of the key functions which maintain reactor safety.

In the event that the MCR is uninhabitable (e.g., due to fire), then the operators will transfer to the Supplementary Control Room (SCR). The SCR is also located within the Reactor Island, located such that a single incident shouldn't threaten both control rooms but also to allow safe transfer of personnel. The SCR will include monitoring and control of safety related systems, in order to ensure a safe state is achieved and maintained.

Whilst the Power Station is operating, the personnel across the Power Station will be conducting Examination, Maintenance, Inspection and Testing (EMIT), and recording and/or reviewing the results of analysis, for example, sampling of coolant, which confirms the Power Station is operating within normal operating bands. These activities are expected to include both manual and automated actions which the operators will monitor the results from.

Local to plant operations are expected, which will include operation of manual valves, monitoring of local gauges and instrumentation, routine maintenance activities, and defect repair.

During Power Operations it is anticipated that personnel will also be planning for the next outage period, undertaking training, and meeting with regulators as part of normal duties amongst other activities.

RR SMR will provide amenities such as food outlets, changing facilities, toilets, showers, and storage locations for personal items on the site.

It is expected that some level of training facility will be provided on-site, but the option is open for a full-scope training facility to be provided off-site. Similarly, an element of business control is expected on site, but the location of full business, finance, planning, human resources capabilities etc, could be off-site.

18.1.5 Outage and Maintenance including Fuel Handling

Outage operations will include activities such as mechanical handling of plant equipment, crane operations, fuel handling, use of specialised tooling, management of fuel pools, and invasive maintenance activities.

These activities are anticipated to require more operator actions than normal critical operations although an appropriate level of automation and remote operations will reduce the need for direct operator intervention.

Fuel handling will be required to refresh the fuel in the reactor core, and to remove spent fuel into an approved container (flask). Flask handling and preparation for storage will be conducted on-site, in addition to monitoring of the stored fuel. The ultimate disposal facility will be located off-site.

18.1.6 Decommissioning

Decommissioning activities will be considered in the design of the facility and site. Decommissioning activities will be required to remove materials and infrastructure from the facility / site such that the site can be re-used. Decommissioning will include the handling and storage of radioactive materials and waste, removal and disposal of systems and equipment, de-construction and demolition of facilities and buildings, and restoration of the site to a usable condition.

18.1.7 Staffing

The SMR aims to have a reduced number of personnel compared with traditional large nuclear stations. This would be realised through increased automation and remote operations where safe and practicable to implement. In addition the Fleet support approach allows for some operations to be shared across stations, for example stores or outage planning, which reduces the number of personnel per site.

The on-site personnel numbers will need to remain sufficient to provide the required operations across all lifecycle modes, and against normal, faulted and post-accident scenarios.

The task analyses, and substantiation of the Human Based Safety Claims (HBSC) and Human Based Security Claims (HBSyC) will inform a bottom-up assessment of the staffing levels required in support of the Claims made in the E3S Case.

The Target Audience Description details the anticipated characteristics of the future operator.

18.2 Human Factors Integration

18.2.1 Introduction

This section provides substantiation of the following hierarchy of Claims:

1. 1. 'Human factors design requirements are incorporated into the RR SMR'
2. 1.1 'Human Factors have been integrated with the RR SMR design development'
3. 1.1.1 'A suite of Human Factors activities have been carried out to integrate HF into the RR SMR design'
4. 1.1.2 'Human Factors requirements have been integrated into the RR SMR design'.

HF have been an integral part of the RR SMR programme since its inception, providing early support to key design decisions. Within the Basis of Design (BoD) and early Preliminary Concept Definition (PCD) phases this integration was delivered through the production and sharing of the HF Integration Plan (HFIP) and consultation for design and decision reviews. HF guidance was produced and shared across the design areas to provide awareness, and design requirements.

Through the latter PCD phase this integration has been formalised through the creation of verifiable requirements which are allocated to the relevant design areas through DOORS. This systematic approach to requirements ensures visibility of the requirements to all relevant areas as well as a simple mechanism for the tracking of compliance with the allocated requirements.

At each SSC Definition Review (DR) stage, compliance with these requirements is evaluated with any non-compliance requiring evidence of their progress towards compliance. Details on how the requirements are evidenced and substantiated is discussed in Section 18.2.3. This evaluation of the achievement of HF requirements is provided by HF SQEP. The DR Checklist (within DOORS) includes an additional prompt for the appropriate HF assessments to have been completed for the stage of the programme, which also requires confirmation from HF Suitably Qualified and Experienced Personnel (SQEP). Both of these directly inform the conclusion of the DR.

Each SSC is required to populate a HF checklist. The HF checklist provides a means of understanding each SSC and the anticipated interaction with personnel through the lifecycle of the SSC. It also directs the SSC owner to relevant HF guidance and standards which they will be expected to embed within their concept to ensure successful HF Integration (HFI).

The HF Risks, Assumptions, Issues, Dependencies and Opportunities (RAIDO) register [3] captures any identified risks and issues, including non-compliance with HF requirements even if these non-compliances can be accepted.

18.2.2 Human Factors Integration Plan

The HFIP Reference [3], is the coordinating document for all HFI activities in the project, defining how the HF 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 HF principles across the project.

The integration of HF across the SMR project will evolve in line with the structured development of the integrated design and E3S Case and will be managed through a Product Introduction and Lifecycle Management process. As the SMR design progresses through the lifecycle, HF activities will be performed with progressive detail to support design decisions and provide evidence of the design against human actions important to safety.

The strategy for HFI into the SMR design is based on early engagement with the design teams, supported by early delivery of design policies and guidance. Recognised HF methods will be applied to the identification and analysis of human-system interactions for the SMR design.

Figure 18.2-1 provides an overview of the HFI process. Each of the methods are discussed within the HFIP, Reference [3], and will be applied as appropriate to the design phase and topic. As the SMR design progresses through the lifecycle, HF activities will be performed with progressive detail to support design decisions and provide evidence of the design against human actions important to safety.

Within this PCD phase, HF support has been focused on supporting early system definition, design decisions, and identifying the key safety related operator actions.

Provision of HF requirements and guidance has informed the early definition of the design, ensuring a human-centred design approach continues to be embedded early in the design lifecycle, and that human elements important to safety have been and will continue to be identified and controlled.

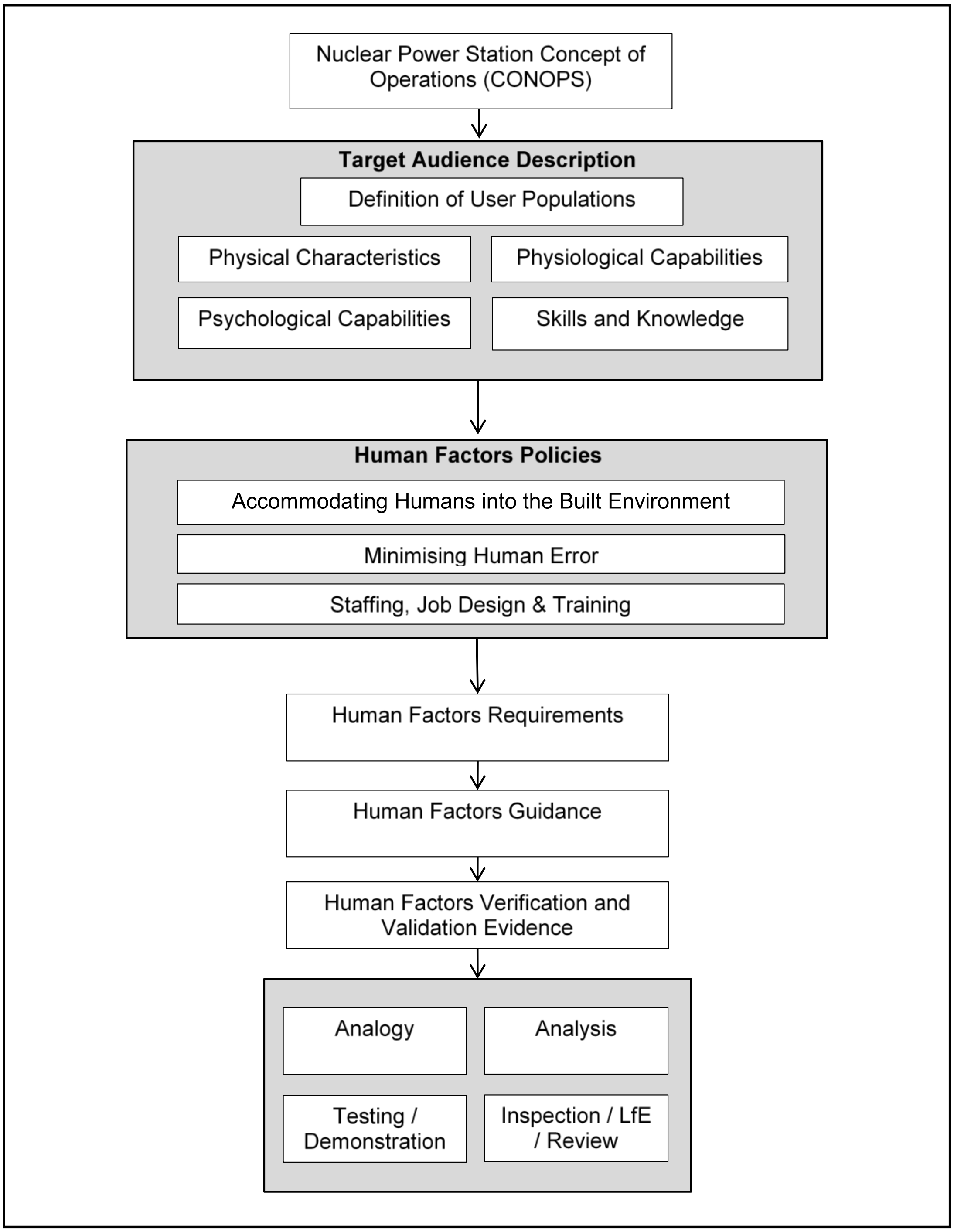

Figure 18.2-1: HFI Process

18.2.3 Requirements

There are two HF related requirements recorded at 'Level 0' for the Power Station in the DOORS database for the RR SMR:

1. The SMR shall ensure that risks to all populations from conventional safety hazards during all modes of operation and lifecycle stages are reduced to levels that are As Low as Reasonably Practicable (ALARP)

2. The SMR shall be capable of safe operation by personnel with the characteristics of the Target Audience Description (TAD).

These requirements are decomposed further, and then allocated to the relevant teams across the SMR programme. As these requirements are applicable to a large range of SSCs, they do not provide a specific requirement such as 'provide a space envelope of x metre' as these are context specific but instead signpost the user to relevant documents such as the TAD (discussed further in Section 18.3).

The achievement of these requirements is monitored through the design maturity review gates, with HF having the ownership of agreeing the requirement status for each SSC the requirement is allocated to.

A verification plan will accompany each requirement, and detail how achievement of the requirement will be demonstrated. Requirements verification could be demonstrated through confirmation of adherence to standards, HF analysis, or, if required, testing e.g., control room mock-ups or use of Virtual Reality (VR).

18.2.4 Guidance

To support the achievement of these requirements three policies have been produced:

1. Accommodation of Humans into the Built Environment (Reference [4])

2. Minimising Human Error (Reference [5])

3. Staffing, Job Design and Training (Reference [6]).

These policies provide policy statements, guidance, and an initial identification of codes and standards suitable for application to the RR SMR project.

The guidance provided within the policies aims to provide the design teams with an understanding of how the policies and requirements should be implemented and achieved. The guidance is supported by references to the relevant codes and standards if further information is required.

For some topics the provision of guidance allows for a graded approach to HFI, with designers making use of other supporting guidance for simple interactions, such as the TAD (Reference [7]) and drawing upon specialist support for more complex examples.

For example, a graded approach which increases the involvement of HF specialists and analysis based on the complexity of designing and demonstrating accessibility has been developed as follows:

1. The designer includes a 'space reservation' or 'space envelope' for accessibility in their design. Dimensions for access, reach and clearance for different postures are provided in the TAD, Reference [7]. Evidence of accessibility is provided by meeting the relevant space reservation from the TAD, Reference [7]

1. The designer draws upon detailed accessibility data in a relevant standard. Support to the designer in the selection of relevant standards and data will be provided by the HF

resource. Evidence of accessibility is provided by reference to the relevant standard and a record of application of the standard in the design

2. The designer identifies an accessibility scenario that is not addressed by simple space reservation or data from the available standards. The designer works with the HF resource to agree a design solution to optimise accessibility. Evidence of accessibility is provided by analysis by the HF resource

3. The designer identifies a complex accessibility scenario with multiple constraints. The designer works with the HF resource to agree a design solution to optimise accessibility, including the option for virtual or physical mock-up of the scenario to assess accessibility. Evidence of accessibility is provided by detailed analysis by the HF resource.

HF specialists will support the design teams in their application of the guidance, and complete specific analysis as required to provide the appropriate verification evidence. One method of sharing the guidance in the policies in a targeted way is the HF checklist.

18.2.5 HF Checklist

The purpose of the HF checklist is to provide each SSC designer with a structured overview of what a HF SQEP would expect to see in the SSC design. It also equips the designer with information required to integrate HF into their design from the start of the design process at DR0. By answering the HF checklists and using the documents and standards provided they are meeting the HF requirements against them in DOORs.

The HF checklist allows the SSC owner to independently initiate the application of HF guidance and standards to aspects of their concept, such as the physical integration of humans. This allows the HF SQEP to prioritise their initial support and assessment on areas of greater complexity, or areas finding the HF requirements challenging to fully achieve. The SSC designers can engage with HF SQEPs during production of the HF checklist, and is required to engage further following initial completion.

The outputs of the HF checklist include:

1. Title Sheet:

    a. Captures information regarding the SSC as well as a record of HF checklist document change to enable accurate tracking of each HF checklist throughout its design

2. Initial Question Set:

    a. Presents eight key HF topics covered by the HF checklist with a single yes or no question. The SSC designer is to answer each of these questions in relation to the SSC captured in the title sheet.

    b. Answering ‘yes’ to a question indicates that the HF topic presented in the question is relevant to the design of the SSC, whereas answering ‘no’ means the HF topic is not involved/relevant to the SSC

3. Required Checklists:

a. Once the SSC designer has identified which HF topics are relevant to their SSC by answering the initial question set, a more comprehensive set of questions for each of the HF topics that were answered 'yes' to is presented

b. Each topic typically consists of seven questions (yes or no answers) with space to document evidence or justification for the answers given. It is expected that as the design matures, all the questions should be answered and evidence (to support a 'yes' answer) or a justification (to support a 'no' answer) provided in the space allowed next to the answer

4. HF Data Tables:

a. Primary and secondary information has been provided for each relevant question. Primary information constitutes RR SMR HF documents and policies which provide the information required. Secondary information constitutes relevant standards and best practice guidance

b. Each HF topic in the checklist has also been associated with the Transverse requirements that they are relevant to. This way, SSC designers can ensure that by answering the HF checklists and using the documents and standards provided they are meeting the HF requirements against them in DOORs

Implementation of the HF checklist is monitored by the HF team. Completing an initial version of the HF checklist is a required output for DR3; an SSC will not pass this design gate without engaging with the HF checklist process.

At PCD, the majority of SSCs have not yet reached DR3, however at the time of writing, 15 SSCs have HF checklists in progress, providing evidence of early integration of HF into the design.

18.2.6 Risks, Assumptions, Issues, Dependencies and Opportunities Register

HF issues will be identified, tracked and managed to resolution via a RAIDO Register [3]. Issues may arise where HF requirements are in conflict with engineering requirements or constraints (e.g., access requirements are not met as a result of equipment being positioned to deliver an engineering function, such as vent valves being located high in the system).

The RAIDO will be managed by HF resource, with significant HF risks or issues reflected within centralised registers for the SMR project. This approach allows HF issues to be considered alongside engineering issues and supports identification of balanced technical solutions to issues.

No significant risks or issues have been logged within this phase. As is to be expected for a PCD phase, the design concept continues to change and develop and therefore whilst the concept may not be optimal in all areas there is still opportunity to influence and change the design.

18.2.7 Conclusions

There is clear evidence of HFI across the SMR programme, supporting the requirements identified in Section 18.2.1. The approach to HFI empowers design teams to initiate less complex assessments, for example placing manikins within the Computer Aided Design (CAD) model to evaluate the achievement of physical space requirements. This allows the HF engineers to focus on the more complex areas of the concept and the application of specialist techniques.

18.3 Target Audience Description

18.3.1 Introduction

This section provides substantiation of the following hierarchy of Claims:

1. 2. 'The RR SMR design provides the operators with the facilities to enable safe and secure operation'
2. 2.1 'The RR SMR design accommodates the target population.'
3. 2.1.1 'The RR SMR Target Population is defined.'
4. 2.1.2 'The RR SMR Target Population is accommodated in the design.'

18.3.2 Target Audience Description

Purpose

The TAD (or 'user profile') is a description of the different types of operators that will interact with the SMR facility, systems and equipment, and their capabilities and physical characteristics.

The overall aim of the TAD is to convey the physical characteristics and design constraints arising from a defined, 'user population', to help ensure the design of the SMR facility, systems and equipment adequately accommodates the operators. The target population is described within the TAD (Reference [7]).

To accommodate the physical characteristics of the TAD the design limitations are based on a higher upper percentile (%ile) of a UK population of 1^{st}-99^{th}%ile. This will both accommodate secular trends and also the wider global population given the global ambitions of RR SMR.

The information presented in the TAD is organised according to the following structure:

1. Physical Characteristics: considers the anthropometric characteristics of the operators (e.g., body size, strength); from which, design requirements can be developed (e.g., clearances and access for ingress/egress, location of controls)
2. Physiological Capabilities: considers aspects relating to thermal, tactile, visual and auditory capabilities of the operators (e.g., field of view, line of sight)
3. Psychological Capabilities: outlines the capabilities of the operators relating to aspects such as cognitive processing, workload, stress, and attention
4. Skills and Knowledge: outlines the background and experience, training needs, skills and knowledge of the operators.

The fundamental physical, physiological and psychological characteristics described in the TAD will apply to all user populations. However, adjustments may be required to physical dimensions for clearance, reach and access for any special clothing or Personal Protective Equipment requirements specific to any user population.

The information and data provided in the TAD describe the current user populations, with discussion provided on the impact of secular change for physical characteristics. Where practicable, additional margin will be included in the design to provide a robust solution with the capacity to cope with future population changes.

Application

The TAD applies to all areas of RR SMR and is referred to from the requirements in DOORS. At this phase of the concept development, it is the physical characteristics contained within the TAD which are of the most interest to the design teams.

To ease the application of the TAD, it is being updated to include an appendix of space envelopes which the design teams can choose from as appropriate for their scenario, rather than searching through individual data sets. The design teams are able to select the appropriate scenario to use, however the HF team will evaluate their use of the data and if required provide them with the correct data set to use.

The incorporation of these space envelopes into the CAD software is being investigated, to provide an easier inclusion of the operator envelopes. There is the potential to include these operator envelopes in the automated clash detection process which the CAD teams are developing.

18.3.3 Conclusions

The TAD is linked from the requirements in DOORS, which are allocated to teams to formally provide evidence against at the design maturity gates. This ensures that the TAD requirements are integrated within the SMR design.

18.4 Human Machine Interface Development

18.4.1 Introduction

This section provides substantiation of the following hierarchy of Claims:

1. 2. 'The RR SMR design provides the operators with the facilities to enable safe and secure operation'
2. 2.2 'The RR SMR equipment and layout supports the reliable performance of the operators through-life'
3. 2.2.1 'Controls and Indications are provided for the operator.'

Interfaces must support the operating personnel in the delivery of their role in power station operations. Interfaces will be designed to provide suitable and sufficient user interfaces at appropriate locations to provide effective monitoring and control of the facility in normal operations, faults and accident conditions.

The RR SMR concept at the end of the PCD phase features a number of locations from where the operators will interact with the power station using a variety of Human Machine Interfaces (HMI). Examples of these locations include:

1. Main Control Room (MCR)
2. Supplementary Control Room (SCR)
3. Emergency Control Centre (ECC), on-site with another ECC off-site
4. Local interfaces.

In addition to fixed locations it is anticipated that operators could have mobile devices which could record maintenance activities or provide operating instructions, plant data etc.

Within this phase, the HMI development has been related to the larger, fixed control locations rather than local or mobile interfaces. These local interfaces will be incorporated into the concept through the subsequent phases as the required controls and indications are identified and as the layout concept is matured.

18.4.2 Design Development

Operations

The MCR will be the primary location for controlling and monitoring RR SMR. The SCR will be used in the event that the MCR becomes unavailable during operations, e.g., due to an internal hazard such as fire.

The ECC will co-ordinate the activities required to manage the response to events such as fires, security incidents or release of radiation. In the event that the ECC cannot manage the event, or requires wider communication with neighbouring communities or institutions, then the off-site ECC would provide support or take control of the event as required. The site layout and staffing concepts will ensure that the required emergency arrangements are achievable; this is described further in E3S Case Chapter 19: Emergency Preparedness, Reference [8].

Location

The current concept incorporates the MCR inside the Reactor Island Hazard Shield, with the SCR being located in the Reactor Island but outside of the Hazard Shield. This concept provides protection against external hazards for the personnel based within the MCR, whilst providing sufficient segregation between the MCR and SCR in the event that the MCR requires evacuation.

ECC activities are currently proposed to be coordinated from the Security and Emergency Control Centre which is based within the Reactor Island. This combined facility would provide the functionality and space required for both Security and Emergency control, whilst optimising the Reactor Island layout and utilisation of space.

Size

The Small Modular Reactor Control Rooms Outline Description, Reference [9], provided an initial view of the control room solution for RR SMR, based upon a review of industry standards and relevant good practice.

Reference [9] provided sizing estimates for the MCR and SCR which have been retained in the concept at the end of PCD. The MCR has been sized as **{REDACTED FOR PUBLICATION}** whilst the SCR has been sized as **{REDACTED FOR PUBLICATION}**. These size estimates are based on existing large nuclear power stations which is considered reasonable at this stage as the control room size is less dependent on the power output of the power station than it is on the interface design (e.g., the extent of hardwired controls and indications compared with software based, and the diversity or redundancy required in the systems supporting the control room displays). It is anticipated that the expanded use of screens will reduce the volume of space required, however the space envelope has been retained at this stage to manage the level of uncertainty with the control room content.

Interface

The classification of the systems being controlled or monitored influences the required classification of the control systems and the technology which can be used in the control room.

Within this latter PCD phase, Controls and Instrumentation, HF, Safety and Systems teams have progressed the identification of functions which require control and/or indication within the control rooms. The need for control and/or indication has been identified through various mechanisms, including reviews of operational experience, the RR SMR Fault Schedule, Reference [10], task analysis and AoF.

The functions already identified as requiring control and/or indication require a combination of hardwired and software-based interfaces. The selection of hardwired compared with software-based interfaces will consider the safety classification of the function to be interacted with.

The identification of the functions which require controls and/or indications will continue into the Final Concept Definition (FCD) design phase.

Verification and Validation

CAD and VR are available to use to verify that requirements for the provision of adequate space have been achieved, and to support the definition of interfaces.

It is recognised that a full scope, high fidelity simulator is a valuable tool for both developing the design of the control room and HMI, and for confirming that requirements have been achieved.

The definition of the simulator requirements and programme is continuing. The FCD phase will include trials to develop the physical size and layout of the control rooms, with some paper or screen-based representations of HMI to test potential HMI concepts.

Subsequent phases will include evaluations of procedures, and operator workload.

18.4.3 Conclusions

The identification of operator actions is continuing, and therefore the required controls and indications have not all been identified. Space Claims for the control facilities have been secured within the concepts, and throughout FCD the equipment required within these facilities to support the Claims will be identified.

18.5 Allocation of Function

18.5.1 Introduction

This section provides substantiation of the following hierarchy of Claims:

1. 3. 'Human Factors design requirements and human-based actions are substantiated.'
2. 3.1 'The operator actions required to operate and maintain the RR SMR are identified.'
3. 3.1.1 'Processes and Actions are appropriately allocated between Machine and Operator'.

AoF is an assessment method which aims to assign those functions required to meet system goals to an optimised combination of human and engineered elements of the design.

As a result of this analysis, tasks for which humans are known to have reduced levels of reliability, such as long-term monitoring, are assigned to the engineered elements of the system, thereby reducing the potential for human error. Conversely, tasks at which humans show improved performance, such as complex decision-making, are not automated in order to improve overall system performance.

The approach to AoF for this phase is presented in Reference [11]. Functional decomposition is continuing, therefore the AoF will continue through the FCD phase. As the RR SMR is a PWR, with targeted areas of innovation, the functions which are required for the SMR to be safely operated are largely as expected for conventional large scale nuclear power plants. The AoF process will be applied across a range of functions, with a prioritisation of the functions which are novel or are traditionally allocated to human rather than system, for example aspects of fuel movement.

18.5.2 Methodology

As described in Reference [11] the following process for consideration of AoF decisions is used:

1. Define concept of operations
2. Define the role of the operator
3. Define the functions (identify and characterise the functions needed to meet the overall design requirements)
4. Select functions for AoF review by employing a risk informed prioritisation
5. Conduct AoF assessment according to risk significance, complexity of the function or sub-functions, or the use of new or novel technologies
6. Identify the level of automation required to support the AoF
7. Identify design support required to implement and substantiate function allocation

8. Conduct a coherence check of the current AoF decision with other AoF decisions across the design (e.g., consistent application of method, potential for conflict between AoF decisions, impact of AoF decisions on the operator role)

9. Agree the AoF decision as part of the engineering governance of design decisions and output (see the Engineering Management Plan, Reference [12])

10. Iterate the AoF assessment as the design solution matures, or for new or modified functions.

A simple allocation between either fully manual or fully automatic is not expected to produce a design where overall system performance is optimised. Therefore, the AoF between human and engineered elements of a system requires consideration of increasing levels of automation.

The RR SMR AoF process, based upon an Electrical Power Research Institute methodology, uses a description of increasing levels of automation (Levels 1-10) based on a scheme proposed by Endsley [13] and arrived at through the use of a flowchart to guide the analyst through a series of questions to identify the optimal level of automation. These questions are standardised, providing consistency to the analysis. The questions prompt the analyst to consider topics including, if the function is central to the human role, if the function is essential in providing situational awareness, or if the function challenges human capabilities.

18.5.3 Analysis

The functional decomposition completed so far across the programme has focused on safety systems, which are required to automatically initiate due to the timescales required.

To test the process and provide some information to the design teams a high-level function identification provided the basis for an initial AoF presented in Reference [11]. This analysis applied the AoF process to processes (e.g., reactor start-up) and to systems (e.g., chemistry control). The methodology was considered to be suitable for application and was used to characterise some high level functions such as alignment of multiple valves.

A number of candidate functions and processes which would benefit from the application of AoF have been identified, for example the reduction of pressure and temperature during shutdown operations, aspects of chemistry control, and activities related to refuelling operations. These have been identified as initial candidates for AoF following reviews of system descriptions, operational experience and discussions with ex-operators.

Through the FCD phase the functional decomposition will progress into normal operational functions and identify lower level functions.

18.5.4 Conclusions

Given the level of design maturity, it cannot yet be demonstrated that all processes and actions are appropriately allocated between human and engineered function. However the process for determining the allocation has been demonstrated within this phase, and will be applied more extensively throughout the FCD phase in line with the design development.

18.6 Identification of Operator Actions

18.6.1 Introduction

This section provides substantiation of the following hierarchy of Claims:

1. 3. 'Human Factors design requirements and human-based actions are substantiated'
2. 3.1 'The operator actions required to safely operate the RR SMR are reasonable, identified and substantiated'
3. 3.1.2 'Operator actions to support the E3S Case are identified'.

HF assessments need to consider all human involvement with the RR SMR, whether for normal, faulted or emergency operations. A number of techniques are used to identify and assess the role of the operator; these are summarised within the HFIP (Reference [14]).

The RR SMR is a PWR, with few areas of novelty in its operation, with the novel areas reducing the reliance on operators, for example through reducing the number of normal operational discharges to manage. A key design principle of the RR SMR is for systems to be passive and automated, which limits Claims on the operator. Similarly there is an expectation that the SMR will be 'secure by design' to limit the need for active security systems and associated security based Claims on the operators.

Therefore there is a level of confidence that the operator actions required by RR SMR will be reasonable and largely in-line with typical PWR activities, and that the limited operator actions required will be reasonable and achievable.

Whilst increased passivity will be provided against all modes of operation, operator actions are still required to perform a number of normal operational duties during power and shutdown operations, monitor the initiation of safety systems, and contribute to the longer-term management of safety systems and emergency arrangements.

Operator actions will be identified through a number of sources, including Hazard Identification (HAZID) studies, Hazard and Operability (HAZOP) studies, Fault Schedule, PSA and the decomposition of operator activities via Task Analysis. Given the current concept maturity, the identification of operator actions is still progressing. Operator actions identified to date are in support of the safety Claims, due to the maturity of the case.

It is anticipated that the FCD phase will identify the majority of operator actions, with a focus on those presenting the highest level of risk to the RR SMR. The identification of detailed operator actions, particularly those in support of lower risk activities, will likely continue into the Developed Design phase.

Through the PCD phase, the HF team have been represented at HAZID and HAZOPs, with HF guidewords used to provide an initial list of considerations, which include references to the related HF checklist sections.

The Fault Schedule identifies a limited number of operator actions given there is an expectation that remote operator actions are not required for at least 30 minutes after an alarm, with local operator actions not required for at least one hour after an alarm. Further detail is provided in Section 18.6.2 .

Some of the assumed operator actions stated within the Fault Schedule may be allocated to systems once the AoF process has completed, however an early review of the operator actions Claimed within the Fault Schedule has not identified any operator actions which would be challenging to demonstrate as achievable.

Task Analyses has been generated for a number of activities, notably Start-Up, Shutdown and some Refuelling activities to identify the role of the operator within these activities.

18.6.2 Human Error Identification

Operator actions are identified from a number of sources, dependent on whether they are in support of normal or faulted operation, and the type of functions they support.

Within the phases to date, the operator actions identified have been for complex normal operations such as transitions between operating modes and safety classified systems.

Hazard Identification

Within this phase, HAZID studies have been largely focused on Reactor Island with a few studies held for Turbine Island and Balance of Plant based on the level of design maturity and level of risk. Subsequent phases will have more detailed HAZID studies and HAZOP studies across all islands and systems.

HF representatives have supported all HAZID and HAZOP activities within this phase and identified opportunities for human error in addition to opportunities for humans to assist with recovery from faulted conditions. These will be recorded in the hazard log and screened which may result in an associated Claim being placed on an operator action.

Areas for further investigation during the subsequent design phases were noted, for example development of appropriate interfaces or controls.

Probabilistic Safety Assessment

Due to the early stage of the concept, there are limited operator actions identified within the PSA at this stage. HRA is discussed further within Section 18.7.

Fault Schedule

The Fault Schedule, Reference [10], identifies a number of explicit Claims on the operator to undertake preventive safety measures and identifies protective safety systems which operators will monitor the initiation and operation of. These are assumed operator actions in support of the E3S Case; these functions will be assessed through the AoF methodology to determine if they should remain allocated to the operator or if they should be automated.

The preventive safety measures identified within the Fault Schedule are presented for completeness but may not be Claimed on a deterministic basis within the E3S Case, as they may require operator action within timescales given in Section 18.6.1, and/or they require Class 3 systems. For the protective safety systems (typically Class 1 or 2) then operator actions are not required within the timescales given in Section 18.6.1, and often not until 72 hours into the event timeline.

At this early design phase there is insufficient design detail to support a detailed assessment of the operators' ability to complete the preventive safety measure actions. However the required actions are not dissimilar to actions which are undertaken at other nuclear power stations (for example, de-energising pressuriser heaters, or manually initiating Scram), and there is confidence that if these actions remain allocated to the operator then the appropriate controls and indications will be provided such that they can complete the actions.

Therefore at this time, it is considered that the operator actions identified as preventive safety measures within the Fault Schedule are reasonable and achievable. If the operator is unable to complete the action, then the protective safety measures are Claimed on a deterministic basis.

The protective safety measures will automatically initiate. The operator will be required to monitor the initiation and operation of these safety measures, but is not required to actuate any controls in the early phases of the safety measure operation. They will be required to complete actions at approximately 72 hours to ensure the long-term operation of the safety measure e.g., connection of additional water sources.

At this time, the actions required 72 hours after an event and beyond are still to be defined. The role of the operator in these activities will be determined during the next design phase, using techniques such as AoF.

Not all of the indications available to the operator to monitor the initiation and operation of these protective safety measures have been identified or designed yet. However, there is confidence that the appropriate controls and indications will be provided for the operators such that they can complete the actions.

The subsequent design phases will systematically assess the Claims on the operator to confirm that the operator has sufficient and appropriate information, indications and controls available to them to complete the task safely.

Task Analysis

Task Analysis identifies the breadth of human-system interactions expected for operation of a power station to inform the ongoing SMR design. The human-system interactions described are well understood and can be delivered with existing technologies.

The Task Analysis provides further decomposition and definition to the operator actions identified within the Fault Schedule or normal operation functional decomposition. It states the task, the personnel, location, and the required indications and controls. The substantiation of the ability of the operator to complete these actions is provided within the HBSC.

The task analysis for this phase is summarised within Reference [15].

In this phase the task analysis has developed from the earlier assessments as required. Further detail has been made available for a number of Reactor Island systems, and various Operating Philosophies have been developed therefore a number of task analyses have been updated to reflect the design.

The task analyses updated within this phase are:

1. Start-Up Operations
2. Shutdown Operations (Normal)
3. Refuelling Operations (Normal)
4. Loss Of Coolant Accident (LOCA).

Compared with the earlier versions of these task analyses, some activities have changed (added, removed or alternative logic), and other activities have had greater definition added to them where the design maturity has allowed. Given the early phase of the design programme, it is anticipated that there will be further changes to the activities identified within the task analysis. The application of AoF will assist with the identification of the appropriate allocation of the activities between operator and automation.

18.6.3 Conclusions

The identification of operator actions has commenced within this phase, with these primarily being associated with safety related systems and complex processes. It is anticipated that a similar process will be followed to identify any environment, security or safeguards based Claims on the operator.

To support the design development some assumptions have been made about the operator actions. As the design development progresses through FCD, more potential operator actions will be identified, which will then be assessed using AoF, and substantiated as appropriate.

18.7 Operator Action Substantiation

18.7.1 Introduction

This section provides substantiation of the following hierarchy of Claims:

1. 3. ‘Human Factors design requirements and human-based actions are substantiated’
2. 3.2 ‘The operator actions required to operate and maintain the RR SMR are substantiated’
3. 3.2.1 ‘Operator actions to support the safety, security, safeguards and environmental cases are substantiated’.

The operator actions identified through the means discussed in the previous section require substantiation.

A sub-set of HF techniques have been applied within this PCD phase, with the remaining techniques (such as Cognitive Workload Assessment) planned for application during the future phases of the programme as the design matures. The assessments completed within this PCD phase are discussed within this section and Section 18.5 Allocation of Function.

These assessments are required for all operator actions, rather than only those modelled within the E3S Case. However the assessment will be proportionate to the level of operator involvement, and the consequences of any errors.

The analysis of operator actions will need to consider the impact on staffing (e.g., number of personnel and location), job design (e.g., requirements for shift work, or multi-skilling) and training (e.g., any additional or atypical requirements). Additionally, the assessment will consider the potential for robotics, remote operations and automation which could support the operator in the delivery of their role.

As discussed within Section 18.5, the Claims which have been identified so far are derived from the E3S Case therefore this section discusses the methods used to substantiate safety related operator Claims.

18.7.2 Qualitative Analysis

HBSC assessments will consider aspects such as whether the operator:

1. Has sufficient space to complete the required activity
2. Can safely undertake the specified activity (e.g., provided with safe access)
3. Has been provided with the required controls and indications
4. Is able to perform the activity within the available time
5. Has appropriate operating documentation e.g., procedures
6. Is, or will be, trained to undertake the activity.

Within this phase, the reviews of operator actions have been limited in scope and detail, as the operator actions are still being identified, and the design definition doesn't currently provide sufficient information to allow for substantiation in detail. Requirements will be captured for the design to include features to enable the operator to successfully complete the Claimed actions.

The TAD has been available to all design teams to use in their development of concept system designs and layout configurations. The HF team has supported the application of the TAD data in determining whether the current concept layout configurations provide safe and sufficient space for personnel to complete the identified tasks, either for Operations or Maintenance. Any requirements for additional tooling or shielding have been identified as part of the assessments to ensure that all aspects of a task can be safely undertaken.

As is typical for the PCD phase and associated design maturity, large components have been included in CAD models whereas smaller components or structural features have not been included in all areas. The potential impact of these additional features on the space available for personnel will be considered as part of the on-going assessments.

During concept reviews and the development of the task analysis, the availability of appropriate controls and indications (including warnings or alarms) has been investigated. At this design phase, not all controls and indications have been identified and the layout concepts don't yet include representations of controls and indications. However the HF analysis has and will continue to identify the controls and indications which will be required, and early engagement with the design teams ensures that these requirements are captured.

Gracetime information is not yet available for all aspects of the plant which the operator interacts with. However as discussed within Section 18.5, the operator is not required to complete actions in support of safety systems for at least 30 minutes after an alarm and is typically not required to take action until approximately 72 hours into an event.

Operating documentation and training are recognised as key elements of demonstrating that activities can be completed, however they have not been progressed during this PCD phase. They will both be progressed during the subsequent design phases, recognising that the licensee will have ultimate responsibility for demonstrating to the regulators that they have the appropriate arrangements in place.

18.7.3 Quantitative Analysis

HRA consists of a range of HF methods for identifying the contribution people make to risk. It provides a structured approach for understanding how human performance and actions can contribute to an overall risk profile by providing probabilities of human error.

This quantitative evaluation builds upon and is completed in conjunction with the qualitative task analysis and HBSC assessments which provide the detailed context around the action which is being quantitatively assessed.

The RR SMR design ensures that limited operator actions are required in the delivery of safety functions through the provision of passive or automated systems. The interaction of personnel with these passive or automated systems is assessed as part of the AoF determination (see Section 18.5 for more details).

Methodology

The structured approach consists of familiarisation, qualitative error analysis, quantitative error analysis and finally derivation refinement. As described in Section 18.7.3, the quantitative and qualitative analysis will be integrated, to ensure the quantitative analysis of actions considers the wider context of plant operation.

The PSA status is described below. Given this status, there are few sequences in the PSA which required an operator action to initiate a safety measure successfully. Where operational data was not accessible, and modelling was therefore required in this early PSA the Nuclear Action Reliability Assessment (NARA) methodology was used.

Whilst NARA was previously used, a review of available HRA methodologies will be undertaken within the FCD phase to confirm the appropriate HRA methodologies which will be applied to the RR SMR.

PCD Status

The PSA has been developed to evaluate the RR SMR at power, with systems in their normal duty line up prior to the occurrence of an initiating event. Operations with the reactor shutdown, refuelling activities, used fuel storage pond and any other site risks have not been explicitly evaluated using PSA at this stage, although safety input including PSA considerations, has been provided for these other lifecycle modes of operation and is detailed in the relevant systems definition documents.

This Level 1 and Level 2 PSA has been constructed and iterated throughout the design process to date. Within this latest phase, the PSA has integrated some of the key design decisions which were considered in earlier phases and transferred the PSA into a different toolset. Further details are available in SMR Probabilistic Safety Assessment, Reference [16].

Reference [16] confirms that failures of the Claimed operator actions in delivery of safety functions are not significantly important. Further operator actions will be identified and modelled in the subsequent design phases.

The SMR Probabilistic Safety Assessment, Reference [17], reports the results of a sensitivity study which modelled operator unavailability i.e. all HEPs were set to one. This resulted in a Core Damage Frequency increase, however the Basic Safety Objective target was still achieved. Sensitivity studies such as this will be completed in future phases to review the contribution of the operator.

18.7.4 Conclusions

As discussed in Section 18.6 the identification of operator actions will continue through the FCD phase, and the substantiation of these will develop as the design matures. The initial operator actions have been substantiated as far as the design definition allows, for example without the detail of the specific controls and indications.

It is anticipated that similar methods will be useful in substantiating operator Claims for other E3S disciplines; as the Claims are identified the applicability of the methods will be reviewed.

Both the qualitative and quantitative substantiation of operator actions will be progressed within the FCD phase.

18.8 Future Dutyholder/Licensee Capability

18.8.1 Introduction

This section provides substantiation of the following hierarchy of Claims:

1. 4. 'The RR SMR design is informed by assumptions on the capability of a future licensee from a Human Factors perspective'

2. 4.1 'The RR SMR can be safely operated and maintained through-life by a future licensee's organisation'

3. 4.1.1 'The staffing concept supports safe operation of the RR SMR'

4. 4.1.2 'The training concept supports safe operation of the RR SMR'

5. 4.1.3 'The procedure concept supports safe operation of the RR SMR'.

Claims placed on the operator are reliant on the future licensee implementing key functions, such as the correct staffing levels, the appropriate training and the provision of adequate procedures. Whilst it will be the future licensee who has responsibility for delivering these, RR SMR will enable the future licensee to deliver these by developing and implementing processes which generate the required information.

Assumptions and Commitments made which the future dutyholder/licensee would be expected to deliver against to support the substantiation of operator Claims are identified in the following sub-sections.

18.8.2 Staffing Concept Development

Given the design maturity at PCD, the current staffing concept has been developed from the top-down through comparisons with existing nuclear facilities and a review of the RR SMR design concept to identify any differences in the design and operation which could influence the staffing levels. This staffing concept has been reviewed by an experienced nuclear utility with knowledge of UK licensing arrangements.

In the future programme phases, the task analysis and AoF will develop the staffing concept through identification of the tasks which personnel are required to complete, when and from where. As more design detail is added, and more task definition is generated, a detailed review of staffing, including workload, will ensure that assigned tasks remain manageable.

From this analysis, a Nuclear Baseline will be developed by the future dutyholder/licensee. The Nuclear Baseline is a means by which a licensee demonstrates that its organisational structure, staffing and competencies are, and remain, suitable and sufficient to manage nuclear safety throughout the full range of the licensee's business and plant lifecycle and for all operational states. RR SMR will develop an initial Nuclear Baseline to support an operator / licensee when taking ownership and responsibility for the design, and to provide an assumed staffing concept to be used in assessments.

The overall staffing concept will include personnel and skillsets additional to the Nuclear Baseline, who are likely required for the general support of the RR SMR such as outage planners, warehouse staff and crane operators.

The requirements and guidance provided within Reference [6] regarding job design will inform the staffing concept, for example suggesting opportunities for multi-skilling of personnel where appropriate and beneficial.

Based on the above, the following Commitment is captured on the future dutyholder/licensee:

Commitment on Future Dutyholder/Licensee C18.1: The future dutyholder/licensee will develop a nuclear baseline from the RR SMR staffing concept which supports the Claims within the E3S Case.

18.8.3 Training

Detailed arrangements for training staff so they can safely undertake the identified activities are the responsibility of the operator/licensee. However, early consideration of training as part of the production of a robust staffing model is beneficial, and key to the provision of a design solution that is attractive to operators/licensees.

For example, decisions on novel technologies or alternative applications of existing technologies can have implications on the training required to deliver staff with the required knowledge, skills and attitude. Early consideration of training establishes a baseline of expected (and established) training methods and technologies and identifies opportunities for exploitation of new technologies to improve training effectiveness and efficiency.

Future phases of the programme will include a Training Needs Analysis (TNA), which is a structured process to identify training requirements and training options for a design solution. The output of the TNA is a set of training recommendations for consideration in training design, which includes selection and development of the most appropriate training medium to deliver the training recommendation.

It is likely that a recommendation from the TNA will be for a full scope training simulator of the control rooms for initial and refresher training. A control room simulator also acts as a valuable design development tool and allows for the verification of certain HF requirements. During this phase, plans for the full scope simulator have been developed.

Based on the above, the following Commitment is captured on the future dutyholder/licensee:

Commitment on Future Dutyholder/Licensee C18.2: The future dutyholder/licensee will deliver a training programme which provides the operators with the knowledge, skills and attitudes required to support the Claims within the E3S Case.

18.8.4 Procedures

Procedures are not yet available for RR SMR given the design phase of the programme. Task Analysis will provide a description of operator activities, identifying the personnel, location, controls and indications, forming a pre-cursor to the procedures themselves. The Task Analysis, and ultimately the procedures, will be a fundamental part of the Training programme.

Through the subsequent design phases, the operating rules for RR SMR will be identified from the E3S Case and collated for the future licensee.

Based on the above, the following Commitment is captured on the future dutyholder/licensee:

Commitment on Future Dutyholder/Licensee C18.3: The future dutyholder/licensee will provide all operational staff (across all disciplines) with procedures which provide them with the required information to complete their activities in line with the Claims of the E3S Case.

18.8.5 Conclusions

A number of assumptions have to be made during the design phases, which will be validated as far as possible, with the remainder recorded and passed to the licensee.

Within this phase there has been a development of a top-down staffing model, however the bottom-up model will be initiated within the FCD phase. The training for these operators is anticipated to be similar to that required for existing civil nuclear operators given the largely conventional technology of RR SMR. Whilst ultimately the responsibility of the licensee, assumptions on the required knowledge, skills and attitudes which support the operator Claims will be captured and shared with the future operator.

The task analysis generated in support of substantiating operator Claims will form a basis for procedures, which can be structured as required for the licensee.

18.9 Conclusions

18.9.1 Summary

Within this PCD phase, and the earlier iterations of PCD, a variety of HF assessments have been completed across the whole scope of RR SMR. Most of the analysis has focused on areas of high complexity, or which are required to reach a greater level of design definition earlier in the design programme. As such, the analysis has focused primarily on the Reactor Island but the analysis outcomes obtained from the Reactor Island are often applicable or useful across the other islands.

The early integration of HF on the RR SMR programme has provided a foundation for future assessments, through requirements derivation, identification of key standards and design guidance. Key information which needs to be communicated to the design teams will be captured within the DOORS requirements tool and flowed to each responsible area.

The forthcoming FCD phase will develop the design to a single concept, which will not be finalised but will have matured significantly compared to the PCD baseline. This FCD phase will be a key phase for HF involvement, including the more extensive deployment of assessment techniques such as AoF, task analysis and HRA to inform and substantiate the design. Whilst the design will continue to develop past FCD into Detailed Design, the FCD baseline is anticipated to provide a large volume of evidence in support of the overall Claim that 'Human Factors is fully integrated into the RR SMR design and substantiation processes, with the aim of minimising harm to personnel or environment and maximising human performance'.

18.9.2 Claim Substantiation

This phase has embedded the HF requirements and principles into the RR SMR design and processes. Early analysis has taken place, to demonstrate the adequacy of the methods and to inform some key design decisions. These have been primarily focused on safety classified systems or processes considered to have a higher potential for risk or error.

As is typical for large engineering programmes, the number of personnel within design teams is greater than the number of HF specialists. Within this programme phase HF familiarisation training of personnel has been launched across all areas of RR SMR to support integration of HF across the programme. Alongside this, the HF checklist and requirements ensure that the design teams have a formalised requirement to engage with HF in order to progress through the design maturity gates.

Given the early stage of the design development it has not been possible at this time to confirm that all HF Claims have been substantiated as greater design definition is required in addition to some areas of testing. However, the analysis of the current concept provides confidence that the HF requirements will be achieved as the design continues to mature and as HF guidance continues to be embedded. It is considered that design and processes will provide the required evidence so that the HF Claims can be substantiated.

18.9.3 Assumptions & Commitments on Future Dutyholder/ Licensee

Table 18.9-1: Assumptions and Commitments on Future Dutyholder/Licensee

Assumption/Commitment	ID	Description
Commitment	C18.1	The future dutyholder/licensee will develop a nuclear baseline from the RR SMR staffing concept which supports the Claims within the E3S Case.
Commitment	C18.2	The future dutyholder/licensee will deliver a training programme which provides the operators with the knowledge, skills and attitudes required to support the Claims within the E3S Case.
Commitment	C18.3	The future dutyholder/licensee will provide all operational staff (across all disciplines) with procedures which provide them with the required information to complete their activities in line with the requirements of the E3S Case.

18.10 References

[1] RR SMR Report, SMR0004294/001, “E3S Case Chapter 1: Introduction,” March 2023.
[2] RR SMR Report, SMR0002155/001, “E3S Case CAE Route Map,” March 2023.
[3] RR SMR Report, SMR0004751/006, “Human Factors Integration Plan V6,” March 2023.
[4] RR SMR Report, EDNS01000925953_001, “Accommodation of Humans into the Built Environment,” November 2020.
[5] RR SMR Report, EDNS01000925954_001, “Minimising Human Error,” November 2020.
[6] RR SMR Report, EDNS01000925955_001 , “Staffing, Job Design and Training,” November 2020.
[7] RR SMR Report, SMR0003975, “Target Audience Description,” January 2023.
[8] RR SMR Report, SMR0004571/001, “E3S Case Chapter 19: Emergency Preparedness & Response,” March 2023.
[9] RR SMR Report, EDNS01000533897_001, “Small Modular Reactor Control Rooms Outline Description,” April 2017.
[10] RR SMR Report, EDNS01000470763_004, “Fault Schedule,” December 2020.
[11] RR SMR Report, EDNS01000488838_002 , “EDNS01000488838_002 Allocation of Function,” April 2021.
[12] RR SMR Report, SMR0000520_003, “Engineering Management Plan for Rolls-Royce SMR,” October 2022.
[13] M. Endsley, “Level of Automation Effects on Performance, Situation Awareness and Workload in a Dynamic Control Task,” *Ergonomics,* vol. 42, no. (3), pp. 462-492, 1999.
[14] RR SMR Report, EDNS01000488825_004 , “Human Factors Integration Plan,” October 2020.
[15] RR SMR Report, EDNS01000488827_002, “Task Analysis,” April 2021.
[16] RR SMR Report, EDNS01000954857_001, “Probabilistic Safety Assessment,” March 2021.
[17] RR SMR Report, EDNS01000537027_001 , “Probabilistic Safety Assessment,” April 2017.

18.12 Appendix A: Claim, Argument, Evidence Route Map

The HF assessments aim to demonstrate the high-level Claim that 'Human Factors is fully integrated into the RR SMR design and substantiation processes, with the aim of minimising harm to personnel or environment and maximising human performance'.

This Claim is supported by a hierarchy of sub-Claims as shown in Table 18.12-1. The full CAE Route Map will be developed in future revisions of the E3S Case.

Table 18.12-1: Human Factors Claim Hierarchy

Claim Level 1	Claim Level 2	Claim Level 3
1. Human factors design requirements are incorporated into the RR SMR.	1.1 Human Factors have been integrated with the RR SMR design development.	1.1.1 A suite of Human Factors activities have been carried out to integrate HF into the RR SMR design.
		1.1.2 Human Factors requirements have been integrated into the RR SMR design
2. The RR SMR design provides the operators with the facilities to enable safe and secure operation.	2.1 The RR SMR design accommodates the target population.	2.1.1 The RR SMR Target Population is defined
		2.1.2 The RR SMR Target Population is accommodated in the design
	2.2 The RR SMR equipment and layout supports the reliable performance of the operators through-life	2.2.1 Controls and Indications are provided for the operator
3. Human Factors design requirements and human-based actions are substantiated.	3.1 The operator actions required to operate and maintain the RR SMR are identified	3.1.1 Processes and Actions are appropriately allocated between Machine and Operator
		3.1.2 Operator actions to support the E3S Case are identified

Table 18.12-1: Human Factors Claim Hierarchy

Claim Level 1	Claim Level 2	Claim Level 3
	3.2 The operator actions required to operate and maintain the RR SMR are substantiated	3.2.1 Operator actions to support the safety, security, safeguards and environmental cases are substantiated
4. The RR SMR design is informed by assumptions on the capability of a future licensee from a Human Factors perspective.	4.1 The RR SMR can be safely operated and maintained through-life by a future licensee's organisation	4.1.1 The staffing concept supports safe operation of the RR SMR
		4.1.2 The training concept supports safe operation of the RR SMR
		4.1.3 The procedure concept supports safe operation of the RR SMR

18.11 Acronyms and Abbreviations

ALARP	As Low As Reasonably Practicable
AoF	Allocation of Function
BoD	Basis of Design
CAD	Computer Aided Design
CAE	Claims, Arguments, Evidence
DR	Definition Review
E3S	Environment, Safety, Security and Safeguards
ECC	Emergency Control Centre
EMIT	Examination, Maintenance, Inspection and Testing
FCD	Final Concept Definition
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HBSC	Human Based Safety Claims
HBSyC	Human Based Security Claims
HEP	Human Error Probability
HF	Human Factors
HFI	Human Factors Integration
HFIP	Human Factors Integration Plan
HMI	Human Machine Interface
HRA	Human Reliability Assessment
LOCA	Loss Of Coolant Accident
MCR	Main Control Room

NARA	Nuclear Action Reliability Assessment
OLCs	Operating Limits and Conditions
PCD	Preliminary Concept Definition
PSA	Probabilistic Safety Assessment
PWR	Pressurised Water Reactor
RAIDO	Risks Assumptions Issues Dependencies and Opportunities
RR	Rolls-Royce
SCR	Supplementary Control Room
SMR	Small Modular Reactor
SQEP	Suitably Qualified and Experienced Personnel
SSC	Structures, Systems and Components
TAD	Target Audience Description
TNA	Training Needs Analysis
VR	Virtual Reality