Revision	Approved by	Number of Pages
001		52
Approval Date	06/02-20	

General Nuclear System

General Nuclear System Ltd.

UK HPR1000 GDA Project

Document Reference:	HPR/GDA/PCSR/0028

Title:

Pre-Construction Safety Report

Chapter 28

Fuel Route and Storage

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TABLE OF CONTENTS

28.1 List of Abbreviations and Acronyms....3

28.2 Introduction....4

28.2.1 Scope....4

28.2.2 Chapter Route Map....8

28.2.3 Chapter Structure....8

28.2.4 Interfaces with Other Chapters....9

28.3 Applicable Codes and Standards....11

28.4 Overview of the PMC [FHSS]....14

28.4.1 Role of the PMC [FHSS]....14

28.4.2 General Layout of the PMC [FHSS]....14

28.4.3 Processes of the PMC [FHSS]....15

28.4.4 Interfaces with Other SSCs....20

28.4.5 Main Equipment of the PMC [FHSS]....20

28.5 Safety Case Strategy....21

28.5.1 Safety Functions....21

28.5.2 Safety Case Structure....22

28.6 Safety Assessment of the PMC [FHSS]....24

28.6.1 Fault Analysis....24

28.6.2 Safety Assessment of Sub-processes....25

28.6.3 Safety Assessment of Main Equipment....26

28.6.4 ALARP Assessment....37

28.6.5 Human Factors....39

28.6.6 Protection against External and Internal Hazards....40

28.6.7 Commissioning....40

28.6.8 Examination, Maintenance, Inspection and Testing (EMIT)....40

28.6.9 Conventional Health and Safety 41

28.7 Concluding Remarks 41

28.8 References 41

Appendix 28A Route Map for the PMC [FHSS] 43

Appendix 28B General Layout and Process of the PMC [FHSS] 45

28B.1 General Layout of the PMC [FHSS] 45

28B.2 Process of the PMC [FHSS] 47

Appendix 28C Classification of the Main PMC [FHSS] Equipment 50

28.1 List of Abbreviations and Acronyms

ALARP	As Low As Reasonably Practicable
BFX	Fuel Building
BRX	Reactor Building
CAE	Claims, Arguments, Evidence
CGN	China General Nuclear Power Corporation
DMK	Fuel Building Handling Equipment [FBHE]
DMR	Reactor Building Handling Equipment [RBHE]
EMIT	Examination, Maintenance, Inspection, Test
EOMM	Equipment Operation and Maintenance Manual
EVR	Containment Cooling and Ventilation System [CCVS]
FA	Fuel Assembly
FCG3	Fangchenggang Nuclear Power Plant Unit 3
GDA	Generic Design Assessment
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
IFA	Irradiated Fuel Assembly
MSQA	Management of Safety and Quality Assurance
NFA	New Fuel Assembly
OPEX	Operating Experience
PCSR	Pre-Construction Safety Report
PIE	Postulated Initiating Event
PMC	Fuel Handling and Storage System [FHSS]
PSA	Probabilistic Safety Assessment
PSR	Preliminary Safety Report
PTR	Fuel Pool Cooling and Treatment System [FPCTS]
RPV	Reactor Pressure Vessel
PWR	Pressurised Water Reactor

RCCA	Rod Cluster Control Assembly
RGP	Relevant Good Practice
SFA	Spent Fuel Assembly
SFIS	Spent Fuel Interim Storage
SFP	Spent Fuel Pool
SFPC	Spent Fuel Pool Crane
SSC	Structures, Systems and Components

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. Fuel Handling and Storage System (PMC [FHSS]).

28.2 Introduction

The purpose of this chapter is to give a general introduction to the design of the PMC [FHSS] for the UK HPR1000, and to demonstrate that the risk associated with the PMC [FHSS] is As Low As Reasonably Practicable (ALARP) throughout the PMC [FHSS] related operations.

The present safety case of PMC [FHSS] is produced based on the design reference version 2.1, as described in *UK HPR1000 Design Reference Report*, Reference [1]. The safety assessment results are documented in this chapter and corresponding safety assessment reports.

28.2.1 Scope

The fuel route process encompasses the entire lifecycle of nuclear fuel within the nuclear plant site boundary. It includes all fuel related activities beginning with the receipt of a New Fuel Assembly (NFA) on site and ending with spent fuel storage in the Spent Fuel Interim Storage (SFIS) facility.

The fuel route process for the UK HPR1000 can be divided into six operations, which are:

a) NFA receipt and storage operations (described in this chapter) - including NFA receipt, inspection and storage in air or underwater within the Fuel Building (BFX).

b) Core loading operations (described in this chapter) - including reactor core loading preparation and fuel loading operations.

c) Reactor power operations (described in Pre-Construction Safety Report (PCSR) Chapter 5) - including fuel located in the reactor core during reactor operation.

d) Core unloading and Spent Fuel Assembly (SFA) storage operations (described in this chapter) - including reactor core unloading preparation, fuel unloading from the reactor core to Spent Fuel Pool (SFP) operations and SFA storage operations within the SFP before delivery.

e) SFA delivery operations (described in this chapter and PCSR Chapter 29) - including spent fuel transfer cask lifting, SFA loading preparation, fuel loading into cask and SFA delivery preparation operations within the BFX.

f) SFIS operations (described in PCSR Chapter 29) - including transfer of spent fuel casks from the BFX to the interim storage facility, receipt and storage operations within the interim storage facility for casks containing SFAs. This operation starts when the SFAs leave the BFX boundary.

These operations are mainly supported by the following related systems:

a) The PMC [FHSS], which performs NFA receipt and storage operations, core loading operations, core unloading and SFA storage operations, and SFA delivery in the BFX operations. The PMC [FHSS] comprises all equipment used for fuel handling and storage within the Reactor Building (BRX) and BFX. A more detailed description of the PMC [FHSS] is given in this chapter.

b) Reactor Building Handling Equipment (DMR [RBHE]), which consists of all the handling equipment in the BRX (except the equipment which has been included in the PMC [FHSS]). The most important DMR [RBHE] equipment related to the fuel route is the polar crane. A more detailed description of the DMR [RBHE] is given in PCSR Chapter 10.

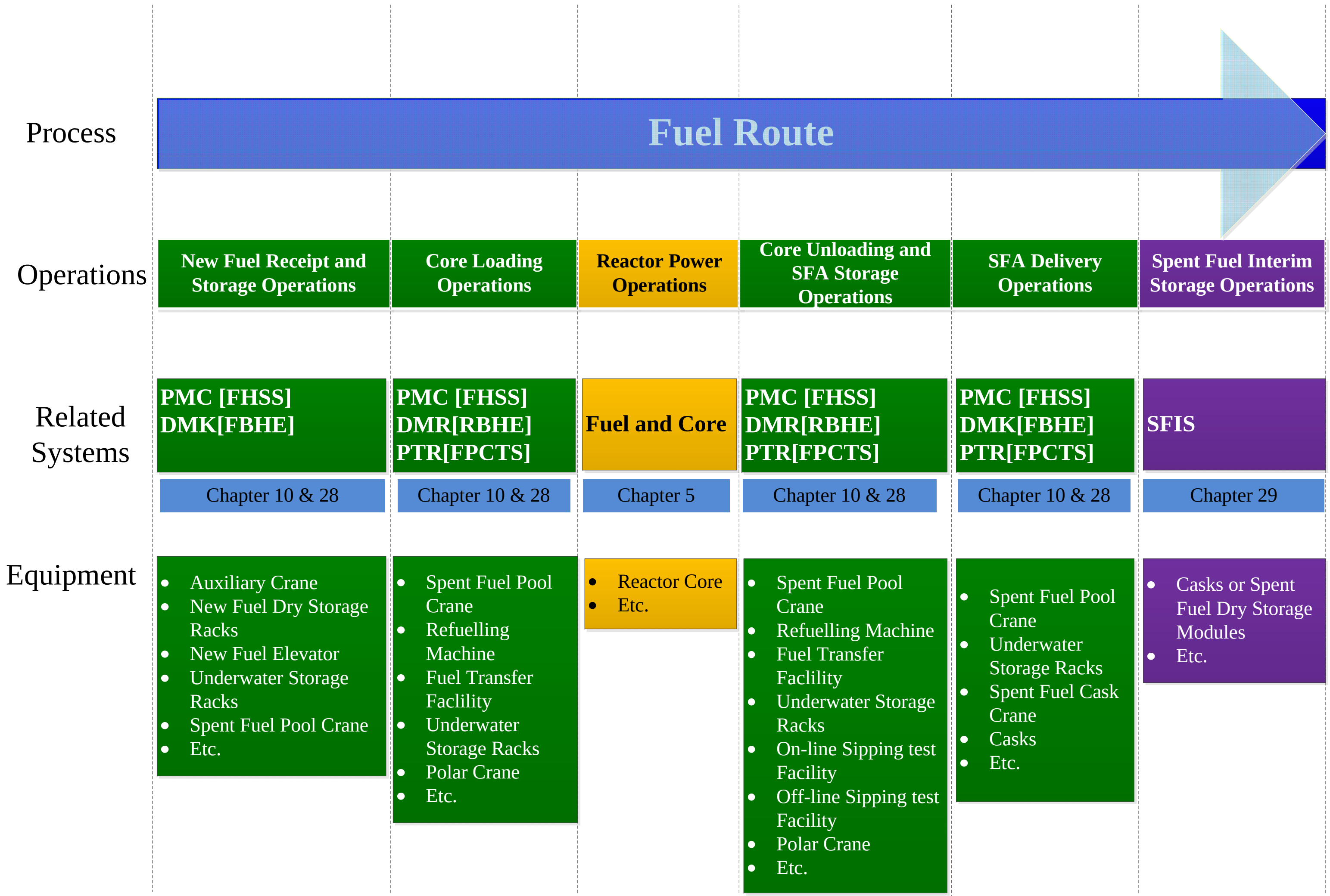
c) Fuel Building Handling Equipment (DMK [FBHE]), which consists of all the handling equipment in the BFX (except the equipment which has been included in the PMC [FHSS]). The most important DMK [FBHE] equipment related to the fuel route is the spent fuel cask crane. A more detailed description of the DMK [FBHE] is given in PCSR Chapter 10.

d) Fuel Pool Cooling and Treatment System (PTR [FPCTS]), which is used to provide cooling and water make-up for the SFP. It also provides water purification, water transferring and skimming for the BRX pools (including the reactor cavity and internal storage compartment) and BFX pools (including the SFP, fuel transfer compartment and cask loading pit). This system also provides shielding, cooling and criticality control for fuel handling and storage. A more detailed description of the PTR [FPCTS] is given in PCSR Chapter 10.

e) The SFIS facility, which includes structures, systems and components (SSCs) specific to SFIS, including spent fuel transfer casks, spent fuel dry storage modules, etc. A more detailed description of the SFIS facility is given in PCSR Chapter 29.

To summarise, this chapter only focuses on the description and demonstration of the

PMC [FHSS], not the whole fuel route. For the remaining fuel route sections, refer to the PCSR chapters highlighted in Table F-28.2-1 below, e.g. Chapters 5, 10, 29, etc.



F-28.2-1 General Structure of the Fuel Route

28.2.2 Chapter Route Map

The ***Fundamental Objective*** of the 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 ***Fundamental Objective,*** five high level claims (Level 1 claims) and a number of Level 2 claims are developed and presented in Chapter 1. This chapter supports the ***Claim 3.3*** derived from the high level ***Claim 3***.

Claim 3*: Nuclear safety*

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 ALARP.

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

To support Claim 3.3, PCSR Chapter 28 develops a chapter claim, that is:

Claim 3.3.12*: The Fuel Handling and Storage process, and design of the associated systems, have been substantiated.*

Finally, the chapter claim can be split into five sub-claims as follows:

a) ***Sub-Claim 3.3.12.SC28.1:*** *The safety functional requirements have been derived for the system.*

b) ***Sub-Claim 3.3.12.SC28.2****: The design intent of the system can be met by the design of process and relevant SSCs.*

c) ***Sub-Claim 3.3.12.SC28.3****: All reasonably practicable measures have been adopted to improve the design of the system.*

d) ***Sub-Claim 3.3.12.SC28.4****: The system performance will be validated by commissioning and testing.*

e) ***Sub-Claim 3.3.12.SC28.5****: The effects of ageing of the system have been addressed in the design.*

The above sub-claims are developed further in sub-chapter 28.5.

28.2.3 Chapter Structure

The structure of PCSR Chapter 28 is as follows:

a) Sub-chapter 28.1 List of Abbreviations and Acronyms:

This section lists the abbreviations and acronyms that are used in PCSR Chapter 28.

b) Sub-chapter 28.2 Introduction:

This section introduces the chapter scope, route map, structure and interfaces with other PCSR chapters.

c) Sub-chapter 28.3 Applicable Codes and Standards:

This section identifies the applied codes and standards for the PMC [FHSS].

d) Sub-chapter 28.4 Overview of the PMC [FHSS]:

This section describes the operation function, general layout, process, interfaces and main equipment for the PMC [FHSS].

e) Sub-chapter 28.5 Safety Case Strategy for the PMC [FHSS]:

This section introduces the safety case strategy for the PMC [FHSS].

f) Sub-chapter 28.6 Safety Assessment for the PMC [FHSS]:

This section introduces the safety assessment for the PMC [FHSS].

g) Sub-chapter 28.7 Concluding Remarks:

This section summarises the concluding remarks of this chapter.

h) Sub-chapter 28.8 References:

This section lists the supporting references for this chapter.

i) Appendix 28.A Route Map for the PMC [FHSS]:

This section describes the route map for the PMC [FHSS].

j) Appendix 28.B General Layout and Process of the PMC [FHSS]

This section describes the general layout and process of the PMC [FHSS].

k) Appendix 28.C Classification of the Main PMC [FHSS] Equipment:

This section describes the classification of the main PMC [FHSS] equipment.

28.2.4 Interfaces with Other Chapters

The interfaces between this chapter and other chapters are listed in T-28.2-1.

T-28.2-1 Interfaces between Chapter 28 and Other Chapters

PCSR Chapters	Interface
Chapter 1 Introduction	Chapter 1 provides the Fundamental Objective, Level 1 Claims and Level 2 Claims. Chapter 28 provides chapter claims, arguments and evidence to support relevant claims that are addressed in Chapter 1.
Chapter 4 General Safety and Design Principles	Chapter 4 provides the selection principles of codes and standards and general engineering substantiation principles relevant to the PMC [FHSS] substantiation in Chapter 28.
Chapter 5 Reactor Core	Chapter 5 covers the design of Fuel Assembly (FA), which is a key input to the design of the PMC [FHSS] SSCs.
Chapter 10 Auxiliary System	Chapter 10 covers the design of several supporting systems to the PMC [FHSS], such as DMK, DMR, PTR, etc.
Chapter 12 Design Basis Condition Analysis	Chapter 12 covers the potential design basis accidents during the PMC [FHSS] related operations and relevant safety assessment.
Chapter 13 Design Extension Conditions and Severe Accident Analysis	Chapter 13 covers design extension conditions relating to the PMC [FHSS].
Chapter 14 Probabilistic Safety Assessment	Chapter 14 provides the main results of the Probabilistic Safety Assessment (PSA) and risk insights for the PMC [FHSS]. Chapter 28 provides the layout and process of the PMC [FHSS], which is a design input for the SFP PSA.
Chapter 15 Human Factors	Chapter 15 provides the principles and methodology of human factor integration that are considered in the design of the PMC [FHSS].
Chapter 16 Civil Work and Structures	Chapter 16 provides the substantiation for the PMC [FHSS] related civil structures. Chapter 28 presents the design of the PMC [FHSS] which is housed in the BRX and BFX described in Chapter16.
Chapter 18 External Hazards	Chapter 18 provides the relevant external hazards that have to be considered in the design of the PMC [FHSS].
Chapter 19 Internal Hazards	Chapter 19 provides the principles that underpin the internal hazard assessment of the PMC [FHSS].
Chapter 21 Reactor	Chapter 21 covers the water quality control of coolant in

PCSR Chapters	Interface
Chemistry	reactor pool and spent fuel pool, which provides support to fuel cooling and control of criticality during the PMC [FHSS] related operations described in Chapter 28.
Chapter 22 Radiological Protection	Chapter 22 provides radiological protection design considerations relevant to the fuel handing, worker dose assessment during normal operations and radiation monitoring. Chapter 28 presents the PMC [FHSS] design proposal for dose assessment.
Chapter 23 Radioactive Waste Management	Chapter 23 provides the demonstration of safe management of potential radioactive waste generated during the PMC [FHSS] related operations.
Chapter 24 Decommissioning	Chapter 24 provides the decommissioning strategy and preliminary decommissioning plan for the PMC [FHSS] SSCs.
Chapter 25 Conventional Safety and Fire Safety	Chapter 25 provides the conventional health and safety risk management techniques and the general prevention principles in the PMC [FHSS] related operations.
Chapter 29 Interim Storage of Spent Fuel	Chapter 29 provides the interim storage of SFA which is part of the overall fuel route described in Chapter 28.
Chapter 30 Commissioning	Chapter 30 provides the arrangements and requirements for commissioning, which shall be considered for the PMC [FHSS] SSCs.
Chapter 31 Operational Management	Chapter 31 provides the principles, content, and methodology of operating limits and conditions, EMIT, ageing and degradation programmes.
Chapter 33 ALARP Evaluation	The ALARP approach presented in Chapter 33 has been applied in Chapter 28 to perform the ALARP demonstration for fuel handling and storage, which supports the overall ALARP demonstration addressed in Chapter 33.

28.3 Applicable Codes and Standards

For the UK HPR1000, the applicable codes and standards for PMC [FHSS] are selected and determined according to the existing Fangchenggang Nuclear Power Plant Unit 3 (FCG3) practices, *General Principles for Application of Laws, Regulations, Codes and Standards,* Reference [2] and the principles presented in PCSR Chapter 4. The purpose is to ensure that the applied codes and standards comply with UK current requirements of applicable acts, regulations and other statutory instruments. International Relevant Good Practice (RGP) is also taken into account.

For the design of the PMC [FHSS] in FCG3, Chinese codes and standards are applied as a priority, and international codes and standards are applied as supplement. For the UK HPR1000, international codes and standards such as the International Atomic Energy Agency (IAEA) guidance are considered as the source of RGP, as well as British and American standards. Since some applied Chinese guidance is developed from IAEA guidance, the IAEA guidance is applied as a priority for the design of the PMC [FHSS] in the UK HPR1000. Some British and American standards are referenced additionally as a supplement, especially for the design of the lifting equipment. The Suitability Analysis of codes and standards relevant to the PMC [FHSS] is contained in *Suitability Analysis of Codes and Standards in Mechanical Engineering*, Reference [3].

The main applicable regulations, codes and standards for the PMC [FHSS] in the UK HPR1000 are as follows:

a) Supply of Machinery (Safety) Regulations, 2008 edition;

b) The Lifting Operations and Lifting Equipment Regulations (LOLER), 1998 edition;

c) The Provision and Use of Work Equipment Regulations (PUWER), 1998 edition;

d) Management of Health and Safety at Work Regulations, 1999 edition;

e) The Construction (Design and Management) Regulations, 2007 edition;

f) The Electromagnetic Compatibility Regulations, 2006 edition;

g) The Low Voltage Electrical Equipment (Safety) Regulations, 1989 edition;

h) The Work at Height Regulations, 2005 edition;

i) 2006/42/EC, Machinery Directive;

j) No. NS-G-1.4, Design of Fuel Handling and Storage Systems in Nuclear Power Plants, 2003 edition;

k) No. NS-G-2.5, Core Management and Fuel Handling for Nuclear Power Plants, 2002 edition;

l) No. SSG-15, Storage of Spent Nuclear Fuel, 2012 edition;

m) No. SSG-27, Criticality Safety in the Handling of Fissile Material, 2014 edition.

n) RCC-M, Design and Construction Rules for Mechanical components of PWR Nuclear Islands, 2007 edition;

o) BS EN 13001, Cranes - General design Part 1: General principles and requirements, 2015 edition;

p) BS EN 15011, Cranes - Bridge and gantry cranes, 2014 edition;

q) ANS 57.1, Design Requirements for Light Water Reactor Fuel Handling Systems, 1992 edition;

r) ANSI/ANS 57.2, Design Requirements for Light Water Reactor Spent Fuel Storage Facilities at Nuclear Power Plants, 1983 edition;

s) ANSI/ANS 57.3, Design Requirements for New Fuel Storage Facilities at Light Water Reactor Plants, 1983 edition;

t) ASME NOG-1, Rules for Construction of Overhead and Gantry Cranes, 2015 edition.

The specific application of the main standards for the PMC [FHSS] is listed in T-28.3-1.

T-28.3-1 Application of the Main Standards in the PMC [FHSS]

Standards No.	**Application for the PMC [FHSS]**
RCC-M 2007 edition	Design, manufacture, and inspection of fuel transfer tube and fuel storage rack
BS EN13001-1 2015 edition	Design, manufacture, and inspection of cranes, such as refuelling machine, Spent Fuel Pool Crane (SFPC) and auxiliary crane
BS EN15011 2014 edition	Design, manufacture, and inspection of cranes, such as refuelling machine, SFPC and auxiliary crane
ANS 57.1 1992 edition	Design of the PMC [FHSS] system and components
ANSI/ANS 57.2 1983 edition	Design of underwater fuel storage rack and associated components
ANSI/ANS 57.3 1983 edition	Design of new fuel storage rack and associated components
ASME NOG-1 2015 edition	Seismic analysis of cranes, such as refuelling machine, SFPC and auxiliary crane

The compliance analysis of PMC [FHSS] for the UK HPR1000 with applicable codes and standards is presented in *Compliance Analysis of RGPs in Mechanical Engineering*, Reference [4].

28.4 Overview of the PMC [FHSS]

28.4.1 Role of the PMC [FHSS]

The major operating functions of the PMC [FHSS] are described hereafter:

a) Receipt, inspection and storage of NFAs;

b) Core loading and unloading;

c) Inspection and storage of Irradiated Fuel Assemblies (IFAs);

d) Storage of failed FAs and Rod Cluster Control Assemblies (RCCAs);

e) Rearrangement of relevant components, namely RCCAs, thimble plug assemblies and neutron source assemblies;

f) Loading SFAs into spent fuel transfer casks for delivery;

g) Lighting for underwater fuel handling;

h) Handling control rod drive shafts, the irradiation surveillance capsule and the specimen access plug with the help of unique tools.

The description of PMC [FHSS] is included in the system design manual, which consists of a series of basic references to present the design of the PMC [FHSS] SSCs. Detail of the scope and content of the system design manual can be found in *Fuel Handling and Storage System Design Manual* Chapter *1 System Design Manual Content and State*, Reference [5].

For a brief introduction to the PMC [FHSS], refer to *Fuel Handling and Storage System Design Manual Chapter 2 Brief Introduction to the System*, Reference [6]. This document includes the scope, responsibility, and some other basic information of the PMC [FHSS].

28.4.2 General Layout of the PMC [FHSS]

The PMC [FHSS] is located in the BRX and BFX.

The equipment inside the BRX includes: the refuelling machine, the fuel transfer facility (BRX part), the fuel transfer tube (BRX part), the blind flange, the on-line sipping test facility, the temporary storage rack, the spent fuel assembly emergency handling tool holder, the BRX refuelling platform and underwater lighting.

The equipment inside the BFX includes: the fuel transfer facility (BFX part), the fuel transfer tube (BFX part), the gate valve, the SFPC, the auxiliary crane, the new fuel elevator, the new fuel dry storage rack, the underwater fuel storage racks, the failed FA storage cells, the failed RCCA storage cells, the off-line sipping test facility, handling tools for FAs and relevant components and their respective holders, and underwater lighting.

More detailed descriptions for the PMC [FHSS] equipment are presented in *Fuel Handling and Storage System Design Manual Chapter 4 System and Component Design*, Reference [7].

Structures associated with the PMC [FHSS] include: the reactor cavity, the core internal pool, the fuel transfer compartment, the SFP, loading pit, the cleaning pit, the fuel hoisting pit, the PMC transport room, the new fuel receipt room and the new fuel storage room.

More detailed descriptions of the structures associated with the PMC [FHSS] are presented in *Fuel Handling and Storage System Design Manual Chapter 5 Layout Requirements and Environment Condition,* Reference [8].

The general layout drawings of the PMC [FHSS] are shown in Appendices 28B F-28B-1 and F-28B-2.

28.4.3 Processes of the PMC [FHSS]

The following key sub-processes of the PMC [FHSS] will be described in more detail:

a) NFA receipt, inspection and storage;

b) Core loading/unloading;

c) SFA delivery in the BFX.

Diagrams of these sub-processes are shown in *Fuel Handling and Storage System Design Manual Chapter 9 Flow Diagrams,* Reference [9].

28.4.3.1 NFA Receipt, Inspection and Storage

a) Receipt of new fuel transport container

The NFAs are transported to the BFX in a new fuel transport container by a transportation truck.

The new fuel transport container is transferred into the new fuel receipt room using the auxiliary crane.

b) NFA inspection

The NFAs are taken out of the transport container for inspection using the auxiliary crane and new fuel handling tool.

c) NFA storage

The NFAs prepared for the next refuelling cycle are initially stored in the SFP. Firstly, they are transferred into a fuel basket on the new fuel elevator using the auxiliary crane. The basket is then lowered to the bottom of the SFP, and the NFAs can be retrieved and placed into the underwater fuel storage racks using the SFPC.

Spare NFAs are transferred to the new fuel dry storage rack using the auxiliary crane.

The process diagram for new fuel receipt and storage is shown in Appendix 28B F-28B-3.

More detail on the sub-process covering receipt, inspection and storage of NFAs is presented in *Fuel Handling and Storage System Design Manual Chapter 6 System Operations and Maintenance*, Reference [10]

28.4.3.2 Core Loading/Unloading

a) First core loading

NFAs, along with the necessary relevant components for the first core loading, are stored in the underwater fuel storage racks. Once preparation work is finished, the first core loading operation can be carried out. The main operating steps are as follows:

1) The NFAs are transferred vertically, one at a time, from the SFP into a fuel carrier located in the fuel transfer facility using the SFPC;
2) The fuel carrier is rotated to the horizontal position and moved from the BFX side to the BRX side;
3) The fuel carrier is rotated back to the vertical position;
4) The NFAs are transferred from the fuel carrier of the fuel transfer facility into the core using the refuelling machine.

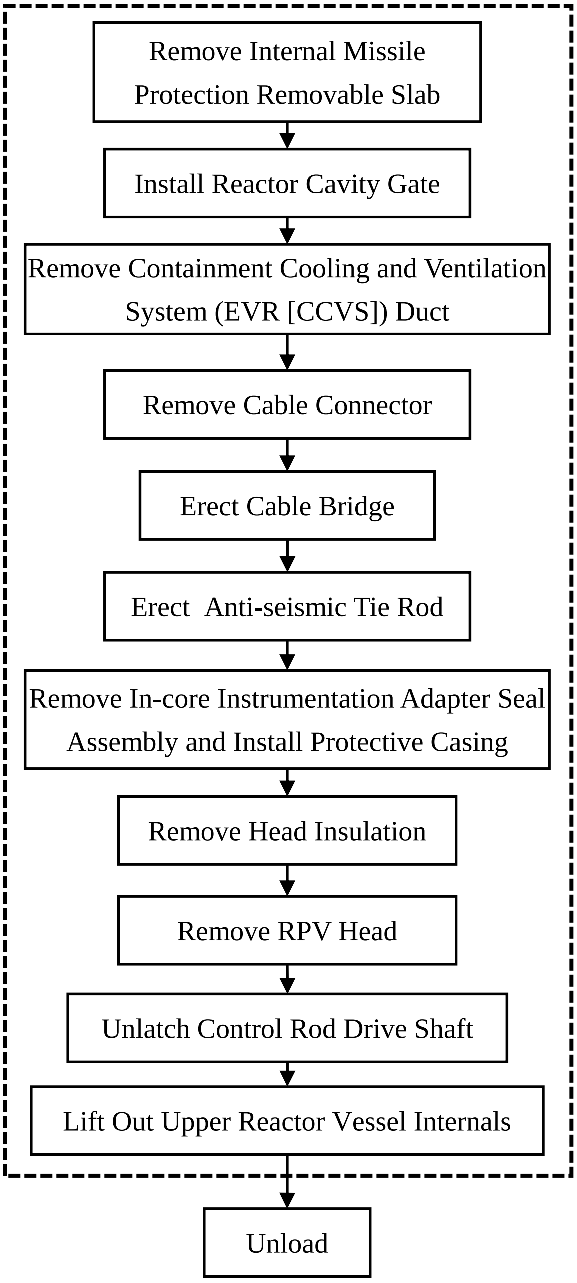
The above steps are repeated to load the reactor core for the first time.

b) Refuelling preparation and reactor disassembly

Before refuelling, it is necessary to remove the Reactor Pressure Vessel (RPV) head from the core using the polar crane. Once completed, reactor structural components are inspected according to the preventive maintenance manual.

The general steps of RPV head removal are shown in F-28.4-1. The majority of these operations are on the critical path for the refuelling outage.

The gate valve and blind flange on the fuel transfer facility are opened so that the BFX and BRX can be connected by the fuel transfer tube.



F-28.4-1 RPV Head Removal for Refuelling

c) Core refuelling

During the refuelling shutdown stage, when the refuelling preparation is complete and the NFAs and relevant components necessary for refuelling are ready for retrieval in the underwater fuel storage racks, the core refuelling operation can be carried out. Refuelling operation can be divided into three stages as follows:

1) Stage 1: Unloading IFAs from the reactor core and transferring to the SFP

The main steps for unloading IFAs from the reactor core to the SFP are as follows:

- IFAs are transferred vertically, one at a time, from the core and placed into a fuel transfer facility fuel carrier using refuelling machine;

- The IFA is inspected to identify whether it is failed or not using the on-line sipping test facility installed on the refuelling machine during the transfer from the core to the fuel transfer facility;
- The fuel carrier is rotated to the horizontal position and transferred from the BRX side to the BFX side;
- The fuel carrier is rotated to the vertical position, and the IFA is transferred from the fuel transfer facility and placed into the underwater fuel storage racks located in the SFP using the SFPC. The final storage position and subsequent operations are based on the results of on-line sipping test (as summarised below);
    - If it is confirmed that the IFA is not damaged, it will be transferred to the underwater fuel storage racks for storage;
    - If it is confirmed that the IFA is damaged, it will be transferred to a failed FA storage cell for storage;
    - If any FA is suspected to be damaged, but this has not been confirmed, it will be transferred to the off-line sipping test facility for quantitative damage detection. The subsequent storage location will be as above, depending on the results.

2) Stage 2: Rearranging relevant components in the SFP

This stage is used to rearrange components associated with the FAs in the SFP using the SFPC and relevant handling tools according to reactor core loading plan.

During the first core refuelling, the discharged neutron source assemblies are not reused, and the thimble plug assembly are loaded in their place.

3) Stage 3: Reloading FAs to the reactor core

When the rearrangement of the relevant components in the SFP is complete and the reloading is ready to commence, the reactor core reloading operation can begin. The reloading operation is in the opposite order to the unloading operation. The FAs in the SFP are reloaded into the reactor core sequentially in series with their relevant components. The main operations include:

- The NFAs and IFAs are transferred vertically from the SFP into fuel carrier using the SFPC, one FA at a time;
- The fuel carrier is rotated to the horizontal position and transferred from the BFX side to the BRX side;
- The fuel carrier is rotated to the vertical position;

- The NFAs and IFAs are transferred from the fuel carrier to the core using the refuelling machine;
- The RPV head is lifted back into place with the polar crane.

The route of fuel loading and unloading is shown in Appendix 28B F-28B-4.

The operation of reactor reassembly is the opposite process of reactor disassembly, as described above, and so is not repeated here.

More details on the process of fuel loading/unloading are presented in *Fuel Handling and Storage System Design Manual Chapter 6 System Operations and Maintenance,* Reference [10].

28.4.3.3 SFA Delivery in the BFX

The SFIS facility is introduced for the UK HPR1000, and the spent fuel delivery operations are closely related to the design of SFIS SSCs, so the specific process of spent fuel delivery is presented in PCSR Chapter 29 Interim Storage of Spent Fuel. In this chapter, only the handling route of a spent fuel transfer cask is briefly introduced.

a) Receipt of a spent fuel transfer cask and fuel storage canister

An empty spent fuel transfer cask is transported into the BFX using a specialised vehicle. The spent fuel transfer cask is lifted to the cleaning pit using the spent fuel cask crane. The outer cover is removed using the auxiliary crane. A fuel storage canister is then transferred into the BFX, and placed into the cask.

b) Empty cask operations within the cleaning pit

The empty cask is inspected and cleaned in the cleaning pit. The cask is then connected to the hook of spent fuel cask crane.

c) Cask loading operations within the loading pit

The cask is lifted to the loading pit using the spent fuel cask crane. The loading pit is then filled with borated water until its surface level is equal to the SFP, and the inner shield cover of cask is simultaneously removed. The sluice gate between the SFP and loading pit is opened, and the SFAs are loaded into the canister using the SFPC. Finally, the cask shield cover is reinstalled.

d) Fully loaded cask related operations within the cleaning pit

The fully loaded cask is lifted to the cleaning pit, and then the outer lid of cask is installed. After the surface of cask is flushed, cleaned and dried, it is ready for delivery to the spent fuel interim storage facility.

The process diagram for SFA delivery in the BFX is shown in Appendix 28B F-28B-5.

More details on the process of SFAs delivery in the BFX are presented in *Fuel Handling and Storage System Design Manual Chapter 6 System Operations and Maintenance*, Reference [10].

28.4.4 Interfaces with Other SSCs

The key interfaces between the PMC [FHSS] and other SSCs are:

a) The DMR [RBHE], which supports the refuelling preparation, including reactor disassembly and reassembly, is described in PCSR Chapter 10;

b) The DMK [FBHE], which supports SFA delivery in the BFX, including spent fuel transfer cask lifting, is described in PCSR Chapter 10;

c) The PTR [FPCTS], which supplies borated water for fuel cooling, shielding and sub-criticality, is described in PCSR Chapter 10 as a typical auxiliary system;

d) Electrical power supply systems, which support the fuel handling and storage related operations, are described in PCSR Chapter 9;

e) Civil design of the BRX and BFX, which are related to the PMC [FHSS], is described in PCSR Chapter 16;

f) Heating, Ventilation and Air Conditioning (HVAC), which plays a role in reducing offsite dose during fuel handling accidents, is described in PCSR Chapter 10.

The above SSCs will be considered while developing the safety case for the PMC [FHSS], particularly with regard to fault analysis and hazard assessment, such that performance demands placed on these SSCs are derived and ultimately achieved.

28.4.5 Main Equipment of the PMC [FHSS]

The PMC [FHSS] for the UK HPR1000 design includes the following sub-processes and main equipment, as listed in T-28.4-1.

T-28.4-1 Main Equipment of the PMC [FHSS]

Sub-Process	Main Equipment	Operational Function
NFA receipt, Inspection and Storage	Auxiliary Crane	Handling new fuel transport containers and NFAs in air; Handling new RCCAs during inspection tests.
	New Fuel Dry Storage Rack	Storing NFAs in dry conditions; Support to inspection and testing activities for the new

Sub-Process	Main Equipment	Operational Function
		RCCAs.
	New Fuel Elevator	Lowering NFAs to the bottom of the SFP.
Core Loading /Unloading	Refuelling Machine	Transferring FAs between reactor cavity pool and the fuel transfer facility in the BRX.
	Fuel Transfer Facility	Transferring FAs between the BRX and BFX.
	SFPC	Transferring FAs between the SFP and fuel transfer compartment in the BFX; Rearranging relevant components in the SFP.
	Underwater Fuel Storage Racks	Storing FAs underwater in the SFP.
	On-line Sipping Test Facility	Sampling FAs to check for failure using qualitative testing.
	Off-line Sipping Test Facility	Sampling FAs to check for failure using quantitative testing.
SFA Delivery in the BFX	SFPC	Transferring FAs between the SFP and cask loading pit in the BFX.
	Spent Fuel Cask Crane	Lifting the spent fuel transfer cask between the loading pit, cleaning pit and fuel hoisting pit.

28.5 Safety Case Strategy

28.5.1 Safety Functions

The PMC [FHSS] is designed to fulfil the following safety functions:

a) Maintaining sub-criticality of FAs

The PMC [FHSS] does not directly participate in the fulfilment of core reactivity control, but it shall maintain the FAs in a sub-critical condition during handling and storage related operations.

b) Removal of residual heat from IFAs

The PMC [FHSS] shall provide sufficient cooling of the IFAs during handling and storage related operations.

c) Confinement of radioactive substances

The PMC [FHSS] shall maintain the integrity of fuel cladding during handling and storage related operations. On the other hand, the safety function to protect workers from radiation emitted by spent fuel assemblies shall be fulfilled during the fuel handling process. During the reactor power operation stage, the fuel transfer facility forms part of the reactor containment boundary.

28.5.2 Safety Case Structure

As illustrated in sub-chapter 28.2.3 Chapter Route Map, the chapter claim can be split into five sub-claims, and each sub-claim will be substantiated with associated arguments and evidence outlined in the following sub-chapters. Further evidence will be given in the appropriate GDA steps in the form of references and supporting documents. The Claims, Arguments, Evidence (CAE) relevant to the PMC [FHSS] are as follows.

a) **Sub-Claim 3.3.12.SC28.1**: The safety functional requirements have been derived for the system.

    1) **Argument 3.3.12.SC28.1-A1**: A thorough process has been followed to identify all faults related to the PMC [FHSS].

        - **Evidence 3.3.12.SC28.1-A1-E1**: Fault analysis in the safety assessment report for the PMC [FHSS].

          Note: For further information on fault analysis, refer to sub-chapter 28.6.1.

        - **Evidence 3.3.12.SC28.1-A1-E2**: System design manual.

    2) **Argument 3.3.12.SC28.1-A2**: The protection requirements have been identified for the PMC [FHSS] in all Sub-operations.

        - **Evidence 3.3.12.SC28.1-A2-E1**: System design manual.

    3) **Argument 3.3.12.SC28.1-A3**: All practicable mitigation measures have been considered in response to failures of the PMC [FHSS] equipment and human errors.

        - **Evidence 3.3.12.SC28.1-A3-E1**: System design manual.

b) **Sub-Claim 3.3.12.SC28.2**: The design intent of the system can be met by the design of process and relevant SSCs.

1) **Argument 3.3.12.SC28.2-A1**: Safety related requirements for NFA receipt are met through appropriate design of sub-process and relevant SSCs.

   - **Evidence 3.3.12.SC28.2-A1-E1**: NFA receipt safety case and safety assessment in sub-chapter 28.6.3.

2) **Argument 3.3.12.SC28.2-A2**: Safety related requirements for NFAs dry storage are met through appropriate design of sub-process and relevant SSCs.

   - **Evidence 3.3.12.SC28.2-A2-E1**: NFA dry storage safety case and safety assessment in sub-chapter 28.6.3.

3) **Argument 3.3.12.SC28.2-A3**: Safety related requirements for refuelling preparations are met through appropriate design of sub-process and relevant SSCs.

   - **Evidence 3.3.12.SC28.2-A3-E1**: Refuelling preparations safety case and safety assessment in sub-chapter 28.6.3.

4) **Argument 3.3.12.SC28.2-A4**: Safety related requirements for refuelling operations are met through appropriate design of sub-process and relevant SSCs.

   - **Evidence 3.3.12.SC28.2-A4-E1**: Refuelling safety case and safety assessment in sub-chapter 28.6.3.

5) **Argument 3.3.12.SC28.2-A5**: Safety related requirements for SFA storage are met through appropriate design of sub-process and relevant SSCs.

   - **Evidence 3.3.12.SC28.2-A5-E1**: SFA storage safety case and safety assessment in sub-chapter 28.6.3.

6) **Argument 3.3.12.SC28.2-A6**: Safety related requirements for SFA delivery in BFX are met through appropriate design of sub-process and relevant SSCs.

   - **Evidence 3.3.12.SC28.2-A6-E1**: SFA delivery in BFX safety case and safety assessment in sub-chapter 28.6.3.

For further information on the aforementioned sub-process safety cases, refer to sub-chapter 28.6.2.

For further information on human factors, refer to sub-chapter 28.6.5.

c) **Sub-Claim 3.3.12.SC28.3**: All reasonably practicable measures have been adopted to improve the design of the PMC [FHSS].

   1) **Argument 3.3.12.SC28.3-A1**: The system design meets appropriate standards, based on RGP and Operating Experience (OPEX), suitable for a UK context.

   - **Evidence 3.3.12.SC28.3-A1-E1**: ALARP assessment report for the PMC [FHSS].

2) **Argument 3.3.12.SC28.3-A2**: The risk from failure of the system is acceptably low, and options for design improvement have been considered and will be adopted where practicable.

   - **Evidence 3.3.12.SC28.3-A2-E1**: ALARP assessment report for the PMC [FHSS] SSCs.

For further information on ALARP assessment report for the PMC [FHSS] SSCs, refer to sub-chapter 28.6.4.

d) **Sub-Claim 3.3.12.SC28.4**: The system performance will be validated through the necessary commissioning and testing.

1) **Argument 3.3.12.SC28.4-A1**: Safety Functional Requirements for the PMC [FHSS] will be met through the appropriate factory acceptance testing.

   - **Evidence 3.3.12.SC28.4-A1-E1**: The requirements for factory acceptance testing.

2) **Argument 3.3.12.SC28.4-A2**: Safety Functional Requirements for the PMC [FHSS] will be met through the appropriate site acceptance testing.

   - **Evidence 3.3.12.SC28.4-A2-E1**: The requirements for commissioning procedures.

For further information on commissioning and testing, refer to sub-chapter 28.6.7 and 28.6.8.

e) **Sub-Claim 3.3.12.SC28.5**: The effects of ageing on the system have been addressed in the design.

1) **Argument 3.3.12.SC28.5-A1**: Appropriate obsolescence management and Examination, Maintenance, Inspection, Test (EMIT) arrangements will be put in place to ensure the design intent of the PMC [FHSS] is maintained.

   - **Evidence 3.3.12.SC28.5-A1-E1**: Equipment Operation and Maintenance Manual (EOMM).

28.6 Safety Assessment of the PMC [FHSS]

The key aim of the safety assessment for the PMC [FHSS] is to demonstrate that the aforementioned five sub-claims could be supported by appropriate and adequate arguments and evidence.

28.6.1 Fault Analysis

To identify potential faults associated with fuel handling and storage related operations, assess the consequences and demonstrate that suitable and sufficient protection has been provided against these faults, the following will be carried out:

a) Postulated Initiating Event (PIE) identification

The identification of faults associated with the PMC [FHSS] related operations is accomplished through the process of PIE identification. PIE is an event identified during design which is capable of leading to anticipated operational occurrences or accident conditions. PIEs which have the potential to lead to any person receiving a significant dose of radiation or to a significant radioactive material release due to the PMC [FHSS] related operations have been identified.

For PIE identification relevant to the PMC [FHSS], the PIEs have been identified by systematically following the fuel handling and storage related operations step by step, to ensure that the potential faults can be identified in a comprehensive manner. The faults considered for the UK HPR1000 PMC [FHSS] include:

1) Loss of cooling;

2) Loss of water inventory;

3) Loss of power;

4) Criticality accident;

5) Over-raising of IFA;

6) Internal and external hazards, including dropped loads and collisions.

b) Protection Measures

Based on the results of PIE identification, the appropriate PIEs are considered as part of the design basis analysis, severe accident analysis and probabilistic safety analysis with the proposed safety functions. If the analysis results show that the risk requires further reduction, potential design changes will be carried out to provide suitable and sufficient protection.

The full fault analysis process and results are presented in *Safety Assessment Report for the PMC [FHSS] Related Operations*, Reference [11].

28.6.2 Safety Assessment of Sub-processes

Based on the stage of operation, the PMC [FHSS] related operations can be divided into three key sub-processes as described in sub-chapter 28.4.3.
For each sub-process, a step by step process is followed to identify and reduce the potential risks which may challenge the safety functions.

a) Firstly, the potential failure mode during the fuel handling and storage related operations is identified, including failure of equipment, human error, miscommunication, etc.

b) Secondly, the relevant consequence and frequency of these identified failures are analysed.

c) Thirdly, adequate protection measures are considered to eliminate or mitigate the risks relating to safety functions.

The detailed process is presented in *Safety Assessment Report for the PMC [FHSS] Related Operations*, Reference [11].

28.6.3 Safety Assessment of Main Equipment

The contribution of specific components or equipment to the achievement of the fundamental safety functions is difficult to discern, as this cannot be achieved by any single piece of equipment alone. Some devices contribute to the achievement of fundamental safety functions directly, while others may do this indirectly. All the PMC [FHSS] related SSCs work together to assure personnel health and fuel handling safety.

The relationship between the PMC [FHSS] equipment and the fundamental safety functions is shown in T-28.6-1.

T-28.6-1 Fundamental Safety Functions of the PMC [FHSS] Equipment

Equipment	**Fundamental Safety Functions**			**Contribution**	**Note**
	Maintaining Sub-criticality of the Fuel	**Removal of Residual Heat From Irradiated Fuel**	**Confinement of Radioactive Substances**		
Refuelling Machine	N/A	N/A	Direct (see note 1)	Preventing fuel from dropping, collision, jamming and being lifted too high.	Note 1: If the structural integrity of the refuelling machine cannot be maintained, the potential fuel drop may result in release of radioactive substances.
Fuel Transfer Facility	N/A	Indirect (see note 2)	Direct (see note 3)	Preventing fuel dropping, jamming and collision; Forming part of reactor containment boundary.	Note 2: If the structural integrity of the fuel transfer tube cannot be maintained, it may result in loss of coolant during refuelling stage. Note 3: If the fuel assembly is jammed during transfer, it may be damaged and result in release of radioactive substances.

Equipment	**Fundamental Safety Functions**			**Contribution**	**Note**
	Maintaining Sub-criticality of the Fuel	**Removal of Residual Heat From Irradiated Fuel**	**Confinement of Radioactive Substances**		
SFPC	N/A	N/A	Direct (see note 4)	Preventing fuel from dropping, collision and being lifted too high.	Note 4: If the structural integrity of the SFPC cannot be maintained, the potential fuel drop may result in release of radioactive substances.
New Fuel Elevator	N/A	N/A	Direct (see note 5)	Preventing fuel from dropping, jamming and being lifted too high.	Note 5: If the structural integrity of the new fuel elevator cannot be maintained, the potential fuel drop may result in release of radioactive substances.
Auxiliary Crane	N/A	N/A	Direct (see note 6)	Preventing fuel dropping and collision.	Note 6: If the structural integrity of auxiliary crane cannot be maintained, the potential fuel drop may result in release of radioactive substances.
New Fuel Dry Storage Rack	Direct	N/A	Indirect	Maintaining sub-criticality of NFAs.	Note 7: The new fuel dry storage rack is designed to maintain the fuel in a sub-critical

Equipment	Fundamental Safety Functions			Contribution	Note
	Maintaining Sub-criticality of the Fuel	**Removal of Residual Heat From Irradiated Fuel**	**Confinement of Radioactive Substances**		
	(see note 7)		(see note 8)	Preventing fuel from damage.	state via geometrical arrangement. Note 8: The new fuel assemblies stored in the new fuel dry storage rack are appropriately protected from physical damage.
Underwater Fuel Storage Rack	Direct (see note 9)	Indirect (see note 10)	Indirect (see note 11)	Maintaining sub-criticality and cooling of FAs. Maintaining confinement of radioactive substances	Note 9: The underwater fuel storage rack is designed to maintain the fuel in a sub-critical state via geometrical arrangement, soluble boron, and fixed neutron absorbers. Note 10: The underwater fuel storage rack shall provide adequate flow access for the coolant to prevent overheating. Note 11: The fuel assemblies stored in the underwater fuel storage rack are appropriately protected from physical damage.

Equipment	**Fundamental Safety Functions**			**Contribution**	**Note**
	Maintaining Sub-criticality of the Fuel	**Removal of Residual Heat From Irradiated Fuel**	**Confinement of Radioactive Substances**		
Fuel Handling Tools	N/A	N/A	Direct (see note 12)	Preventing fuel dropping.	Note 12: If the structural integrity of fuel handling tools cannot be maintained, the potential fuel drop may result in release of radioactive substances.
Sipping Test Facility	N/A	N/A	Indirect (see note 13)	Identifying the fuel cladding leakage or break.	Note 13: The damaged fuel will be stored in a special cell to reduce the diffuseness of radioactive substances.

Notes:

a) “N/A” means the equipment does not contribute to the achievement of fundamental safety functions.

b) “Direct” means the equipment participates in the achievement of fundamental safety functions directly.

c) “Indirect” means the equipment participates in the achievement of fundamental safety functions indirectly.

The classification of the main PMC [FHSS] equipment is presented in Appendix 28C T-28C-1. More detailed information about classification is presented in *Handling and Storage System Design Manual Chapter 3 System Functions and Design Bases*, Reference [12]. Therefore, the equipment can be designed in accordance with relevant codes and standards based on its classification.

The following sub-chapters only give a preliminary safety assessment of the main PMC [FHSS] equipment, in order to show how the main safety related requirements allocated by the system can be met and supported by the relevant specific design features of the equipment.

28.6.3.1 Refuelling Machine

The safety related requirements allocated to the refuelling machine are met and supported by the following design features (this list is not exhaustive):

a) The refuelling machine has been designed to prevent the FAs from dropping during the handling operation.

    1) The hoisting mechanism is equipped with redundant load paths.

    2) The hoisting mechanism is equipped with triple brakes.

    3) The hoisting mechanism is equipped with dual load cells.

    4) Logical interlocks prohibit the incorrect release of carried loads.

    5) The support structure is designed to withstand the maximum loads due to all normal and fault conditions.

    6) The refuelling machine is fitted with manual controls to enable fuel handling in the event that the control and protection systems fail.

b) The refuelling machine has been designed to prevent the FAs from experiencing collision during the handling operation.

    1) The route of the refuelling machine is planned and verified in advance and the absence of obstacles during handling operations is ensured.

    2) The FAs are protected by the stationary sleeve installed on the refuelling machine during transfer.

    3) Multiple electrical interlocks are provided to maintain adequate space.

    4) Limit switches are provided on the ends of travel.

c) The refuelling machine has been designed to prevent the FAs from being lifted too high.

    1) The lifting height can be limited by travel limit switches.

2) Position encoders can measure the real-time height of the FA continuously and display it on a screen.

3) The real-time lifting height is inputted into the control system and limited by interlocks.

4) The lift height is limited by engineered mechanical stops to ensure adequate shielding water.

d) The refuelling machine has been designed to prevent the FAs from misloading.

1) Core loading is executed according to a pre-determined and approved plan which is previously inputted into the control system of the refuelling machine.

2) The refuelling machine can reach the correct position automatically to prevent human error, with independent checks and verification for critical steps.

28.6.3.2 Fuel Transfer Facility

The safety related requirements allocated to fuel transfer facility are met and supported by the following design features:

a) The fuel transfer facility has been designed to prevent the FAs from dropping during the handling operation.

1) The lifting winch of fuel transfer facility is equipped with dual cables.

2) The lifting winch of fuel transfer facility is equipped with dual brakes.

3) Logical interlocks prohibit the incorrect release of carried loads.

4) The support structure is designed to withstand the maximum loads due to all normal and fault conditions.

b) The fuel transfer facility has been designed to prevent the FAs from jamming, collision and damage during the handling operation.

1) Continuous rails are provided to guide the movement of fuel carrier.

2) Manual drive mechanism is provided to deal with emergent events.

c) The fuel transfer facility has been designed to maintain the containment during the plant operation phase.

1) The reactor building end of the fuel transfer tube is sealed by a blind flange fitted with a twin gasket leak-tightness control device.

2) The fuel building end of the transfer tube is sealed by a gate valve fitted with a twin gasket leak-tightness control device.

d) The fuel transfer tube has been designed to maintain the structural integrity during the refuelling phase.

    1) The fuel transfer tube is welded to an integer to eliminate leakage access for the coolant;

    2) The fuel transfer tube is fixed to the building structures via expansion joints to eliminate potential stress induced by the relative displacement between the reactor building containment, the BFX and the BRX.

28.6.3.3 SFPC

The safety related requirements allocated to the SFPC are met and supported by the following design features:

a) The SFPC has been designed to prevent the FAs from dropping during the handling operation.

    1) The hoisting mechanism is equipped with redundant load paths.

    2) The hoisting mechanism is equipped with triple brakes.

    3) The hoisting mechanism is equipped with dual load cells.

    4) Logical interlocks prohibit the incorrect release of carried loads.

    5) The support structure is designed to withstand the maximum loads due to all normal and fault conditions.

    6) The refuelling machine is fitted with manual controls to enable fuel handling in progress in the event that the control and protection systems fail.

b) The SFPC has been designed to prevent the FAs from experiencing a collision during the handling operation.

    1) The travel route of SFPC is planned in advance and the absence of obstacles during handling operations is ensured.

    2) Boundary protection is provided using interlock control.

    3) Limit switches are provided on the ends of travel.

c) The SFPC has been designed to prevent the FAs from being lifted too high.

    1) The lifting height is limited by travel limit switches switch.

    2) Position encoders can measure the real-time height of the FA continuously and display it on the screen.

    3) The real-time lifting height is input into the control system and limited by interlocks.

4) The lift height is limited by engineered mechanical stops to ensure adequate shielding water.

d) The SFPC has been designed to prevent the misloading of fuel.

1) Refuelling is executed according to a pre-determined and approved plan which is previously inputted into the control system of SPFC.

2) The SFPC can reach the correct position automatically to prevent human error, with independent checks and verification for critical steps.

28.6.3.4 New Fuel Elevator

The safety related requirements allocated to the new fuel elevator are met and supported by the following design features:

a) The new fuel elevator has been designed to prevent the FAs from dropping during the handling operation.

1) The hoisting mechanism is equipped with redundant load paths.

2) The hoisting mechanism is equipped with dual brakes.

3) The hoisting mechanism is equipped with dual load cells.

4) A guidance structure is equipped to keep the fuel basket running on the rail.

5) The support structure is designed to withstand the maximum loads due to all normal and fault conditions.

b) The new fuel elevator has been designed to prevent the FAs from jamming during the handling operation.

1) The FAs are transferred in the fuel basket to be protected.

2) Continuous rails ensure the correct orientation of the fuel carrier is maintained.

c) The new fuel elevator has been designed to prevent the FAs from being lifted too high.

1) The lifting height can be limited by travel limit switches.

2) Position encoders can measure the real-time height of the fuel basket continuously and display it on a screen.

3) The real-time lifting height is inputted into the control system and limited by interlocks.

28.6.3.5 Auxiliary Crane

The safety related requirements allocated to the auxiliary crane are met and supported by the following design features:

a) The auxiliary crane has been designed to prevent the FAs from dropping during the handling operation.

  1) The hoisting mechanism is equipped with redundant load paths.

  2) The hoisting mechanism is equipped with triple brakes.

  3) The hoisting mechanism is equipped with dual load cells.

  4) Logical interlocks prohibit the incorrect release of carried loads.

  5) The support structure is designed to withstand the maximum loads due to all normal and fault conditions.

b) The auxiliary crane has been designed to prevent the FAs from collision during the handling operation.

  1) The running route of the auxiliary crane is planned in advance and the absence of obstacles is ensured prior to handling operations.

  2) Limit switches are provided at the ends of travel.

28.6.3.6 New Fuel Dry Storage Rack

The safety related requirements allocated to new fuel dry storage rack are met and supported by the following design features:

a) The new fuel dry storage rack has been designed to maintain the NFAs in a sub-critical state at all times.

  1) The new fuel storage rack prevents criticality by ensuring proper geometrical structure and appropriate fuel-to-fuel distance.

  2) To prevent water ingress or flooding, there are no water pipes within the new fuel storage area.

The criticality analysis of the new fuel dry storage rack is presented in *Criticality Analysis of Fuel Storage*, Reference [13].

b) The new fuel dry storage rack has been designed to prevent the fuel from becoming damaged.

  1) Each storage cell is composed of a stainless steel sleeve with a lead-in chamfer to facilitate the fuel handling.

  2) The inner surface of the cell is a flat, smooth surface, which can provide physical protection for the stored fuel assembly against outside impact.

  3) The new fuel storage rack is designed to withstand seismic loads and other impacts resulting from postulated events.

4) The top of each storage cell is equipped with a protective plug to protect the stored fuel from contamination.

5) The storage area is covered with a metal plate to protect the fuel assembly against damage or impact.

28.6.3.7 Underwater Fuel Storage Racks

The safety related requirements allocated to underwater fuel storage racks are met and supported by the following design features:

a) The underwater fuel storage racks have been designed to maintain the stored fuel in a sub-critical state at all times through the following design features:

1) The racks are flooded with borated water.

2) Solid neutron absorbers are fixed to the racks.

3) Geometrical arrangement to ensure sub-criticality

The criticality analysis of underwater fuel storage racks is presented in *Criticality Analysis of Fuel Storage*, Reference [13]. The analysis result shows that the fuel storage racks can maintain a criticality margins of 0.05 (K_{eff}<0.95) even when flooded with demineralised water.

b) The underwater fuel storage racks have been designed to provide adequate cooling to SFAs.

1) The underwater fuel storage racks are immerged in the spent fuel pool.

2) The structure of the racks permits natural circulation of coolant through the storage cells to cool the fuel assemblies.

c) The underwater fuel storage racks have been designed to maintain confinement of radioactive substances.

1) Five cells are provided with failed fuel assembly storage filters to store the fuel assemblies which are known to be damaged in order to prevent radioactive material from diffusing into the coolant.

2) The fuel assemblies are stored in independent sleeves to prevent physical damage.

28.6.3.8 Fuel Handling Tools

The safety related requirements allocated to fuel handling tools are met and supported by the following design features:

a) The fuel handling tools have been designed to prevent the FAs and relevant components from dropping during the handling operations.

1) All the fuel handling tools are equipped with a positioning device, which will provide positive indication of a good connection between the tools and the assemblies.

2) The gripper is designed to ensure that the fuel assembly can be smoothly grabbed and securely locked to avoid accidental loosening.

3) All the fuel handling tools are equipped with a mechanical locking device, which can only be unlocked through the correct manual operation.

28.6.3.9 Sipping Test Facilities

There are two facilities which check whether a FA has failed during the fuel handling and storage process. The first one is the on-line sipping test facility, which is mounted on the refuelling machine and used for qualitative detection of irradiated fuel assemblies during the fuel unloading process. The second facility is the off-line sipping test facility, which is installed in the spent fuel pool. It is used for detailed quantitative testing of suspected damaged FAs, based on results from the on-line sipping test facility. For the off-line sipping test facility, the damage assessment of the FA is based on the gamma activity concentration resulting from the release of fission nuclides, and the analysis of water and gas samples extracted from the off-line sipping test facility. The FA can be heated in the airtight sleeve of the off-line sipping test facility, which will promote the release of fission nuclides inside the cladding. By comparing the gamma activity concentration of the fission nuclides before and after heating up, the operator can detect FA failure and quantify the size of a clad crack.

28.6.4 ALARP Assessment

Demonstration that risks have been reduced to an ALARP level is an important part of developing the safety case for the PMC [FHSS]. PCSR Chapter 33 provides general ALARP methodology for the UK HPR1000. This chapter describes how the ALARP assessment is applied to the PMC [FHSS].

The general process that is adopted for the PMC [FHSS] SSCs ALARP assessment is shown as follows:

a) Review of design against RGP & OPEX - the design of PMC [FHSS] SSCs is reviewed against the applicable RGP and OPEX. Where gaps are identified between the UK HPR1000 and RGP or OPEX, considerations will be given to the implementation of design improvements.

b) Insights from risk analysis - A systematic assessment is carried out to challenge the UK HPR1000 design. The PMC [FHSS] processes are reviewed step by step to identify the potential design improvements.

c) Specific review of potential improvements - the PMC [FHSS] design undergoes an optioneering process, which considers the rationale of the design improvements, while also considering "what more can be done?" in terms of safety improvements. The optioneering process is as follows:

1) Define and characterise the problem (potential area for improvement);

2) Generate the potential options to address the problem;

3) Assess the options and their merits/drawbacks;

4) Identify, develop and justify the best option or options;

5) Implement the reasonably practicable option(s).

d) Finally, a conclusion is provided which demonstrates that there are no further reasonably practicable design improvements.

The ALARP assessment is not carried out in isolation, but also considers holistic risk and potential risk transfer (i.e. where a safety improvement in one area could cause a safety disadvantage in another area).

Protection measures to eliminate or mitigate risks have been considered in the design of the PMC [FHSS] SSCs, as described in sub-chapter 28.6.3 above. As part of the ALARP assessment, the areas which cannot fully meet the RGP have been identified as potential areas for improvement, to further reduce the risks of nuclear safety and conventional health and safety.

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For each gap and potential risk, further analysis and justifications or modifications will be carried out. These gaps and potential risks will be traced systematically until closed. Once the assessment discussed above has been completed, and all of the identified areas for potential improvement have been subject to optioneering, and all of the reasonably practicable improvements have been incorporated, it will be possible to demonstrate that the safety risks associated with PMC [FHSS] are ALARP.

The whole process is described in *ALARP Demonstration Report of the PMC [FHSS] SSCs*, Reference [14], which will be updated as necessary.

28.6.5 Human Factors

Many aspects of the PMC [FHSS] involve human actions. Therefore, consideration of human factors is an important aspect of developing the PMC [FHSS] safety case. Human factors shall be integrated into the whole process of PMC [FHSS] design. The detailed integration process is presented in *Assessment of the Human Factors Integration in the PMC [FHSS] Related Operations*, Reference [15].

PCSR Chapter 15 provides the human factors approach for the UK HPR1000 design. This sub-chapter summarises the approach taken to assess human factors for the PMC [FHSS] related operations and equipment.

The process of considering human factors for the PMC [FHSS] related operations is outlined as follows:

a) Process review and participation in fault analysis - during this stage, human factors specialists review the PMC [FHSS] SSCs design as well as fuel handling processes and procedures. This step identifies the operator actions that are undertaken during normal operational conditions for the PMC [FHSS]. It also reviews the required operator actions during fault and hazard conditions for the PMC [FHSS].

b) Identification of operator initiated faults, administrative controls, and post fault operator actions - this step identifies how operators may cause faults (i.e. how a human performance issue could initiate an event), while also considering operator actions to prevent faults, provide protection against the fault sequence, or mitigate fault consequences.

c) Task analysis and reporting - during this stage the required operator performance is evaluated and detailed human based safety claims are developed. This step identifies areas where significant dependence is placed on operators to support safe operation of the plant.

d) Detailed human factors assessment and analysis to support development of a design which reduces risks to levels that are ALARP – once the human based safety claims are developed these will be assessed to determine where design or procedural improvements can be made to optimise the design, in terms of minimising human based performance issues as far as reasonably practicable.

The detailed human factors analysis for the PMC [FHSS] related operations is presented in *Human Reliability Assessment for Fuel Handling Operations*, Reference [16].

28.6.6 Protection against External and Internal Hazards

The PMC [FHSS] is designed to withstand internal and external hazards in accordance with the principles described in PCSR Chapter 18 and PCSR Chapter 19.

Hazard protection has been considered during the design of the PMC [FHSS]. The specification is described in the document *Fuel Handling and Storage System Design Manual Chapter 3 System Functions and Design Bases*， Reference [12].

According to the assessment carried out during the GDA step 3, the main issue associated with hazards relating to PMC [FHSS] is dropped load. The relevant assessment can be found in sub-chapter 6.2 of *Safety Assessment Report for the PMC [FHSS] Related Operations*, Reference [11].

28.6.7 Commissioning

Initial testing of the PMC [FHSS] equipment before delivery to site (e.g. factory acceptance tests) will be undertaken in accordance with procurement, manufacturing and commissioning quality arrangements. These technical documents shall be prepared by the equipment designer and reviewed by the system designer, installation contractor and operator. All the operational and safety requirements and performances listed in the specification shall be confirmed before delivery to the site.

Following acceptance of the PMC [FHSS] equipment by the commissioning organisation on site, a structured, systematic and progressive test programme will be implemented. This will include all the activities required for confirmation and demonstration of the plant SSCs’ operational and safety functional performance requirements. The arrangements for the development of commissioning, and the management of commissioning activities, are discussed in PCSR Chapter 30. These activities include the requirements for system performance tests to establish and demonstrate the plant performance characteristics, which can be used subsequently to help demonstrate the PMC [FHSS] SSCs’ performance and potentially detect the onset of unacceptable degradation.

The testing and commissioning arrangements will be based on those developed for the design reference plant. Further detailed site specific arrangements for the UK HPR1000 commissioning activities, in addition to those described in PCSR Chapter 30, will be presented during the nuclear site licensing phase.

28.6.8 Examination, Maintenance, Inspection and Testing (EMIT)

The design of the PMC [FHSS] equipment has taken into account maintenance work, and all parts that may be damaged or worn are positioned such that they are as accessible as possible, for ease of removal and replacement.

The PMC [FHSS] equipment will be inspected and tested regularly according to appropriately defined regimes to ensure performance and early detection of potential issues. For example, the fuel handling equipment and tools will be checked and tested before the reactor is shut down for refuelling.

Each device will be provided with an EOMM when supplied to the plant site, which includes all the EMIT requirements and related guidance. These procedures are out of GDA scope, and will be produced by the equipment supplier after detailed design and manufacture.

28.6.9 Conventional Health and Safety

The design of the UK HPR1000 shall ensure that foreseeable conventional health and safety risks to the workers and the public are identified. Risk assessment of conventional health and safety shall be carried out in the design of the UK HPR1000 and the design mitigation shall be developed to eliminate, reduce and control the risks so far as is reasonably practicable.

The conventional health and safety risks relating to PCM [FHSS] have been analysed. The information of these risks is recorded in the conventional health and safety Design Risk Register, which is regarded as a live document and will be continually developed throughout the lifetime of the design.

28.7 Concluding Remarks

This chapter provides the general design information for the UK HPR1000 PMC [FHSS], as well as the outline safety case strategy. Safety claims, arguments and preliminary evidence are also summarised.

According to the preliminary assessment, the fundamental safety requirements relating to fuel handling and storage related operations can be fulfilled through proper design of the system and equipment. {

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28.8 References

[1] CGN, UK HPR1000 Design Reference Report, NE15BW-X-GL-0000-000047, Rev E, 2019.

[2] CGN, General Principles for Application of Laws, Regulations, Codes and Standards, GHX00100018DOZJ03GN, Rev F, 2018.

[3] CGN, Suitability Analysis of Codes and Standards in Mechanical Engineering, GHX00800005DNHX02GN, Rev A, 2018.

[4] CGN, Compliance Analysis of RGPs in Mechanical Engineering, GHX00800006DNHX02GN, Rev A, 2018.

[5] CGN, Fuel Handling and Storage System Design Manual Chapter 1 System Design Manual Content and State, GHX17PMC001DPFJ45GN, Rev B, 2019.

[6] CGN, Fuel Handling and Storage System Design Manual Chapter 2 Brief Introduction to the System, GHX17PMC002DPFJ45GN, Rev B, 2019.

[7] CGN, Fuel Handling and Storage System Design Manual Chapter 4 System and Component Design, GHX17PMC004DPFJ45GN, Rev B, 2019.

[8] CGN, Fuel Handling and Storage System Design Manual Chapter 5 Layout Requirements and Environment Condition, GHX17PMC005DPFJ45GN, Rev B, 2019.

[9] CGN, Fuel Handling and Storage System Design Manual Chapter 9 Flow Diagrams, GHX17PMC009DPFJ45GN, Rev B, 2019.

[10] CGN, Fuel Handling and Storage System Design Manual Chapter 6 System Operations and Maintenance, GHX17PMC006DPFJ45GN, Rev B, 2019.

[11] CGN, Safety Assessment Report for the PMC [FHSS] Related Operations, GHX00100001DPFJ45GN, Rev. B, 2019.

[12] CGN, Fuel Handling and Storage System Design Manual Chapter 3 System Functions and Design Bases, GHX17PMC003DPFJ45GN, Rev B, 2019.

[13] CGN, Criticality Analysis of Fuel Storage, GHX00600005DRDG02GN, Rev B, 2019.

[14] CGN, ALARP Demonstration Report of the PMC [FHSS] SSCs, GHX00100065KPGB03GN, Rev B, 2019.

[15] CGN, Assessment of the Human Factors Integration in the PMC [FHSS] Related Operations, GHX00100003DPFJ45GN, Rev. A, 2019.

[16] CGN, Human Reliability Assessment Report for Fuel Handling Operations, GHX06001055DIKX03GN, Rev. A, 2019.

Appendix 28A Route Map for the PMC [FHSS]

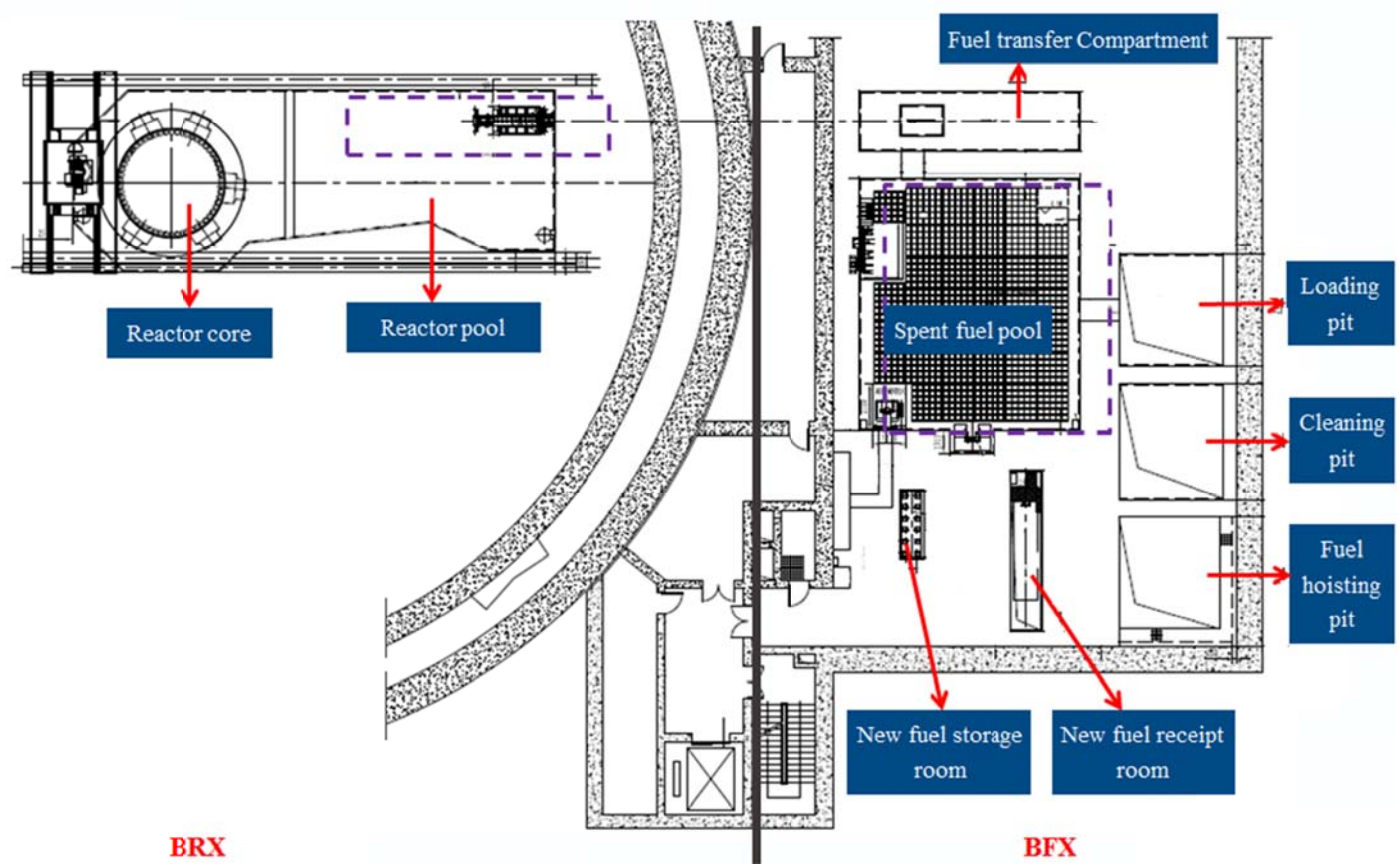
T-28A-1 Route Map of the PMC [FHSS]

Fundamental Objective	Claim 3 (Level 1)	Claim 3.3 (Level 2)	Chapter Claim 3.3.12	Sub-claims	Arguments	Evidence
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 the environment	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, reducing the nuclear safety risks to a level that is as low as reasonably practicable;	The design of the processes and systems has been substantiated and the safety aspects of operation and management have been substantiated.	The fuel handling and storage process, and design of the associated systems, have been substantiated.	The safety functional requirements have been derived for the system.	A thorough process has been followed to identify all faults related to the PMC [FHSS].	Fault analysis in the safety assessment report for the PMC [FHSS].
					The protection requirements have been identified for the PMC [FHSS] in all Sub-operations.	System design manual
					All practicable mitigation measures have been considered in response to failures of the PMC [FHSS] equipment and human errors.	
				The design intent of the system can be met by the design of process and relevant SSCs.	Safety related requirements for NFA receipt are met through appropriate design of sub-process and relevant SSCs.	NFA receipt safety case and safety assessment in sub-chapter 28.6.3.
					Safety related requirements for NFAs dry storage are met through appropriate design of sub-process and relevant SSCs.	NFA dry storage safety case and safety assessment in sub-chapter 28.6.3.
					Safety related requirements for refuelling preparations are met through appropriate design of sub-process and relevant SSCs.	Refuelling preparations safety case and safety assessment in sub-chapter 28.6.3.
					Safety related requirements for refuelling operations are met through appropriate design of sub-process and relevant SSCs.	Refuelling safety case and safety assessment in sub-chapter 28.6.3.
					Safety related requirements for SFA storage are met through appropriate design of sub-process and relevant SSCs.	SFA storage safety case and safety assessment in sub-chapter 28.6.3.
					Safety related requirements for SFA delivery in BFX are met through appropriate design of sub-process and relevant SSCs.	SFA delivery in BFX safety case and safety assessment in sub-chapter 28.6.3.
				All reasonably practicable measures have been adopted to improve the design of the PMC [FHSS].	The system design meets appropriate standards, based on RGP and Operating Experience (OPEX), suitable for a UK context.	ALARP Demonstration Report of the PMC [FHSS] SSCs.
					The risk from failure of the system is acceptably low, and options for design improvement have been considered and will be adopted where practicable.	

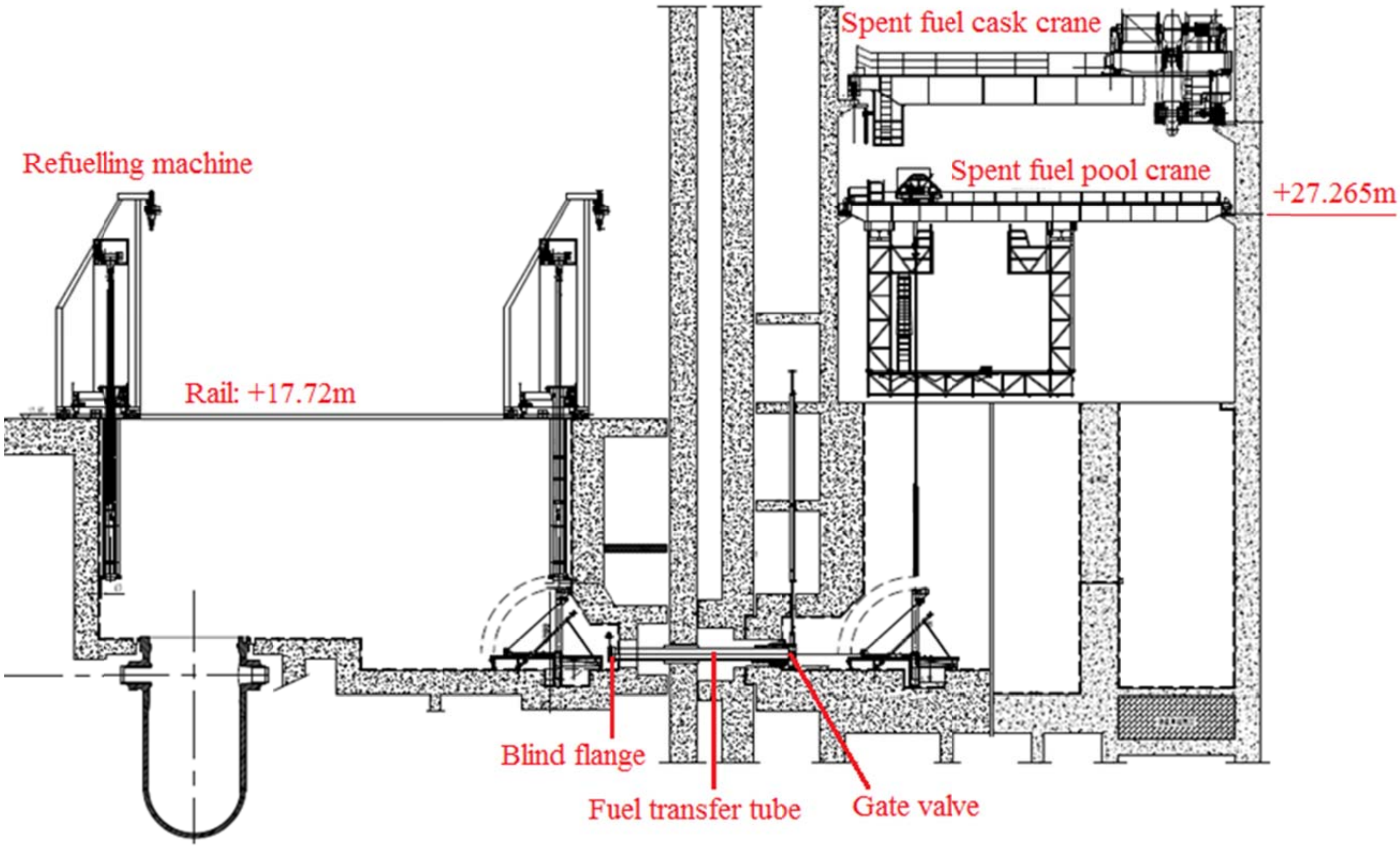
Fundamental Objective	Claim 3 (Level 1)	Claim 3.3 (Level 2)	Chapter Claim 3.3.12	Sub-claims	Arguments	Evidence
				The system performance will be validated through the necessary commissioning and testing.	Safety Functional Requirements for the PMC [FHSS] will be met through the appropriate factory acceptance testing.	The requirements for factory acceptance testing.
					Safety Functional Requirements for the PMC [FHSS] will be met through the appropriate site acceptance testing.	The requirement for commissioning procedure.
				The effects of ageing on the system have been addressed in the design.	Appropriate obsolescence management and Examination, Maintenance, Inspection, Test (EMIT) arrangements will be put in place to ensure the design intent of the PMC [FHSS] is maintained.	EOMM

Appendix 28B General Layout and Process of the PMC [FHSS]

28B.1 General Layout of the PMC [FHSS]

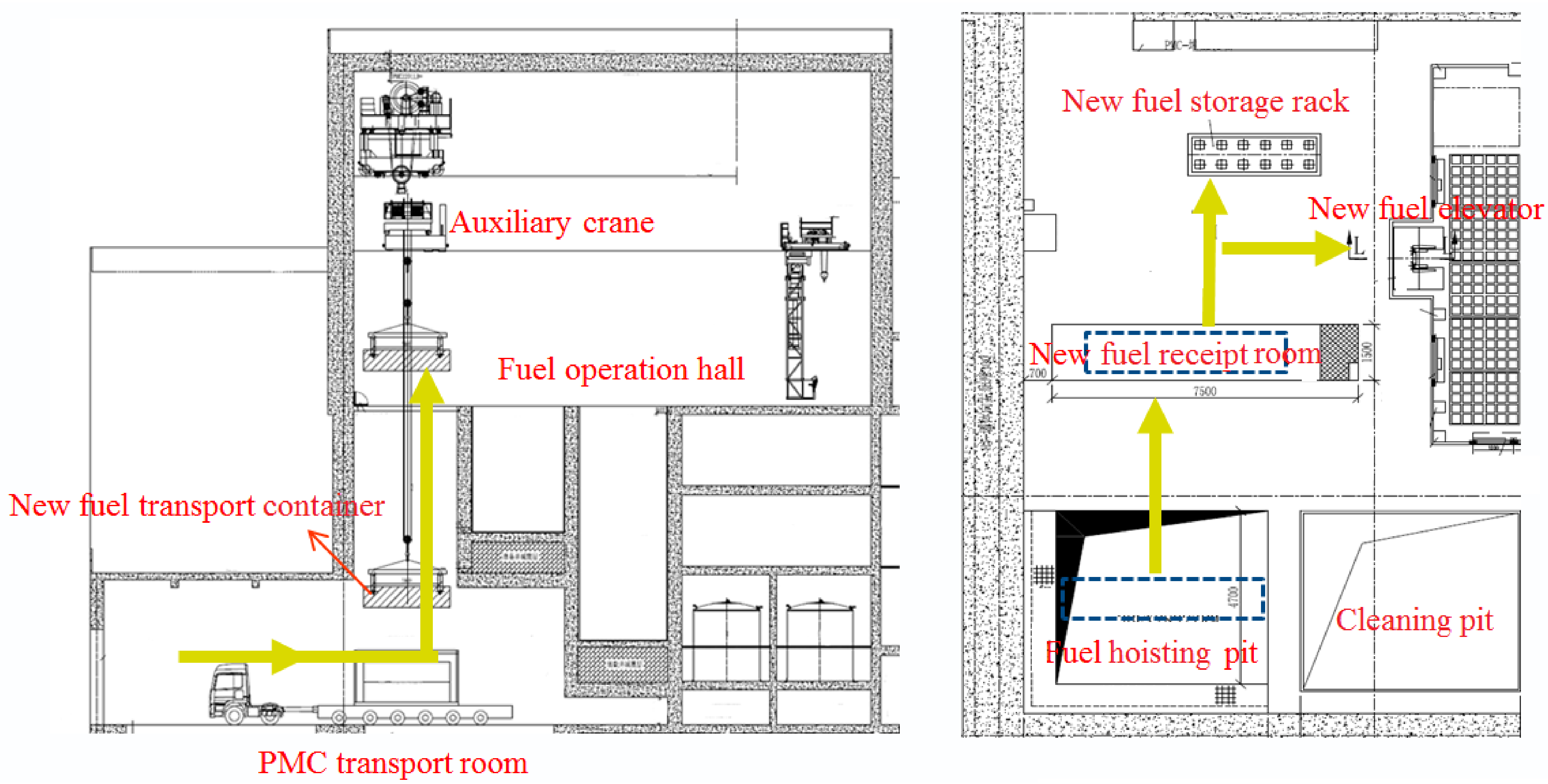


F-28B-1 General Layout of the PMC [FHSS] System and Equipment (Plan View)

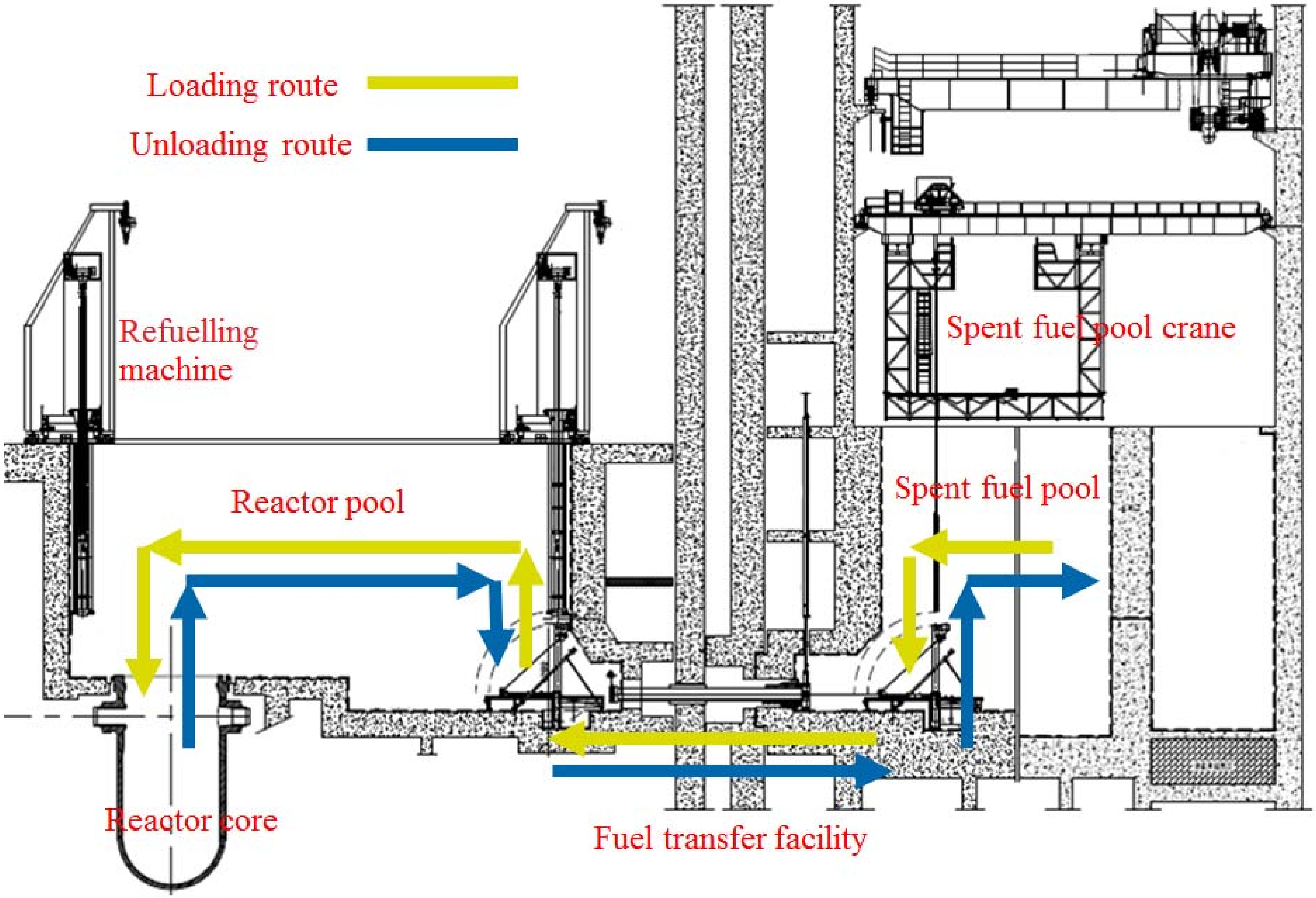


F-28B-2 General Layout of the PMC [FHSS] System and Equipment (Cross-Section)

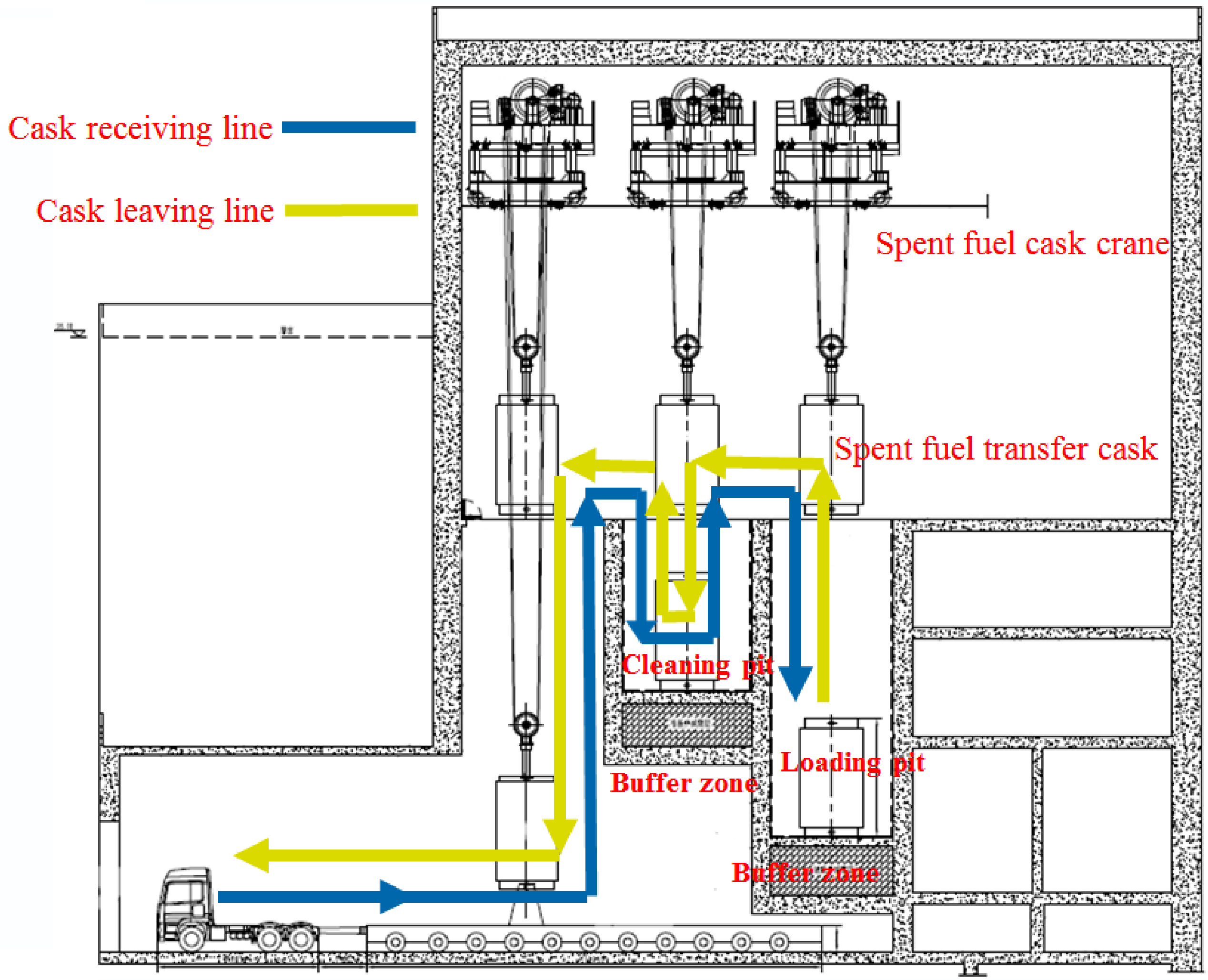
28B.2 Process of the PMC [FHSS]



F-28B-3 Receipt, Inspection and Storage of NFAs



F-28B-4 Core Loading/Unloading, and Storage of SFAs



F-28B-5 SFAs Delivery in BFX

Appendix 28C Classification of the Main PMC [FHSS] Equipment

T-28C-1 Classification of the Main PMC [FHSS] Equipment

No.	Equipment	Function Classification	Provision Category	Seismic Classification	Quality Assurance Classification
1	Refuelling Machine	NC	B-SC2	SSE1	Q1
2	Fuel Transfer Facility	NC	B-SC2	SSE1	Q1
3	Spent Fuel Pool Crane	NC	B-SC2	SSE1	Q1
4	Spent Fuel Assembly Handling Tool	NC	B-SC2	SSE1	Q1
5	Blind Flange/ Transfer Tube/ Gate Valve	F-SC1	B-SC2	SSE1	Q1
6	Auxiliary Crane	NC	B-SC3	SSE2	Q2
7	New Fuel Elevator	NC	B-SC3	SSE2	Q3
8	New Fuel Assemble Handling Tool	NC	B-SC3	SSE2	Q3
9	Spent RCC/ Neutron Source/ Thimble Plug Assembly Handling Tool	NC	NC	NO	Q3
10	New Fuel Storage Racks	F-SC3	B-SC3	SSE1	Q3
11	Underwater Fuel Storage Racks	F-SC1	B-SC2	SSE1	Q1
12	Off-line Sipping Test Facility	NC	NC	SSE2	Q3
13	On-line Sipping Test Facility	NC	NC	NO	Q3

Note: At this stage, the classifications provided are judgments based on existing information. They may therefore be subject to change in the future as the design develops.