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General Nuclear System Ltd.

UK HPR1000 GDA Project

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Title:

Pre-Construction Safety Report
Chapter 15
Human Factors

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15.1 List of Abbreviations and Acronyms

ACP	Auxiliary Control Panel
ALARP	As Low As Reasonably Practicable
AoF	Allocation of Function
BSI	British Standards Institution
CCF	Common Cause Failure
CDM	Construction (Design and Management)
CGN	China General Nuclear Power Corporation
CRS	Control Room System
DBC	Design Basis Condition
DEC-A	Design Extension Condition A
DEC-B	Design Extension Condition B
DHP	Diverse Human interface Panel
DR	Design Reference
ECC	Emergency Control Centre
ECP	Emergency Control Panel
EMIT	Examination, Maintenance, Inspection and Testing
EOP	Emergency Operating Procedure
FCG3	Fangchenggang Nuclear Power Plant Unit 3
GB	Chinese National Standard
GDA	Generic Design Assessment
HBSC	Human-Based Safety Claim
HEP	Human Error Probability
HF	Human Factors
HFE	Human Factors Engineering
HFI	Human Factors Integration
HFIP	Human Factors Integration Plan
HMI	Human Machine Interface

HPR1000 (FCG3)	Hua-long Pressurised Reactor under construction at Fangchenggang nuclear power plant unit 3
HRQ	Human Reliability Quantification
HTA	Hierarchical Task Analysis
IAEA	International Atomic Energy Agency
I&C	Instrumentation and Control
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITS	Issue Tracking System
KIC	Plant Computer Information and Control System [PCICS]
LDP	Large Display Panel
MCA	Main Control Area
MCR	Main Control Room
NB	Chinese Energy Standard
NOP	Normal Operating Procedure
NPP	Nuclear Power Plant
NUREG	Nuclear Regulatory Commission technical report designation (US)
OER	Operating Experience Review
ONR	Office for Nuclear Regulation (UK)
OPEX	Operating Experience
OTS	Operating Technical Specification
OWP	Operator Workplace
PCSR	Pre-Construction Safety Report
PIE	Postulated Initiating Event
PSA	Probabilistic Safety Assessment
PSF	Performance Shaping Factor
RCP	Reactor Coolant System [RCS]

RGP	Relevant Good Practice
RPS	Protection System [PS]
RSS	Remote Shutdown Station
SAA	Severe Accident Analysis
SAMG	Severe Accident Management Guideline
SAS	Safety Automation System
SHP	Severe accident Human interface Panel
SME	Subject Matter Expert
SPAR-H	Standardised Plant Analysis Risk - Human Reliability Analysis
SQEP	Suitably Qualified and Experienced Personnel
SRO	Senior Reactor Operator
SSC	Structures, Systems and Components
TLA	Time Line Analysis
TSC	Technical Support Centre
TTA	Tabular Task Analysis
UK HPR1000	UK version of the Hua-long Pressurised Reactor
VDU	Video Display Unit
V&V	Verification and Validation
WANO	World Association of Nuclear Operators

Note:

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. Extra Cooling System (ECS [ECS]).

15.2 Introduction

Human Factors (HF) is considered for this stage of the Generic Design Assessment (GDA) in the design to support the safety case assertion of achieving the plant's fundamental safety functions and to reduce the risks associated with human interactions with the system to As Low As Reasonably Practicable (ALARP).

This chapter describes how HF claims have been addressed in the UK version of the Hua-long Pressurised Reactor (UK HPR1000) Pre-Construction Safety Report (PCSR). Given that HF is a cross-cutting discipline, this chapter also supports relevant claims made in other chapters that are associated with HF. During the GDA phase, the activities of the HF area are as follows:

a) Identify and summarise the HF safety case claims (specified as sub-claims in this chapter), one of which is the identification of Human-Based Safety Claims (HBSCs);

b) Demonstrate that the HF safety case claims are realistic, and can be substantiated by the appropriate evidence in the form of HF analysis and assessment;

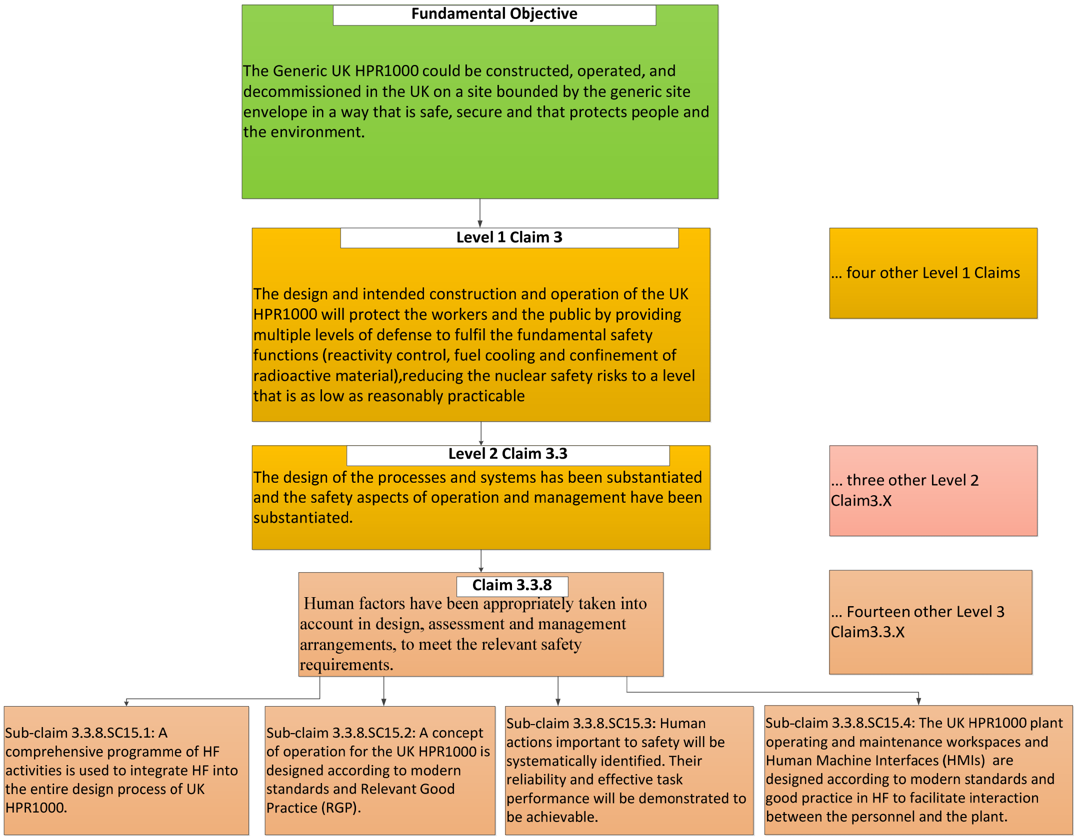
c) Demonstrate that the risks related to human elements are adequately considered and ALARP;

d) Summarise the HF-related activities to be carried out as part of GDA phase.

The present safety case of HF is produced based on the Design Reference (DR) version 2.0 except for important human actions identification, as described in UK HPR1000 Design Reference Report (Reference [1]). The important human actions identification in Chapter 15 based on Design Reference version 1.0. The safety assessment results are documented in this chapter and corresponding safety assessment reports. However, all the design changes between DR1.0/2.0 and DR2.1 have been assessed from HF point of view and corresponding insights have been provided to support the determination of these design changes.

15.2.1 Chapter Route Map

This Sub-chapter describes the HF route map. The HF claims development process is shown in F-15.2-1.



F-15.2-1 HF Claims Development Process

The ***Fundamental Objective*** of UK HPR1000 is that: *The generic UK HPR1000 could be constructed, operated, and decommissioned in the UK on a site bounded by the generic site envelope in a way that is safe, secure and that protects people and the environment.*

To underpin this objective**,** five high-level claims and a number of level 2 claims have been developed and presented in PCSR Chapter 1. This chapter supports ***Claim 3.3.8*** derived from the high-level ***Claim 3.3*** and ***Claim 3***.

Claim 3*: The design and intended construction and operation of the UK HPR1000 will protect the workers and the public by providing multiple levels of defence to fulfil the fundamental safety functions (reactivity control, fuel cooling and confinement of radioactive material), reducing the nuclear safety risks to a level that is as low as reasonably practicable.*

Claim 3.3*: The design of the processes and systems has been substantiated and the safety aspects of operation and management have been substantiated.*

Claim 3.3.8*: Human Factors have been appropriately taken into account in the design, assessment and management arrangements, to meet the relevant safety requirements.*

To support ***Claim 3.3.8****, four Sub-claims and a number of relevant arguments have been made, and are to be completed with the required evidences, which are listed* *below.*

a) ***Sub-claim 3.3.8.SC15.1**: A comprehensive programme of HF activities is used to integrate HF into the entire design process of UK HPR1000.*

1) ***Argument 3.3.8.SC15.1-A1**: The HF activities are organised and managed by a Human Factors Integration Plan (HFIP) (see Sub-chapter 15.5.1).*

- ***Evidence 3.3.8.SC15.1-A1-E1**: The HFIP, Reference [2], contains a programme that demonstrates an adequate HF scope of work is planned and resourced and that appropriate management oversight is in place.*

2) ***Argument 3.3.8.SC15.1-A2**: The HFIP is implemented and results in demonstrable integration of HF in the design and safety analysis of the plant (see Sub-chapter 15.5.2).*

- ***Evidence 3.3.8.SC15.1-A2-E1**: A summary will be provided into the updated HFIP.*

3) ***Argument 3.3.8.SC15.1-A3**: The HF activities are carried out by Suitably Qualified and Experienced Personnel (SQEP) (see Sub-chapter 15.5.3).*

- ***Evidence 3.3.8.SC15.1-A3-E1**: Human Factors Engineering (HFE) Training Plan, Reference [3], prepared to enable members of the relevant CGN engineering disciplines to acquire the appropriate HFE competence.*

b) ***Sub-claim 3.3.8.SC15.2:** A concept of operations for the UK HPR1000 is designed according to modern standards and Relevant Good Practice (RGP).*

1) ***Argument 3.3.8.SC15.2-A1**: Suitable RGP and Operating Experience (OPEX) are identified (see Sub-chapter 15.3 and 15.4).*

- ***Evidence 3.3.8.SC15.2-A1-E1**: The relevant codes and standards are listed in Sub-chapter 15.3.3.*

- ***Evidence 3.3.8.SC15.2-A1-E2**: The Plan for Operating Experience Review, Reference [4], shows how the OPEX review is performed.*

- ***Evidence 3.3.8.SC15.2-A1-E3**: The Operating Experience Feedback Review Summary Report, Reference [5], shows the OPEX identified is suitable.*

2) ***Argument 3.3.8.SC15.2-A2**: The concept of operations is suitable for the UK HPR1000 (see Sub-chapter 15.6.1).*

- ***Evidence 3.3.8.SC15.2-A2-E1**: The UK HPR1000 concept of operations is developed based on reference design, Reference [6].*

- ***Evidence 3.3.8.SC15.2-A2-E2**: The concept of operations could be* *adjusted according to HBSCs' substantiation.*

3) ***Argument 3.3.8.SC15.2-A3****: The allocation of safety functions between human and engineered systems is designed to be commensurate with human capabilities (see Sub-chapter 15.6.2).*

   - ***Evidence 3.3.8.SC15.2-A3-E1****: Function Allocation Methodology, Reference [7], provides the Allocation of Function (AoF) criteria taking account of human capabilities and limitations.*

   - ***Evidence 3.3.8.SC15.2-A3-E2****: An allocation of function review will determine the appropriate balance between human control and automation for each function and will determine if the reference design matches this allocation.*

4) ***Argument 3.3.8.SC15.2-A4:*** *The concept for the use of computerised procedures, supported by paper-based procedures, for reliable operation is planned to be demonstrated against the associated HBSCs substantiation using the Hua-long Pressurised Reactor Simulator under construction at Fangchenggang nuclear power plant unit 3 (FCG3) (see Sub-chapter 15.6.3).*

   - ***Evidence 3.3.8.SC15.2-A4-E1:*** *Operating Feedback Report of Procedure from Existing Plants with Similar Design, Reference [8], supports demonstration that the concept of procedures is suitable.*

   - ***Evidence 3.3.8.SC15.2-A4-E2:*** *The relevant HBSCs assessment reports demonstrate that the concept of procedures can support reliable operation.*

   - ***Evidence 3.3.8.SC15.2-A4-E3****: HF Verification reports will be produced with the progress of the design reference project.*

5) ***Argument 3.3.8.SC15.2-A5:*** *The appropriate staffing and qualification requirements are identified based on the defined job roles, for all essential plant operations in normal operation and accident conditions (see Sub-chapter 15.6.4).*

   - ***Evidence 3.3.8.SC15.2-A5-E1:*** *Operating Feedback Report of Operating Staffing Level for Existing Similar Plants, Reference [9], described Staffing requirements from existing similar plants.*

   - ***Evidence 3.3.8.SC15.2-A5-E2:*** *In addition to the OPEX from similar plant further evidence on the suitability of planned staffing comes from the assessment of HBSC. The HBSC include pre and post fault actions and include some very demanding scenarios. The HBSC assessment of these scenarios builds confidence that staffing is adequate.*

c) ***Sub-claim 3.3.8.SC15.3****: Human actions important to safety will be systematically identified. Their reliability and effective task performance will be demonstrated to be achievable.*

1) ***Argument 3.3.8.SC15.3-A1****: A systematic approach will be taken to identify Type A, B and C human actions and administrative controls that could impact safety under Design Basis Conditions (DBCs), Design Extension Condition A (DEC-A) and severe accident conditions (see Sub-chapter 15.7.1).*

- ***Evidence 3.3.8.SC15.3-A1-E1****: The strategy for identification and assessment of HBSCs is described in Treatment of Important Human Actions Implementation Plan, Reference [10].*

2) ***Argument 3.3.8.SC15.3-A2****: Human actions important to nuclear safety and human activities related to conventional safety and radiological protection are identified (see Sub-chapter 15.7.1).*

- ***Evidence 3.3.8.SC15.3-A2-E1****: Human actions important to nuclear safety are presented in the HBSC list, Reference [11].*

- ***Evidence 3.3.8.SC15.3-A2-E2****: Human activities related to conventional safety are identified and managed through the Construction Design Management Strategy document, Reference [12] and the CDM Design Risk Management Work Instruction, Reference [13].*

- ***Evidence 3.3.8.SC15.3-A2-E2****: Human activities related to radiological protection are presented in Worker Dose Evaluation Topic Report, Reference [14] and Post-accident Accessibility Analysis Topic Report, Reference [15].*

3) ***Argument 3.3.8.SC15.3-A3****: Representative samples of HBSCs will be substantiated during GDA (see Sub-chapter 15.7.2).*

- ***Evidence 3.3.8.SC15.3-A3-E1****: The strategy for identification and assessment of HBSCs is described in Treatment of Important Human Actions Implementation Plan, Reference [10].*

- ***Evidence 3.3.8.SC15.3-A3-E2****: Task Analysis Methodology, Reference [16], has been produced, which provides the qualitative analysis methodology of the proportionate human reliability assessment.*

- ***Evidence 3.3.8.SC15.3-A3-E3****: Human Reliability Quantification Methodology, Reference [17], has been produced, which provides the quantitative analysis methodology of the proportionate human reliability assessment.*

- ***Evidence 3.3.8.SC15.3-A3-E4****: A set of HBSCs assessment reports is / will be produced.*

d) ***Sub-claim 3.3.8.SC15.4****: The UK HPR1000 plant operating and maintenance workspaces and Human Machine Interfaces (HMIs) are designed according to modern standards and good practice in HF to facilitate interaction between the personnel and the plant.*

1) ***Argument 3.3.8.SC15.4-A1****: Suitable RGP and OPEX are identified (see Sub-chapter 15.3 and 15.4).*

- ***Evidence 3.3.8.SC15.4-A1-E1****: The relevant codes and standards are listed in the Suitability Analysis of Codes and Standards in Human Factors, Reference [18];*

- ***Evidence 3.3.8.SC15.4-A1-E2****: The Plan for Operating Experience Review, Reference [4], shows how the OPEX review is performed.*

- ***Evidence 3.3.8.SC15.4-A1-E3****: The Operating Experience Feedback Review Summary Report, Reference [5], shows the OPEX identified is suitable.*

2) ***Argument 3.3.8.SC15.4-A2****: RGP and OPEX are used to develop HFE guideline (see Sub-chapter 15.8.1).*

- ***Evidence 3.3.8.SC15.4-A2-E1****: RGP and OPEX are integrated into the HFE guidelines, Reference [19], [20] and [21].*

3) ***Argument 3.3.8.SC15.4-A3****: The HF evaluation is completed on HMIs and workspaces by reviewing the UK HPR1000 design against the HFE Guidelines (see Sub-chapter 15.8.2).*

- ***Evidence 3.3.8.SC15.4-A3-E1****: HF review reports present the HF implementation for the HMIs and workspaces design, Reference [22], [23] and [24]. HF review report will be produced on workspaces and HMIs for high risk and complexity of areas or systems.*

- ***Evidence 3.3.8.SC15.4-A3-E2:*** *The HBSCs assessment will demonstrate the suitability of the key HMIs and workspace designs.*

- ***Evidence 3.3.8.SC15.4-A3-E3****: HF Verification reports will be produced with the progress of the design reference project.*

15.2.2 Chapter Structure

The structure of this chapter is as follows:

a) Sub-chapter 15.1 lists the abbreviations and acronyms mentioned in this chapter;

b) Sub-chapter 15.2 gives the brief introduction of this chapter;

c) Sub-chapter 15.3 gives the applicable codes and standards;

d) Sub-chapter 15.4 presents the OPEX consideration;

e) Sub-chapter 15.5 provides a description of Human Factors Integration (HFI) to support HF Sub-claim 3.3.8.SC15.1;

f) Sub-chapter 15.6 gives the concept of operations information for UK HPR1000 to support HF Sub-claim 3.3.8.SC15.2;

g) Sub-chapter 15.7 gives a description of substantiation of HBSCs, including the process and methodology, to support HF Sub-claim 3.3.8.SC15.3;

h) Sub-chapter 15.8 gives a description of design support of HF activities to support HF Sub-claim 3.3.8.SC15.4;

i) Sub-chapter 15.9 presents the progress of ALARP assessment;

j) Sub-chapter 15.10 gives a summary of the main aspects of this chapter;

k) Sub-chapter 15.11 provides the reference documents.

15.2.3 Interfaces with Other PCSR Chapters

The interfaces with other PCSR chapters are listed in the following table.

T-15.2-1 Interfaces between Chapter 15 and Other PCSR Chapters

No.	PCSR Chapter	Interface
1	Chapter 1 Introduction	Chapter 1 presents the high-level objectives and claims. Chapter 15 provides the substantiation of high-level objectives and claims relative to HF.
2	Chapter 4 General Safety and Design Principles	Chapter 4 presents the HF principles. Chapter 15 presents substantiation of HF principles.
3	Chapter 6 Reactor Coolant System	Chapter 6 provides the specific design of RCP [RCS] considered the HF principles, which is taken into account for further estimate in HF area. Chapter 15 provides the principles and methodology of HF integration that shall be considered in system and component design.
4	Chapter 7 Safety	Chapter 7 provides the specific design of safety systems considered the HF principles, which is taken

No.	PCSR Chapter	Interface
	System	into account for further estimate in HF area. Chapter 15 provides the principles and methodology of HF integration that shall be considered in system and component design.
5	Chapter 8 Instrumentation & Controls	Chapter 8 provides the specific design of Instrumentation and Control (I&C) systems considered the HF principles, which is taken into account for further estimate in HF area. Chapter 15 provides the principles and methodology of HF integration that shall be considered in I&C system and component design.
6	Chapter 9 Electric Power	Chapter 9 provides the specific design of electric systems considered the HF principles, which is taken into account for further estimate in HF area. Chapter 15 provides the principles and methodology of HF integration that shall be considered in Electric system and component design.
7	Chapter 10 Auxiliary Systems	Chapter 10 provides the specific design of the principles in auxiliary systems design considered the HF principles, which is taken into account for further estimate in HF area. Chapter 15 provides the principles and methodology of HF Integrity that shall be considered in auxiliary system and component design.
8	Chapter 11 Steam and Power Conversion System	Sub-chapter 11.3 provides the specific design of Steam and Power Conversion Systems considered the HF principles, which is taken into account for further estimate in HF area. Chapter 15 provides the principles and methodology of HF integration that shall be considered in system and component design.
9	Chapter 12 Design Basis Condition	Chapter 12 provides human-related claims (implied and explicit) in fault studies, which need SQEP HF analysis and/or review.

No.	PCSR Chapter	Interface
		Chapter 15 substantiates the claims on operator actions under DBCs.
10	Chapter 13 Design Extension Conditions and Severe Accident Analysis	Chapter 13 provides human-related claims (implied and explicit) in design extension conditions and Severe Accident Analysis (SAA), which need SQEP HF analysis and/or review. Chapter 15 substantiates the claims on operator actions under DEC-A and severe accident conditions.
11	Chapter 14 Probabilistic Safety Assessment	Chapter 14 provides human-related claims (implied and explicit) in Probabilistic Safety Assessment (PSA), which need SQEP HF analysis and/or review. Chapter 15 provides the scope, methodology and principle of HRA in PSA. And also substantiates the claims on operator actions to support an iterative analysis of PSA.
12	Chapter 17 Structural Integrity	Chapter 17 provides the specific design of relevant human factors principles integrated into structural integrity related equipment design. Chapter 15 provides the principles and methodology of human factors that shall be considered in the system and component design.
13	Chapter 18 External Hazards	Chapter 18 provides human-related claims (implied and explicit) in external hazards, which need SQEP HF analysis and/or review. Chapter 15 substantiates the claims on operator actions relating to external hazards.
14	Chapter 19 Internal Hazards	Chapter 19 provides human-related claims (implied and explicit) in internal hazards, which need SQEP HF analysis and/or review. Chapter 15 substantiates the claims on operator actions relating to internal hazards.
15	Chapter 23 Radioactive Waste	PCSR Chapter 23 provides the design of radioactive waste management systems, which is further

No.	PCSR Chapter	Interface
	Management	estimated in HF area. PCSR Chapter 15 provides the principles and methodology of HF integration that shall be considered in the system and component design.
16	Chapter 24 Decommissioning	Chapter 24 provides the concept design of decommissioning, which is taken developed further in consideration of HF requirements. Chapter 24 provides decommissioning design considerations relevant to the HF of UK HPR1000. Chapter 15 provides the principles and methodology of HF integration that shall be considered in decommissioning design.
17	Chapter 25 Conventional Safety and Fire Safety	Chapter 15 supports the conventional health and safety risk management and references the health and safety risk management techniques.
18	Chapter 28 Fuel Route and Storage	Chapter 28 provides the substantiated HBSCs that are achievable and supported by appropriate HF assessments, including fuel handling operations that are taken into account under the HF area. Chapter 15 provides the principles and methodology of HF integration that shall be considered in the design of fuel handling and storage related operations.
19	Chapter 29 Interim Storage of Spent Fuel	PCSR Chapter 29 provides the substantiation of Interim Storage of Spent Fuel design, which is further estimated in the HF area. PCSR Chapter 15 provides the principles and methodology of HF integration that shall be considered in the system and component design.
20	Chapter 31 Operational Management	Chapter 31 provides procedure types and the process of procedure development. Chapter 15 provides the principles and methodology of HF integration that shall be considered.

No.	PCSR Chapter	Interface
21	Chapter 33 ALARP Evaluation	Chapter 15 provides the assessment of human actions impacting safety which supports the overall ALARP demonstration addressed in Chapter 33.

15.3 Applicable Codes and Standards

Based on HPR1000 design, the applicable codes and standards for UK HPR1000 HF design are predominantly selected and determined according to the selecting principles and the process presented in the PCSR Chapter 4 and *General Principles for Application of Laws, Regulations, Codes and Standards*, Reference [25], to ensure the applied codes and standards comply with the existing UK requirements, applicable acts, regulations, as well as taking cognisance of international good practice.

15.3.1 Codes and Standards Selection Principle

The main principles for the selection of design codes and standards are listed as follows:

a) International good practice is selected for use;

b) The latest versions of design codes and standards are selected. Whenever historic versions are to be chosen in the UK HPR1000, a gap analysis has been carried out, and remedial measures have been identified and applied, as appropriate;

c) Nuclear-specific design codes and standards are selected in preference where available to ensure that the design is conservatively produced to a level commensurate with the importance of the delivered safety function(s);

d) Evaluation of each selected design code or standard is required to determine its applicability, adequacy and sufficiency. If necessary and appropriate, selected design codes are to be supplemented and/or modified to ensure requirements are met.

15.3.2 Applicability Analysis of Codes and Standards

FCG3 adopts HAF 102-2004 *Safety Regulations for Design of Nuclear Power Plants of the People's Republic of China*, Reference [26] which is equivalent to International Atomic Energy Agency (IAEA) NS-R-1-2000 (updated to *IAEA SSR-2/1-2016)*, Reference [27], and with the exception of HAF 102-2004 also considering the regulatory practices of Nuclear Power Plants (NPPs) in China. As such, HAF 102-2004 reflects both the international and Chinese consensus on how to ensure safety is maintained to a high level and has, therefore, been considered as the best practice for the newly-designed NPPs in China. After the Fukushima nuclear accident (March 2011), the *General Technical Requirements for Post-Fukushima-Accident Improvement Actions of Nuclear Power Plants*, Reference [28], was established by the

National Nuclear Safety Administration (China) in June 2012 in order to draw lessons from the Fukushima nuclear accident in Japan and further improve the safety level of NPPs in China. Hua-long Pressurised Reactor under construction at Fangchenggang nuclear power plant unit 3 (HPR1000 (FCG3)) was then reviewed against those requirements to confirm that the relevant safety improvements had already been considered in the design. Thereafter, a similar review against *IAEA SSR-2/1-2016*, Reference [27], was conducted to ensure that the design of HPR1000 (FCG3) was benchmarked against, and in line with, international good practices.

The other available Chinese standards, such as Chinese National Standard (GB) series and Chinese Energy Standard (NB) series are also used, the main technical clauses of which are equivalent to international codes and standards, such as International Electrotechnical Commission (IEC). In addition, some of Nuclear Regulatory Commission Technical Report Designation (NUREG) guidelines, International Organization for Standardization (ISO) series and Institute of Electrical and Electronics Engineers (IEEE) standards are adopted.

UK HPR1000 HF activities are based on the Design Reference 2.0, and good practice from the NPPs in China has been considered and taken into account where appropriate. The UK HPR1000 design mainly adopt British Standards (BS), such as “BS IEC”, and “BS ISO”, which are identical to the corresponding codes and standards adopted by HPR1000 (FCG3) of “IEC”, “ISO” series.

The suitability of codes and standards applied in UK HPR1000 HF area has been analysed according to the principles and process presented in *General Principles for Application of Laws, Regulations, Codes and Standards*, Reference [25], see *Suitability Analysis of Codes and Standards in Human Factors*, Reference [18] for detail. This report can discuss why one standard is chosen over another or data taken from part of a standard.

The current identified applicable codes and standards for HF areas are listed in T-15.3-1. These codes and standards are identified as the source of RGP, and are, therefore, appropriate for supporting the UK HPR1000 HF design. The scope of UK HPR1000 codes and standards covers the main topics of the HF activities and the HF support activities to other disciplines, such as HMI; Control Room System (CRS) workspace; and Structures, Systems and Components (SSCs) in local areas. The topics where the codes and standards used are shown in the column “Topics”.

T-15.3-1 Applicable Codes and Standards List

NO.	Standard Number	Version	Title	Issued by	Topics
1	IAEA SSR-2/1	2016	Safety of Nuclear Power Plants: Design	International Atomic Energy	Top requirements of HF

NO.	Standard Number	Version	Title	Issued by	Topics
				Agency (IAEA)	
2	NUREG-0711	2012	Human Factors Engineering Program Review Model Office	United States Nuclear Regulatory Commission (U.S. NRC)	HFIP, Task analysis, HF (Verification and Validation) V&V, HBSC identification, OPEX
3	NUREG-0700	2002	Human-System Interface Review Guidelines	U.S. NRC	HFE guideline for HMI design
4	NUREG/CR-3331	1983	A Methodology for Allocation Nuclear Power Plant Control Functions to Human or Automatic Control	U.S. NRC	AoF
5	NUREG-1792	2005	Good Practices for Implementing Human Reliability Analysis (HRA)	U.S. NRC	Human Reliability Quantification (HRQ)
6	NUREG/CR-6883	2005	The Standardized Plant Analysis Risk (SPAR) Human Reliability Analysis Method	U.S. NRC	HRQ (Type C)
7	NUREG/CR-4772	1987	Accident Sequence Evaluation Program Human Reliability Analysis Procedure	U.S. NRC	HRQ (Type A)
8	NUREG/CR-1278	1983	Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Application Final Report	U.S. NRC	HRQ (Type B)
9	IEEE 1023	2004	Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment and Facilities of Nuclear Power Generating Stations and	Institute of Electrical and Electronic Engineers (IEEE)	HFE guideline for SSC Design

NO.	Standard Number	Version	Title	Issued by	Topics
			other Nuclear Facilities		
10	BS EN 61839	2014	Nuclear power plants – Design of control rooms – Functional analysis and assignment	British Standards Institution (BSI)	AoF
11	BS IEC 60964	2009	Nuclear power plants – Control rooms – design	BSI	HFE guideline for MCR Design, HFIP of MCR
12	BS EN 60965	2016	Nuclear power plants —Control rooms —Supplementary control points for reactor shutdown without access to the main control room	BSI	HFE guideline for RSS Design, HFIP of RSS
13	BS EN 61772	2013	Nuclear power plants – Main control room – Application of visual display units (VDUs)	BSI	HFE guideline for VDUs Design
14	BS EN 62241	2015	Nuclear power plants – Main control room – Alarm functions and presentation	BSI	HFE guideline for Alarm functions and presentation Design
15	BS EN 61227	2016	Nuclear power plants-Control rooms - Operator controls	BSI	HFE guideline for Operator control design
16	BS EN ISO 11064-2	2001	Ergonomic design of control centers-Part 2: Principles for the arrangement of control suites	BSI	HFE guideline for arrangement of control suites design
17	BS EN ISO 11064-3	2000	Ergonomic design of control centers-Part 3: Control room layout	BSI	HFE guideline for control room layout design
18	BS EN ISO 11064-4	2013	Ergonomic design of control centres-Part 4: Layout and dimensions of workstations	BSI	HFE guideline for Layout and dimensions of workstations

NO.	Standard Number	Version	Title	Issued by	Topics
19	BS EN ISO 11064-6	2005	Ergonomic design of control centers-Part 6: Environmental requirements for control centres	BSI	HFE guideline for Environmental design for control centres
20	BS EN ISO 9241-112	2017	Ergonomics of human-system interaction Part 112: Principles for the presentation of information	BSI	HFE guideline for presentation of information
21	BS EN ISO 12100	2010	Safety of machinery-General principles for design-Risk assessment and risk reduction	BSI	HFE guideline for machinery
22	ISBN 978 0 85293 555 2	2010	Guidance on managing human and organisational factors in decommissioning	Energy Institute	HFE guideline for decommissioning design
23	BS EN 12464-1	2011	Light and lighting - Lighting of work places-Part 1: Indoor work places	BSI	HFE guideline for Lighting design of indoor work places
24	IEC 62271-1	2017	High-voltage switchgear and control gear - Part 1: Common specifications	IEC	HFE guideline for High – voltage switchgear and control gear design
25	IAEA-TECDOC-1058	1998	Good practices with respect to the development and use of nuclear power plant procedures	IAEA	OPEX

15.3.3 Compliance Analysis of Codes and Standards

The compliance confirmation and justification of the codes and standards applied in HF area have been carried out and are described in *Compliance Analysis of Codes and Standards in Human Factor,* Reference [29]. Based on the compliance analysis, most of these codes and standards are compliant in the UK HPR1000 HF area, and 4 items are not compliant. For these gaps, further analysis and the justifications or modifications should be given to ensure the risk is ALARP, see Sub-chapter 15.9.

15.4 OPEX

For FCG3, OPEX from the Chinese and international NPPs has been considered. HFE-related problems and issues for the Main Control Room (MCR), Remote Shutdown Station (RSS), and a proportion of HMIs in local areas have been identified and analysed. The content of the plant-wide operating experience review covers:

a) Previous plants and systems;

b) Recognised nuclear industry problems;

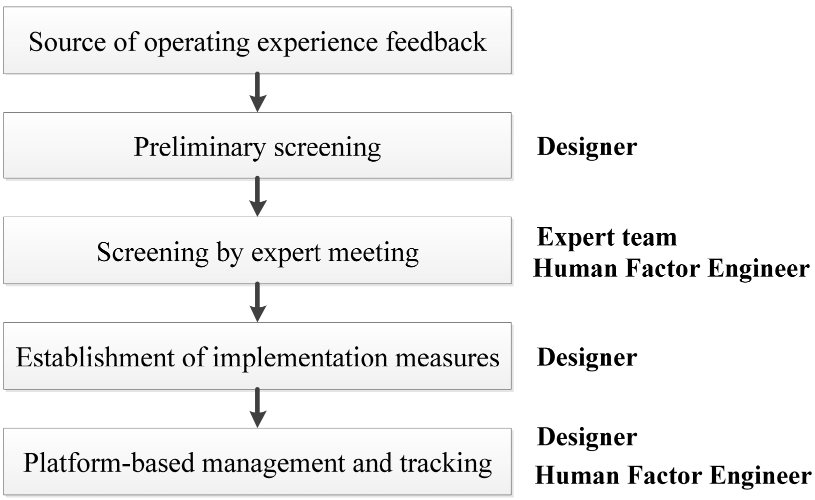
c) Relevant HMI technologies;

d) Problems identified by plant personnel;

e) Important human actions.

Furthermore, to obtain OPEX in the areas of operation, inspection and maintenance, the plant workers with experience have been interviewed by each participating discipline to identify relevant HF short-falls.

OPEX review is carried out for the UK HPR1000 as defined in *Plan for Operating Experience Review*, Reference [4]. This expands the scope of the Operating Experience Review (OER) to include the newly-operating Taishan NPP and a world-wide review using information from World Association of Nuclear Operators (WANO). The HF OPEX review is widened to include areas such as construction, commissioning, operation, inspection and maintenance, and decommissioning to identify where human unreliability has been observed and to identify enhancements to the UK HPR1000 design. The routine process for operating experience feedback review is summarised in F-15.4-1.



F-15.4-1 Routine Process for Operating Experience Feedback Review and Analysis

The sources of OPEX include design changes, reasonable design improvement proposed by the owner, important feedback given during the exchange and cooperation with external organizations. HFE related OPEXs are screened out through the considerations about environment, organisation, procedures, person, equipment, task and training. For example, during the OPEX review process, it is discovered that the circulating water outlet measuring sleeve is about 4.9 meters away from the ground in Fangchenggang nuclear power plant phase I. The operator can't reach the measuring sleeve. After analysis, a temperature measuring platform is added to reach the measuring sleeve. This design change avoids a lot of scaffolding work and reduces the risk of falling injuries. The review results are shown in *Operating Experience Feedback Review Summary Report,* Reference [5].

In addition, operating experience related to existing NPPs procedures and staffing has been reviewed. OPEXs related to procedures have been collected from the experience feedback system or other systems regarded as the experience feedback information sources. OPEXs related to procedures are screened out by a team composed of multi-discipline experienced experts. The review results are shown in *Operating Feedback Report of Procedure from Existing Plants with Similar Design,* Reference [8].

The source of staffing related operating experience is the staffing plan and qualification requirement in the single-unit layout NPPs in China: advanced passive pressurized water reactor of Sanmen NPP, water-water energetic reactor of Tianwan NPP and European pressurized reactor of Taishan NPP. Based on the research of existing operation staffing and qualification documents, interview with the operation staffs of the nuclear power plant in service or commissioning, the UK HPR1000 staffing plan is established. The review results are shown in *Operating Feedback Report of Operating Staffing Level for Existing Similar Plants,* Reference [9].

15.5 Human Factors Integration Management

This Sub-chapter supports HF Sub-claim 3.3.8.SC15.1.

15.5.1 Introduction

For FCG3, using *NUREG-0711*, Reference [30], a programme of HF activities has been conducted, including HFE programme management, OER, functional requirements analysis and functional allocation, task analysis, staffing and qualifications, treatment of important human actions, HMI design, procedure development and HF verification and validation.

The scope of HF activities covers the nuclear island, conventional island and balance of plant, including the MCR, RSS and other plant locations where operation and maintenance activities take place. Particular HF focus from the CGN HF team has been given to the MCR, the central location for monitoring and control of the plant. During SSC design (such as pumps and the refuelling crane), for consideration of operator role, relevant codes and standards, engineering procedures and experience from previous plants have been taken into account.

For the UK HPR1000, the process by which the equipment and human components are brought together to work in a system is known as HFI. According to *NS-TAST-GD-058*, Reference [31], “HFI is a good practice approach to the application of Human Factors (HF) to systems development. As a methodology, it provides an organising framework to help ensure that all relevant HF issues are identified and addressed. In addition, the HFI approach has a management strategy that aims for timely and appropriate integration of HF activities throughout the project.”

The aim of the HFI for UK HPR1000 is reducing risks caused by human errors to ALARP. For HFI, it means integrating HF into the system design to minimise human error risk, identifying and substantiating human actions that are important to nuclear safety and ensuring that the AoF is appropriate and the task is feasible and can be undertaken reliably.

In order to manage the HFI in a well-managed and traceable fashion, an HFIP has been developed and used, Reference [2].

In the HFIP, the actual HF activities based on FCG3 and planned throughout the various stages of project are described, including RGP identification, gap identification, OER, AoF review, identification and substantiation of HBSCs, HFE guidelines development, HMIs and SSCs design review, HF V&V, training for SQEP, and interface management, etc. For each activity, further gap analysis is on-going and the results will enable update to the HFIP and guide HF activities.

There are four main approaches to make sure the HF integration effectively:

a) A dedicated HF team is established (including specialists with extensive UK experience) to manage the integration process and to inform HF expertise to design and safety case development.

b) HF integration activities are divided into four work packages and cover all plant phase through the plant life, which will be continued throughout the GDA phase as follows:

    1) HF Management - covering production of the HFIP, HFE organisation and operating principles, training plan, HF issues register, quality assurance arrangements and progress monitoring;

    2) HF Planning - covering identification of RGP, concept of operations, TAD, OPEX and allocation of function review;

    3) HF input to safety assessment - covering HBSCs identification, Task Analysis, HRQ and Substantiation;

    4) HF support to design - covering development of HFE guidelines, HF review

of MCR HMIs, MCR workspaces, local area HMIs and workspaces, etc.

c) HF good practices and OPEX are encapsulated with UK HPR1000 various design process.

d) Standards and guideline documents are identified and delivered to various design disciplines, HF inputs and supports are provided to the SSCs design.

The HFIP is a separate live document which will be updated regularly as required during the GDA phase.

15.5.2 HFIP Understood and Adhered to by Other Disciplines

The HFIP is one of the top-level documents for UK HPR1000, which is included in the overall documents list. The project general management procedure shows the HFIP is used as a design input for all disciplines. To ensure the HFIP is understood and adhered to by other disciplines, the CGN HF team maintains communication with these disciplines, and the following aspects have been enforced:

a) Hold Points

Hold points will be set to enable HF checks for design modifications and improvements. HF assessment will be carried out at these points.

b) Design Review

Design reviews are held as a governance mechanism to verify that the design is correct, complete (for that design stage), satisfies requirements and adheres to standards. Design reviews also provide a mechanism for confirming resolution of outstanding issues and trade-offs, reviewing resources and scheduling. Ultimately they formally enable the project to proceed to the next stage.

c) Process Monitoring and Reporting

The performance of HFI will be monitored by some key index. The HF team will hold periodic meetings with the relevant disciplines, reporting current progress and existing issues, discussing solutions and implementation of the forward plan. If HF activities raise issues relevant to specific disciplines, a specific meeting or discussion can be held to coordinate resolution.

Key Performance Indicators are being developed for the implementation of HF in the UK HPR 1000 GDA project in three groups, such as percentage of work scope completion, HF resource and HF integration level.

The Issue Tracking System (ITS) is used for recording, tracking and management of all HF issues raised from HF activities, assumptions and elements of concept of operations. The tracking system is also used as a tool for clear and traceable handover from GDA phase to the site licensing phase. The contents of handover include issues to be resolved during the site licensing phase, assumptions and other information related to operation management and organisation.

Detailed information related to the process of HF issues tracking is described in *Human Factors Issue Management Method*, Reference [32].

15.5.3 HF Activities Carried Out by SQEP

A dedicated HF team has been set up for the UK HPR1000 project. The team is fully integrated into the project and interfaces with other disciplines. The organisation of HF team is described in *Human Factors Integration Plan*, Reference [2].

The HF team is responsible for the HF work and engages with the engineering areas to gain design information and provides support in terms of any HF analysis required in relation to plant safety case.

Role profiles have been developed for the HF team and other disciplines that need to consider human factors. These describe the required qualifications, training and experience for each role. HF team members cover multiple disciplines to ensure comprehensive integration of HF into all design areas including, but not limited to, mechanical design, PSA, electrical system design, I&C system design, architecture design, fault studies, internal and external hazards, plant operation, etc.

Seven role profiles have been developed for HF team members, which are HF area Lead, HF Quality Control, HF Safety Engineer, HF Design Engineer, Engineering discipline HF representative, External HF Advisor and HF Project Correspondent.

The education and related professional experience of the HF team members need to satisfy the minimum qualification for each area of expertise. Qualifying professional experience (e.g., design, development, analysis) for each area is directly related to those technologies and techniques that is part of the HFE design and implementation process.

Meanwhile, CGN acquired support from external HF specialists. HF advisors are HF specialists with previous HF experience. The HF advisors provide HF support to the designers. The HF advisors are CGN staff and external HF Subject Matter Experts (SME). They are involved in several work streams including:

a) Providing the technical review on HF delivery documents

b) Technical HF training, such as:

    1) HBSC identification and task analysis workshop in 2018

    2) UK context and HF review training in the end of 2019

c) HBSCs assessment workshops and reports development in 2019

To improve HF ability, the training requirement is analysed and a training plan for HF team is developed. The HF team provided HF awareness training to the designers and engineers of disciplines interfacing with HF, and explained the purpose and content of the HFIP and HFE guidelines. The objective of the training is to help the designers and engineers to understand the HFIP, key HF principles and the roles of operators in supporting the ALARP argument.

Training has been delivered to the HF team and other disciplines. It is recognised that further training is required and this will be further detailed in the updated training plan. Training and skills development is on-going in both Human Reliability and Design Review. CGN have experience using ASEP, THERP and SPAR-H. The UK context is to base the HRA on task and error analysis as well as the deterministic rules found in the ONR SAPs. Training was provided to the HF team in March 2018 that covered these areas. This has been supplemented by the CGN HF team working with EDF energy (UK) (EDF E) on a number of HBSC assessments after the training. These have given the CGN staff the opportunity to practice the skills learnt in training. These training courses have been delivered as follows:

a) The GDA fundamental knowledge

b) The UK context competence training is on-going

c) Human factors integration management

d) Human factors engineering basic knowledge and awareness training

e) Function allocation

These training courses are planned as follows:

a) Task analysis

b) HF design principles

c) UK Context RGP and legal requirements for HF

Further specific training will be provided to the HF team, designers and engineers of disciplines as specified in *HFE training plan*, Reference [3]. The HFE training plan will be updated if needed to identify the need for role profiles and to recognise the need for on the job mentoring to support staff to meet those guides.

15.6 Concept of Operations

This Sub-chapter supports HF Sub-claim 3.3.8.SC15.2.

The concept of operations has been developed to a level of detail to underpin all relevant HF analysis and evaluation in GDA phase which will be refined as further detail is available. It includes operational purpose of the plant, basic AoF concept, staffing and qualifications, command and control philosophy, concept of use of HMIs, and basic details of the working environment.

15.6.1 Concept of Operations for UK HPR1000

The concept of operations for the UK HPR1000 has been developed based on design reference project. The fundamental operational purpose of the UK HPR1000 is the safe and effective generation of electricity and protection of the public from potential radiological hazards.

a) Basic Allocation of Function Concept

The UK HPR1000 adopts a moderate level of automation and is designed in such a way to meet the following autonomy objectives:

1) Automatic power control (regulation) capability in the range of 15%-100% nominal power during the start-up process of the reactor;

2) No human intervention required from the MCR in the first 30 minutes from the first significant signal, and no action required outside the MCR within 1 hour from the first significant signal;

3) The plant could be taken to the controlled state by the automatic protection functions for the most DBCs (and, therefore, relies less on the manual intervention of operators).

The UK HPR1000 optimises dependence on human actions to maintain or recover a stable, safe state, and, therefore, relies less on the manual intervention of operators during operation of the plant. The split of responsibility between human and engineered systems is clear. The functions allocated to human match human capabilities. Situational awareness of operators during automatic operations is maintained by the requirement for specific supervisory operator actions and for operator confirmation of successful implementation of automated sequences. The review of the function allocation refers to Sub-chapter 15.6.2.

b) Staffing and Qualifications

UK HPR1000 staffing and qualifications are based on OPEX from the 14 operating NPPs of CGN. The following paragraphs describe the roles and responsibilities for those roles.

1) Shift supervisor, holding a valid certification (Senior Reactor Operator (SRO)), is responsible for overall plant operation. Normally shift supervisor is in an office adjacent to the Main Control Area (MCA) within the MCR. However, the shift supervisor could be anywhere within the power plant during the plant operation;

2) Safety engineer, holding a valid certification (SRO), is responsible for providing independent supervision and evaluation of plant safety conditions. This individual is normally in the MCR, but could be anywhere within the power plant during the plant operation;

3) Unit supervisor, holding a valid certification (SRO), is responsible for the direct supervision of the reactor operators in the MCR. During the plant operation, this role can be anywhere within MCR.

4) Deputy shift supervisor, holding a valid certification (SRO), as the unit supervisor and shift supervisor, is part of each shift. This individual is responsible for work permission and prevention activities. This individual assists the shift supervisor to lead, coordinate, command and control the whole shift. In addition, this individual assists the shift to complete the operational actions, to ensure the unit is safe, stable and economical.

5) Reactor operators, holding the certificate of reactor operator issued by the regulation department, are responsible for plant operations in the MCA and are normally located within the MCA. One reactor operator is responsible for nuclear island and the other one is responsible for conventional island.

6) Field operators responsible for operating local equipment in the plant are normally located at various locations throughout the plant and take direction from reactor operators in the MCR. Field operators must have more than one year of local working experience in the nuclear power plant.

c) Command and Control Philosophy

During DBCs the operators are responsible for control of the unit and refer to procedures and other documents as required to keep or return the plant to within its defined safe operating envelope. The unit supervisor provides support and oversight to the operators.

In the event of a severe accident, operators are still responsible for implementing specific procedures and responding to emerging plant conditions as required. However, the On-site Emergency Control Centre (ECC) has a priority role in developing the response strategy, advising on operational decisions, and keeping a broader overview based on the status of the entire station in the context of the conditions emerging throughout the event.

The shift supervisor is the acting emergency controller if a site accident is declared, until the on-site ECC is established.

Table 15.6-1 shows the control rooms and their function.

T-15.6-1 Control Rooms and Their Function

Control room	**Function**
MCR	MCR is the main control room in all plant conditions

RSS	RSS is a supplementary control room when the MCR is unavailable
TSC	Technical Support Centre (TSC) is the workplace for the staff of the technical support group where they initiate and implement emergency response actions
ECC	ECC is the command center under the emergency state. It is responsible for commanding the emergency response action, contact and coordination with the emergency organizations of the national, local and competent departments.

d) Concept of Use of HMIs

1) When the MCR is available, the plant is monitored and controlled by the operators on Operator Workplace (OWP) with Large Display Panel (LDP). In the event that the OWPs are unavailable, the shift transfers to Auxiliary Control Panel (ACP) to monitor and control the plant;

2) In case of the unlikely coincidence of frequent faults and postulated Common Cause Failure (CCF) in the Protection System (RPS [PS]) and Safety Automation System (SAS), the operators need to transfer to Diverse Human interface Panel (DHP) to monitor and control the plant;

3) When OWPs are unavailable in Design Extension Condition B (DEC-B) that is mainly caused by loss of power supply for long term, the operators need to transfer to Severe accident Human interface Panel (SHP) to monitor and control the plant;

4) OWP, LDP, ACP, DHP and SHP are all located in the MCR. When the MCR is unavailable, the operators need to transfer to RSS to monitor and control the plant;

5) The HMIs in local areas are normally used by field operators cooperating with operators in MCR for plant operation.

Refer to PCSR Chapter 8 for more detail of HMIs in MCR and RSS.

e) Procedures Structure

Procedures are pre-approved instructions to support the achievement of effective and reliable operation.

There are three kinds of operating procedures, which are Normal Operating Procedures (NOPs), Emergency Operating Procedures (EOPs) and Severe Accident Management Guidelines (SAMGs). The UK HPR1000 uses computerised procedures, supported by paper-based procedures.

NOPs are developed to ensure that the plant is operated within the operating limits and conditions, and it provides instructions for safe conduct of all operating mode. NOPs generally include unit operating procedures, system operating procedures, alarm response procedures, and abnormal operating procedures.

Unit operating procedures are used for changing the state of the plant including start-up, shutdown, preparation of refuelling, etc., and for providing integrated operation of the plant.

System operating procedures are used for system charging, energising, starting up, shutting down, changing modes of system operation, and other instructions appropriate for the operation of various systems in the plant.

Alarm response procedures are used to determine the remedial action to be taken after an alarm appears.

Abnormal operating procedures are used to manage an abnormal situation and bring the plant back to normal operation before the safety systems are initiated.

EOPs define the actions necessary to prevent or mitigate the consequences of accident conditions. These procedures cover verification of automatic actions, operator actions to prevent or mitigate consequences, and operator actions necessary to stabilise the plant. EOPs are designed to be flexible to handle a variety of events in a conservative manner. As such, EOPs contain specified entry and exit conditions. Once activated, the automatic diagnosis provides one operating procedure option to the operating team via the Plant Computer Information and Control System (KIC [PCICS]). The reactor operator and the unit supervisor also follow the paper-based orientation procedure to diagnose the plant state once the criteria to entry into the emergency operation are met. Then an operating procedure to be applied is obtained. The operating team is always responsible for the choice of operating procedure.

SAMGs provide guidance to MCR operators and emergency response personnel on how to respond to a plant emergency when specific plant parameters have reached a point where core damage may have occurred.

f) Basic details of the working environment

Environmental factors can increase both physical and mental stress, resulting in distortion or filtering of important sensory information and increased human error potential and/or direct health and safety risks. Key environmental factors that are likely to be encountered on nuclear sites/facilities, e.g. visual environment, thermal environment, auditory environment and vibration, are considered as HF design requirement inputs, and integrated into system engineering process.

The concept described above is the same as that for design reference project. Concept of operations for the UK HPR1000 has already been issued, Reference [6]. Furthermore, it is anticipated that this concept could be partly refined during steps 3&4 of GDA to ensure consistency with substantiation of the HBSCs.

The operating assumptions (such as procedure structures, command and control philosophy, staffing and qualification) are captured and entered into the ITS. It ensures that the basis for the HF analyses and support provided during GDA phase can be understood and further validated as necessary in future stages of the plant lifecycle.

15.6.2 Allocation of Function Review

As a part of HFI process activities, allocation of function review is carried out to ensure the allocation of safety functions between human and engineered systems is commensurate with human capabilities.

For the UK HPR1000, review and justification of existing AoF will be performed to ensure the validity of the current assignment, or to identify any mis-allocation. The details of AoF such as its methodology and criteria are described in *Function Allocation Methodology*, Reference [7]. The methodology is developed taking into account the research and development, design experience with consideration of relevant good practices (RGP) and UK regulatory guidance. The process recommended in the methodology provides reviewer with a value relating to the appropriate ‘Automation Level’ to apply to the function. Automation Levels define the boundaries of human responsibility and boundaries of automation responsibility for the function in order to identify an appropriate allocation range. When assessing the suitability of the reference design, once the allocation range(s) has been identified for a function reviewer should then compare it with the reference design function, to identify if a discrepancy exists. Function Allocation Methodology will be updated according to the pilot study and experience feedback. The discrepancy identified through AoF review and the HF recommendations given to improve associated designs are recorded in the ITS. The function allocation review result will be specified in Allocation of Function Review Report.

15.6.3 Procedures Review

UK HPR1000 procedures are based on those used for design reference project. The final procedures will be developed during the site licensing phase. However, the concept of the use of computerised procedures, supported by paper-based procedures, for reliable operation will be justified during the GDA phase.

Operating experience on procedures is gathered from FCG3 and existing NPPs featuring similar and relevant designs to identify any issues with their format, navigation, content and presentation. This has been reported in the *Operating Feedback Report of Procedure from Existing Plants with Similar Design*, Reference [8].

In addition, as part of the HBSCs assessment, procedures (FCG3 procedures, including Paper-based procedures for local operation and maintenance) will be used and any issues or concerns with procedures will be identified. This will include tests and review of reverting to paper-based procedures.

15.6.4 Staffing and Qualifications Review

Staffing and qualification requirements for the UK HPR1000 are based on FCG3 and the feedback from existing plants with similar design. The final staffing and qualification requirements will be developed and validated during the site licensing phase. However, the preliminary staffing and qualification requirements for the UK HPR1000 will be justified during the GDA phase.

Relevant staffing and qualification feedback collected from existing similar plants has been reported in Operating *Feedback Report of Operating Staffing Level for Existing Similar Plants*, Reference [9].

In addition, as part of the HBSCs assessment, preliminary requirements for operating staffing and qualifications will be assessed through a task analysis and any issues will be identified. The task analysis provides the input for establishing staffing and qualifications requirements for both normal operation and accident conditions. Staffing requirements are typically lower for normal operation when compared with accident conditions. Therefore, the task analysis mainly focuses on accident conditions.

15.7 Substantiation of Human-Based Safety Claims

This Sub-chapter supports HF Sub-claim 3.3.8.SC15.3.

The systematic identification and assessment of human actions important to achieve safety in all permitted operating modes and all accident conditions is known as the substantiation of HBSCs. The aim of substantiation of HBSCs is to demonstrate that important human actions are feasible and sufficiently reliable.

The identified HBSCs are traceable back to the fundamental safety functions including control of reactivity, removal of heat, confinement and additional safety functions. HBSCs are classified based on either the significance of the safety function affected or their risk significance, and are assessed proportionately at different levels based on their classification. The overall process is a closed loop with iterations. The HF issues raised are managed by the HF ITS.

Three corresponding levels of SSC class and human action class are summarised in the T-15.7-1 below.

T-15.7-1 Criteria of the HBSC Classification

Safety Function Category	**SSC Class**	**Human Action Class**
Category 1	Class 1	Class 1
Category 2	Class 2	Class 2
Category 3	Class 3	Class 3

15.7.1 Identification of HBSCs

In FCG3, the risk-important human actions are identified in the level 1 and level 2 PSA. Deterministic identification is an important supplement for probabilistic identification using accident analysis and severe accident analysis. Currently, the important human actions have been identified and grouped into several significant important human actions.

For the UK HPR1000, the HF team works closely with the PSA, DBC and SAA topic areas to identify HBSCs, including the safety actions of personnel responsible for monitoring and controlling the plant and of personnel carrying out maintenance, testing and calibration activities.

The process to identify HBSCs for UK HPR1000 is as follows:

a) Review FCG3 important human actions list;

b) Identify HBSCs through the development of the PSA for the UK HPR1000, including type A, B and C HBSCs;

c) Identify HBSCs through operating experience feedback, including type A, B and C HBSCs;

d) Identify HBSCs from the Examination, Maintenance, Inspection and Testing (EMIT) strategy of the UK HPR1000, particularly the list of class 1, 2 or 3 components, to get type A human actions identified effectively;

e) Identify HBSCs from the Postulated Initiating Event (PIE) and fuel route, to get type B human actions identified effectively;

f) Identify HBSCs through the developing of Fault Studies, SAA and internal hazards , to get type C human actions identified effectively;

g) The categorisation and classification of the HBSCs based on the category of the safety function the operator action delivers and the importance of the operator action in achieving the safety function.

More detailed information is described in the *Treatment of Important Human Actions*

Implementation Plan, Reference [10], More than 200 important human actions have been identified, details shown in the *HBSCs List*, Reference [11].

15.7.2 Assessment of HBSCs

For FCG3, the HF assessment activities for important human actions include task analysis and HRQ.

Task analysis evaluates the demands of these tasks placing upon personnel in terms of perception, decision making and action. Physical and psychological factors that could impact on human performance are also taken into account. The detailed topics addressed in task analysis include information, decision-making, response, teamwork and communication, work load, task support, workplace factors, situation and Performance Shaping Factors (PSFs) and potential hazards. The result of the task analysis forms the basis for evaluating the design of HMIs, staffing and qualifications, procedures, training programmes, task support verification and HRQ analysis.

The preliminary calculation of HRQ has been completed and incorporated into the PSA model.

For the UK HPR1000, the identified HBSCs are assessed through qualitative and quantitative analysis and contribute to:

a) Identification of key design aspects (HMIs or procedures), which need rigorous assessment and/or improvement to ensure their expected support to task performance;

b) Identification of the recommendations related to operational arrangements (such as the minimum requirements for operation, training, qualifications) to ensure that the risk of human error in these tasks important to safety is reduced to ALARP.

According to the HBSCs classification, two levels of assessment are carried out. More significant HBSCs are assessed in detail, while less significant HBSCs are assessed to a high level. The HBSCs assessment level based on the class or risk of HBSCs is showing in T-15.7-2.

T-15.7-2 Assessment level of HBSC

Assessment	**Human Actions (HBSCs)**
Detailed Level Assessment	Class 1
	Class 2
	Type A HBSCs from F-SC1 equipment EMIT

Assessment	Human Actions (HBSCs)
	High Risk HBSC in PSA (RAW>=2,or FV>=0.005)
High Level Assessment	Class 3
	Type A HBSCs from F-SC2 equipment EMIT
	Type A HBSCs from F-SC3 equipment EMIT
	Low Risk HBSC in PSA (RAW<2 and FV<0.005)

The process of detailed assessment is as follows:

a) Define the context and requirements of HBSCs in consultation with the system designers and safety assessment teams;

b) Consider OPEX related to HBSCs;

c) Identify task-related information such as system descriptions and procedures to develop initial task analysis;

d) Task data collection. More task data such as perceived workload, task timing, observed errors and qualitative feedback from operators, are collected through simulator, plant representations (e.g. a 3D model) or paper-based system descriptions and drawings;

e) Task analysis. Hierarchical Task Analysis (HTA), Tabular Task Analysis (TTA) and Time Line Analysis (TLA) are candidates for task analysis methods. Through task analysis, how the constituent tasks interact and how the tasks performed are described. The topics include personnel requirements, task description, interface description, information needed or presented, location, timing, workload, stress, situational awareness, technological factors, environmental factors, organisational factors, job factors, errors of commission and omission and violation are analysed. The results of the task analysis are used as an input to the design of HMIs and workspaces, staffing and qualifications, procedures, training programmes, HBSCs verification and HRQ analysis, and forms the basis for their evaluation. Detailed information is described in *Task Analysis Methodology*, Reference [16].

f) Task Assessment. A qualitative task assessment sheet is developed to provide a mechanism to consistently record the key aspects of the task as they are related to HRQ. Any assumptions are made explicitly and listed in ITS for tracking;

g) Quantification. Based on a sound understanding of the task, potential errors and PSFs provided by task analysis and the task assessment sheet, HRQ is carried out using the methodology described in *Human Reliability* Quantification *Methodology*, Reference [17]. The results of HRQ are fed back to the appropriate iteration of PSA.

h) Reporting. Finally the assessment, findings, recommendations and conclusions is reported.

The process of high-level assessment is as follows:

a) A structured review of the task and PSFs to get a concise description of the task, task requirements, PSFs and errors is made;

b) A task sheet is designed to ensure that the principle elements affecting task reliability are captured;

A judgment of task feasibility is made to support the HRQ;

a) HRQ calculation

b) Finally the assessment, findings, recommendations and conclusions are reported.

The methods for Human Error Quantification (HRQ) are as follows:

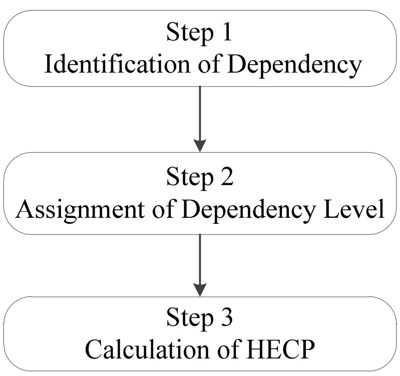
a) Type A human errors are assessed with Accident Sequence Evaluation Program (ASEP) in NUREG/CR-4772.

b) Type B human errors are calculated by using the database in NUREG/CR-1278.

c) Type C human errors are assessed with Standardized Plant Analysis Risk Human Reliability Analysis (SPAR-H) in NUREG/CR-6883.

In GDA phase, HRQ is done by using the high level assessment for all the Type A, Type B and Type C events, which belong to the HBSCs coming from PSA model.

For the HRQ of UK HPR1000 project, the dependencies between/among Human Failure Events have been considered to avoid underestimation of risk. The potential impact of dependency between/among separate activities is assessed by using the following process.



F-15.7-1 Process of Assessment of Dependency

More detailed information is described in *Treatment of Important Human Actions Implementation Plan*, Reference [10].

Some HBSCs for Type A, Type B and Type C have been assessed in GDA Step 3, which focussing on the development and testing of appropriate methods for the qualitative and quantitative assessment of Type A, B and C HBSCs. To summarise briefly:

For Type A, typical valve maintenance tasks have been qualitatively analysed. Risk significant actions were identified and quantified. Corresponding recommendations were raised and delivered to the relevant discipline. More detailed information is described in *Human Reliability Assessment Report for Typical Valve*, Reference [33].

For Type B, a number of Type B HBSCs have been identified and assessed in fuel handling operations. The assessment captured a number of recommendations to the related SSC design of fuel handling route, thereby to mitigate the likelihood of operator induced errors. More detailed substantiation process is described in *Human Reliability Assessment Report for Fuel Handling Operations*, Reference [34].

For Type C, the reliability of operator action to manage a SGTR has been assessed. The important actions can be carried out reliably and several potential improvements are recommended. More detailed information is described in *Human Reliability Assessment Report for Isolating Impaired SG Manually*, Reference [35].

15.7.3 Consideration of Human Actions from Other Areas

Besides HBSCs derived from the PSA, DBC and SAA topic areas, a risk identification and assessment will also be carried out on identified human actions placed on personnel related to:

a) Conventional safety

Conventional health and safety is addressed as a specific element of the UK HPR1000 nuclear power plant during the lifecycle. It is required to eliminate, reduce or control, so far as is reasonably practicable, the conventional health and safety risks to workers and the public that may arise during the construction, commissioning, operation, maintenance, and decommissioning of the nuclear power plant.

The UK HPR 1000 is being designed with conventional health and safety in mind. The conventional safety team developed checklist of typical health and safety issues and workplace regulations checklists.

More details see PCSR Sub-chapter 25.3.2.

b) Radiological protection

For radiological protection, the high dose activities during normal operation are identified as follows:

1) Select international OPEX;

2) Prioritise them based on estimated worker dose from OPEX;

3) Identify the high priority tasks.

The following two aspects will be considered while identifying the high dose activities:

1) The single activity with high individual dose;

2) The most exposed group activities that contribute significantly to collective dose.

Dose assessment for workers during normal operation can be found in PCSR Sub-chapter 22.9.

Accidents considered in post-accident accessibility analysis are representative DBC and severe accident for which direct interventions of workers are needed to mitigate the accident and to bring the plant to a safe condition. The dose received by the intervention workers during operation tasks is assessed for the associated DBC and severe accident sequences.

The dose assessments for the workers who participate in the mitigation of accidents are covered in PCSR Sub-chapter 22.11.

15.8 Design Support Activities

This Sub-chapter supports HF Sub-claim 3.3.8.SC15.4.

15.8.1 Development HFE Guidelines

Two HFE guideline documents have been developed for FCG3 to guide the workspaces, HMIs, layout and environments design in CRS. HFE requirements are taken into account for SSCs design in local area (outside of the CRS), by using relevant codes and standards, working procedures and engineering practices.

For the UK HPR1000, HFE guideline documents have been developed based on CGN existing project experience and international codes and standards. This is to help ensure SSCs design is consistent with the human cognitive and psychological characteristics, which covers aspects such as visibility or readability of information, operability and maintainability of components, comfort and safety of personnel, etc.

There are three guideline documents for UK HPR1000 project, two for workspaces, HMIs, layout and environments design in CRS and the third one for SSCs design in local area. They are:

a) HFE Guidelines for Control Room Design (GHX06001021DIKX03GN, Rev. D)

b) HFE Guidelines for HMI Design (GHX06001039DIKX03GN, Rev. C)

c) HFE Guidelines for Local Area Design (GHX00100001DIGL03GN, Rev. C)

HFE Guidelines for Control Room Design, Reference [19], is applicable to the design of the MCR and the related rooms (shift handover room and computer room), RSS and TSC. This document is used to guide the following objects design:

a) OWP: nuclear island OWP, conventional island OWP, unit supervisor OWP, safety engineer OWP;

b) Emergency Control Panel (ECP);

c) ACP: nuclear island ACP, conventional island ACP, unit supervisor ACP;

d) MCR hard control panel;

e) LDP;

f) DHP;

g) SHP;

h) Layout and environment of MCR and RSS.

HFE Guidelines for HMI Design, Reference [20], is applicable to the design of HMI resources in the MCR, RSS, TSC, and ECC. This document is used to guide the following objects design:

a) Control panel layout, including ACP, DHP, SHP, ECP;

b) Computerized displays, including VDU displays, LDP displays, ACP-VDU displays, ACP safety control and information device displays, DHP displays, and SHP displays;

c) Alarms;

d) Computer-based procedures.

HFE Guidelines for Local Areas Design, Reference [21], provides HF requirements and good practice that will assist designers when considering the selection, location and layout of controls and displays device outside the MCR. It is intended that this guidance is applied to both the operation of these devices and it's EMIT. This document is used to guide the following objects design:

a) Local components;

b) Local control panels;

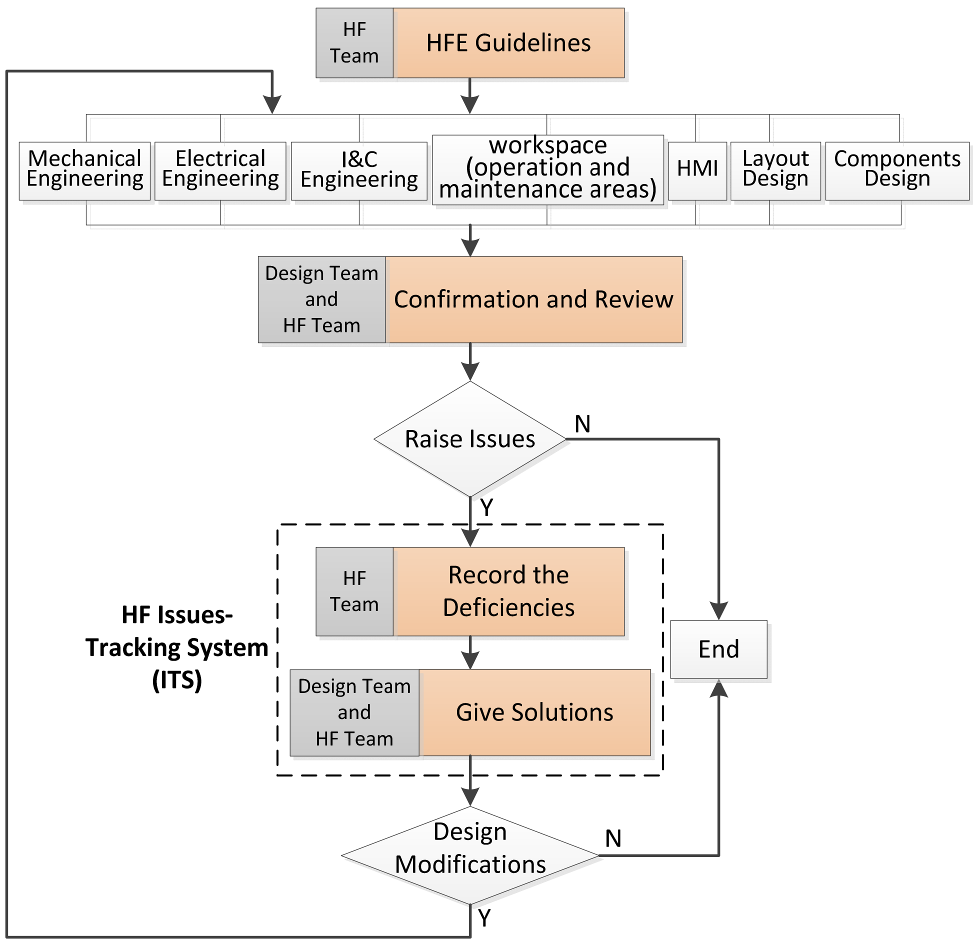
c) Local control station;

d) Local environment: thermal, noise, light, and vibration;

e) Local communications.

As the basis for the HF review, HFE guidelines will be updated considering missing requirements and end user data.

The HFE guideline documents are developed by the HF team; they are used as the top level documents, and provide a key reference and evaluation principles for both the design and HFE teams. The process of integrating HF into design is described in F-15.8-1. As shown in the upper section of the figure F-15.8-1, the HF team delivers HFE guidelines to the necessary design disciplines. Each design discipline produces its design, and then coordinates with the HF team to evaluate and review the design documents, and form the HF review report. At the same time, identify any discrepancies in accordance with HFE requirements described in the HFE guideline documents and HF specifications. Solutions to any discrepancies identified will be developed and the HF team records deviation items into the ITS.



F-15.8-1 Process of Integrating HF into Design

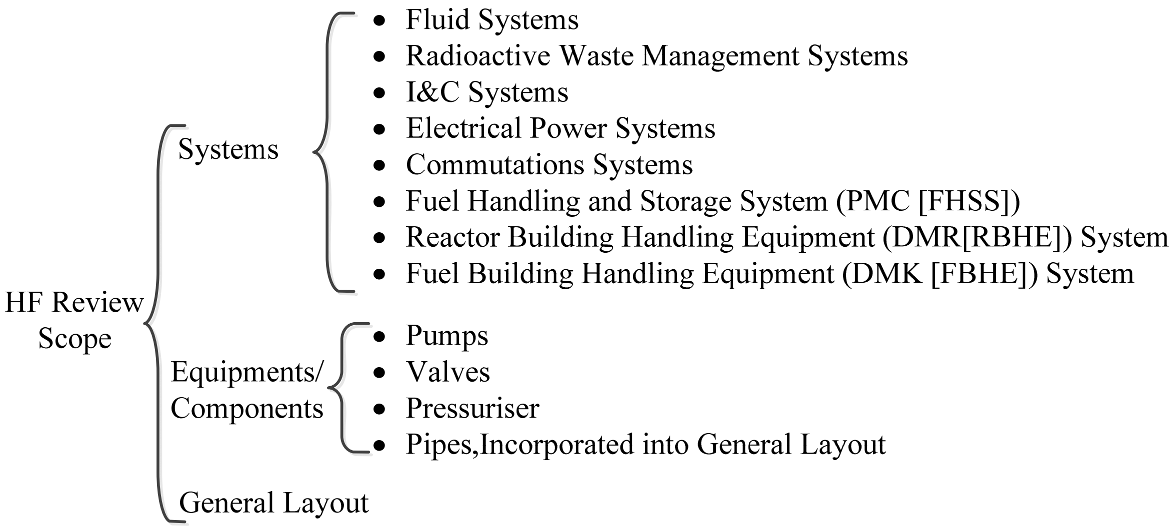
15.8.2 HF Evaluation

During step3 of UK HPR1000 GDA, HF review has been carried out mainly using an ergonomics checklist method, covering high risk and complex SSCs, and three HF review reports have been issued. They are:

a) *MCR Workspaces Design HF Review Report*, Reference [22], summarised the assessment result on workspace design process, environment design, layout design and structural design of main equipment in MCR of HPR1000 (FCG3).

b) *MCR HMI Design HF Review Report*, Reference [23], summarised the assessment result on control panel layout, computerized displays, alarms, computer-based procedures in MCR of HPR1000 (FCG3).

c) *Local Area HMIs and Workspaces Design HF Review Report*, Reference [24], mainly covers assessment results on: systems, equipment and general layouts based on project System Design Manuals (SDMs), technical specifications, equipment specifications and 3D model of UK HPR1000 DR 2.0, shown in F-15.8-2.



F-15.8-2 Local HF Review Scope

As the result, several discrepancies have been found through the plant HF review. The detailed discrepancies have been recorded in above HF review reports.

Based on the design reference project, further reviews of workspaces and HMIs for high risk and complexity SSCs will be carried out during Step 4.

HF verification activities are to demonstrate that the UK HPR1000 design attains a high standard of HF adequacy and that it conforms to the HF principles as specified in the HFIP and requirements of the HFE guidelines. HF verification mainly focuses on the HMIs and workspaces related to significant HBSCs during the GDA phase.

HF verification is conducted as part of the overall verification programme providing evidence and substantiation of the HBSCs. As part of the GDA HF activities, it has been determined that safety-important human actions need to be examined to a more detailed level than that provided in desktop studies.

To support HF verification activities, data is collected using the FCG3 full scope simulator run by experienced operators. A wide variety of techniques of data collection will be used including: overview video cameras, sound recordings, status parameter recording, HF specialist observation, and briefing and debriefing interviews. For local tasks, site interviews or physical site walkthroughs are used to carry out the HF verification testing.

HF verification relative to risk significant HBSCs will be carried out at Step 4 and the verification report as the evidence and substantiation of the HBSCs and the SSCs design will be delivered at Step 4.

Complete HF verification and HF validation, performed on a fully-integrated system representation with users, procedures and finalised design, will be conducted during the site licensing phase.

The detailed methodology for the HF verification is described within *HFE Verification and Validation Methodology*, Reference [36].

The HF issues identified through HF verification and the HF recommendations given to improve associated designs are recorded in the ITS along with their respective resolutions.

15.8.3 Human Factors Consideration in Decommissioning

Decommissioning is considered throughout the processes of siting, design, construction, operation, although it is the last stage in the lifecycle of nuclear facilities. HF consideration is an indispensable issue in decommissioning, which involves serial radioactive and non-radioactive activities. HF consideration in decommissioning may focus on the following aspects:

a) Facilitate the implement of decommissioning activities

b) Minimise human errors in decommissioning

c) Protect human against potential harms

More details see PCSR Sub-chapter 24.6.7.

15.9 ALARP Assessment

The aim of ALARP assessment of HF area is to ensure that the nuclear safety risks associated with human error are ALARP. Meanwhile, HF provides the assessment of human actions impacting safety which supports the overall ALARP demonstration addressed in Chapter 33. The ALARP assessment of HF area is undertaken in line with the *ALARP Methodology*, Reference [37] and *ALARP Demonstration Instruction*, Reference [38].

The ALARP approach includes consideration of four areas that are common to the demonstration of ALARP in the UK, Reference [39]:

a) Comparison with RGP and OPEX;

b) Risk assessment, as a way of understanding the significance of the issue to the overall demonstration of ALARP;

c) Identification and evaluation of options;

d) Implementation of all reasonably practicable improvements.

15.9.1 Comparison with RGP and OPEX

Comparison with RGP is the starting point of the ALARP analysis. In addition, relevant OPEX is also analysed to identify potential improvements.

The suitability analysis of codes and standards applied in HF area has been completed and provide a list of applicable codes and standards. Furthermore, the preliminary compliance analysis of the applicable codes and standards has been completed. 4 gaps which are not compliant with RGP have been identified. See Sub-chapter 15.3.

OPEX from the Chinese, international NPP fleets, and a world-wide review using information from WANO has been considered. The OPEX summary report has been developed and the OPEX related to existing NPPs procedures and staffing has been reviewed. See Sub-chapter 15.3. Most of the items identified from OPEX have been fed back or implemented; 3 potential improvements have been identified in the UK HPR1000, shown in T-15.9-1.

T-15.9-1 Potential Improvements from OPEX

No.	Title
1	Available operating time for SGTR
2	Manual action needed in spurious Pressuriser Heater Operation transient
3	Human actions required to mitigate the internal flooding

15.9.2 Risk Assessment

The HF risk assessment provides the potential improvements to lower the risk associated with human error to the SSC Chapters. The HF risk assessment mainly includes assessment of HBSCs, HF review and evaluation of SSC/HMI design. Some HBSCs for Type A, Type B and Type C have been assessed in GDA Step 3, see Sub-chapter 15.7.2 for detail. There are 8 potential improvements of priority 1 and 2 from the above HBSC analysis in total. 6 potential improvements have been identified from HF review of local area design.

15.9.3 Evaluation of Options

Optioneering is the process of generation and evaluation of options which can potentially deliver a required specific potential improvement. A formal option assessment process is used for the evolution of numerous UK HPR1000 design aspects (refer to Chapter 33). The optioneering is undertaken according to *Requirements on Optioneering & Decision-Making*, Reference [40].

Optioneering for the gaps and potential improvements identified by comparison with RGP and OPEX (Sub-chapter 15.9.1) and risk assessment from HF insight or to HF area (Sub-chapter 15.9.2) is in process.

During optioneering of gaps/potential improvements, HF should be considered. HF team members participate in the design improvement process in the options assessment process when necessary to ensure the HF requirements are properly considered, in different HMIs and SSCs design options. For example, HF team provides the HF overall requirements for the spent fuel interim storage modification.

15.9.4 ALARP Demonstration

The comparison with RGP/OPEX, and HF risk analysis have been completed in GDA step 3, and several insights from HF risk analysis have been given to SSC design disciplines, and 3 insights are received from PSA. For each gap and potential improvements, further analysis and justifications or modifications should be given. The optioneering is in process. The ALARP Demonstration will be detailed in *ALARP Demonstration Report of PCSR Chapter 15*, Reference [41].

For more HBSCs will be assessed in GDA Step 4, and HF risk assessment is still on-going, and the ALARP assessment of HF will be moved forward and the *ALARP Demonstration Report of PCSR Chapter 15* will be updated.

15.10 Concluding Remarks

For FCG3, the HF principles and requirements have been integrated into CRS design and considered in SSCs design on a case-by-case basis. The HF integration within FCG3 is presented in Sub-chapters 15.4～15.8, which forms the starting point for the UK HPR1000 HF area. This baseline HF position has been assessed in the UK context and against modern practice requirements (see *Baseline Human Factors Assessment Report*, Reference [42]). Gaps have been identified and are to be resolved through the GDA HFI programme, as outlined in the HFIP, Reference [2].

CGN is currently implementing HFI activities, which is described in the HFIP document. The processes are functioning correctly in delivering informed human factors expertise to the design and safety case development.

Step 3 activities have been carried out that support both the design and safety case appropriate to their current state of maturity:

a) RGP relevant to HF has been identified and analysed;

b) OPEX relevant to HF has been identified and reviewed;

c) The methodologies for AoF have been developed and will be used to review the results of function allocation;

d) The method report of HBSCs identification and assessment has been updated;

e) The HBSCs linked to safety functions of the plant have been identified;

f) Several HBSCs assessment results are presented and further work of the remaining HBSCs will be undertaken during Step 4;

g) HFE guideline documents have been developed to support other disciplines and the preliminary HF review to substantiation of workspaces and HMI design have been carried out and reported and will be continued in Step 4.

The HF activities will be continued throughout the GDA phase. At this stage, given the identification of HF claims, the arguments, evidence presented and the forward programme of HF integration, particularly to further identify and substantiate the HBSCs, the conclusion of this chapter is that there has been and will continue to be adequate and timely HF contribution to the UK HPR1000 design to help ensure that the nuclear safety risks associated with HBSCs are ALARP.

It should be noted that design changes made during Step 3 have not been totally reflected in the present version of HF safety assessment reports due to the design development progress of UK HPR1000. The relevant safety assessment reports will be updated based on the latest version of UK HPR1000 design reference.

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