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Pre-Construction Safety Report

Chapter 16

Civil Works & Structures

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16.1 List of Abbreviations and Acronyms

ALARP	As Low As Reasonably Practicable
BDA	Emergency Diesel Generator Building A
BDB	Emergency Diesel Generator Building B
BDC	Emergency Diesel Generator Building C
BDU	SBO Diesel Generator Building for Train A
BDV	SBO Diesel Generator Building for Train B
BEJ	Extra Cooling System and Fire-fighting Water Production System Building
BEX	Equipment Access Building
BFX	Fuel Building
BGA	Essential Service Water Supply Gallery A
BGB	Essential Service Water Supply Gallery B
BGC	Essential Service Water Supply Gallery C
BGH	Diesel Buildings Integrated Gallery H
BGI	Diesel Buildings Integrated Gallery I
BGJ	Diesel Buildings Integrated Gallery J
BGL	Essential Service Water Drain Gallery L
BGM	Essential Service Water Drain Gallery M
BGN	Essential Service Water Drain Gallery N
BMX	Turbine Generator Building
BNX	Nuclear Auxiliary Building
BPA	Essential Service Water Pumping Station A
BPB	Essential Service Water Pumping Station B
BPW	Circulating Water Pumping Station
BPX	Personnel Access Building
BRX	Reactor Building
BSA	Safeguard Building A

BSB	Safeguard Building B
BSC	Safeguard Building C
BWX	Radioactive Waste Treatment Building
CDM	Construction (Design and Management)
DBE	Design Basis Earthquake
EMIT	Examination, Maintenance, Inspection and Testing
FRS	Floor Response Spectra
GDA	Generic Design Assessment
IAEA	International Atomic Energy Agency
NRC	Nuclear Regulatory Commission (US)
ONR	Office for Nuclear Regulation (UK)
PCSR	Pre-Construction Safety Report
PSA	Probabilistic Safety Assessment
RGP	Relevant Good Practice
SPSA	Seismic Probabilistic Safety Assessment
SSC	Structures, Systems and Components
SSE	Safe Shutdown Earthquake
SSI	Soil-Structure Interaction
UK HPR1000	UK version of the Hua-long Pressurised Reactor

16.2 Introduction

This Chapter is part of the Pre-Construction Safety Report (PCSR) which is submitted to the Office for Nuclear Regulation (UK) (ONR) under the Generic Design Assessment (GDA) process. The PCSR demonstrates that the design, construction, operation and decommission of the UK version of the Hua-long Pressurised Reactor (UK HPR1000) are safe, secure and protect people and the environment.

This chapter presents the contents of the civil structures design of the UK HPR1000. The safety case, including the relevant supporting documents, is described in this chapter to underpin the fundamental objective of the UK HPR1000 which is described in Chapter 1.

16.2.1 Scope

This sub-chapter provides the scope of UK HPR1000 PCSR Chapter 16 to be assessed during GDA. The scope includes the building scope and extent of scope which are consistent with the *Scope for UK HPR1000 GDA Project*, Reference [1].

16.2.1.1 Building Scope

The structures in scope for assessment during GDA comprise of:

a) Safety Class 1 and 2 structures and/or Seismic Category 1 (SSE1) and 2 (SSE2) structures that are independent of the site specific conditions;

b) Site specific structures that are important to nuclear safety;

c) Non-classified structures in GDA scope of which collapse could affect safety Class 1 and 2 structures.

The generic site layout for the UK HPR1000 is based on a single unit reactor design, which is shown in F-16.2-1. The aerial view is shown in F-16.2-2.

The structures which are within the scope of GDA include the:

a) Reactor Building (BRX), which includes BRX internal structures, internal containment and external containment;

b) Safeguard buildings, which include Safeguard Building A (BSA), Safeguard Building B (BSB) and Safeguard Building C (BSC);

c) Fuel Building (BFX);

d) Nuclear Auxiliary Building (BNX);

e) Diesel generator buildings, which include Emergency Diesel Generator Building A (BDA), Emergency Diesel Generator Building B (BDB), Emergency Diesel Generator Building C (BDC), SBO Diesel Generator Building for Train A (BDU) and SBO Diesel Generator Building for Train B (BDV);

f) Radioactive Waste Treatment Building (BWX);

g) Extra Cooling System and Fire-fighting Water Production System Building (BEJ);

h) Equipment Access Building (BEX);

i) Personnel Access Building (BPX).

The structures which are outside the scope of GDA include the:

a) Essential Service Water Pumping Station A (BPA) and Essential Service Water Pumping Station B (BPB);

b) Circulating Water Pumping Station (BPW);

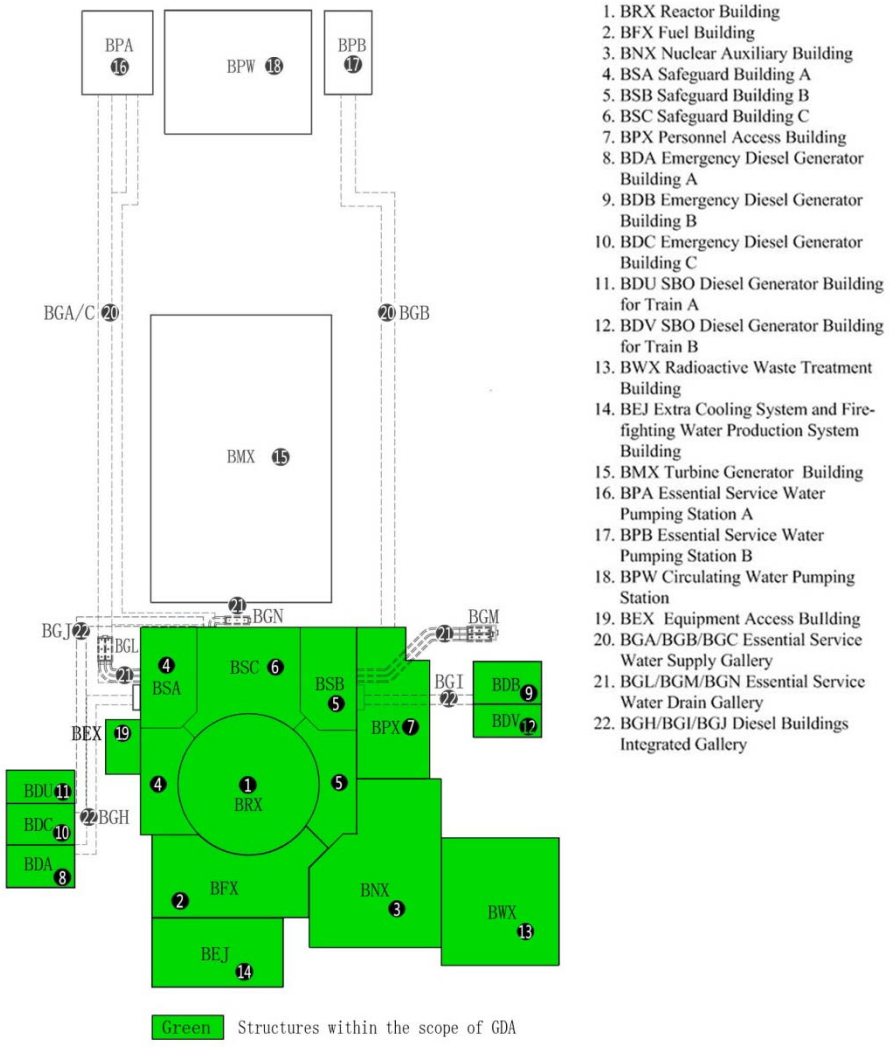
c) Essential Service Water Supply Gallery A (BGA), Essential Service Water Supply Gallery B (BGB) and Essential Service Water Supply Gallery C (BGC);

d) Diesel Buildings Integrated Gallery H (BGH), Diesel Buildings Integrated Gallery I (BGI) and Diesel Buildings Integrated Gallery J (BGJ);

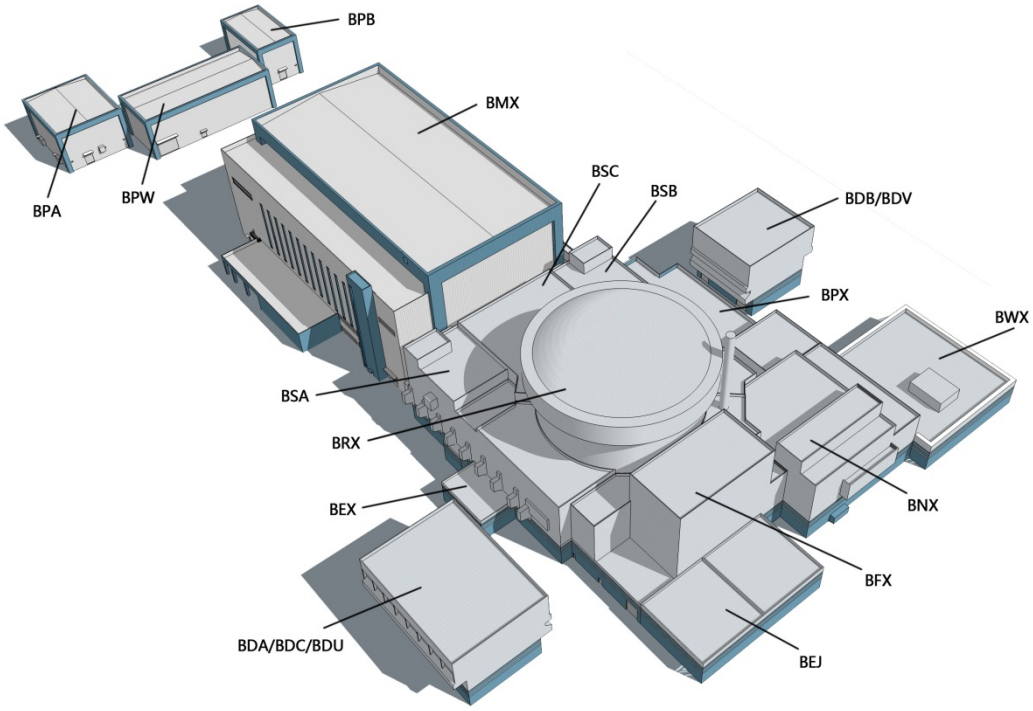
e) Essential Service Water Drain Gallery L (BGL), Essential Service Water Drain Gallery M (BGM) and Essential Service Water Drain Gallery N (BGN);

f) Turbine Generator Building (BMX);

g) Other buildings.



F-16.2-1 Generic Site Layout of the UK HPR1000



F-16.2-2 Overall View of the UK HPR1000

16.2.1.2 Extent of Scope for GDA

The extent of scope for GDA is proportional to the classification of the buildings. For safety class structures, a complete safety case is provided based on the generic site parameters which includes safety function and design requirements, design substantiation, construction, Examination, Maintenance, Inspection and Testing (EMIT), etc. For non-classified structures, the assessment that demonstrates they will not impact or adversely affect the safety class buildings will be provided.

Detailed design documents that have to take into account site characteristics, such as the settlement, soil bearing capacity, and soil nonlinear behaviour will not be provided for GDA. Detailed construction specifications are site-specific and will not be addressed in GDA.

16.2.2 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 objective**,** five high level 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*: The design and intended construction and operation of 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.*

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

In terms of civil structures, **Claim 3.3.9** is developed according to the ***Claim 3.3.***

Claim 3.3.9*: The design of the civil works and structures has been substantiated.*

To support the Claim 3.3.9, this Chapter developed five Sub-claims and a number of relevant arguments and evidence:

a) ***Sub-claim 3.3.9.1****: The safety functional requirements have been derived for the civil works and structures;*

1) ***Argument 1.1****: The safety functional requirements have been identified based on fundamental safety functions, described in Sub-chapter 16.3.1.*

- ***Evidence 1.1.1****: The safety functional requirements of internal and external containment have been identified, Reference [2];*
- ***Evidence 1.1.2****: The safety functional requirements of the BRX internal structures have been identified, Reference [3];*
- ***Evidence 1.1.3****: The safety functional requirements of the safeguard buildings have been identified, Reference [4];*
- ***Evidence 1.1.4****: The safety functional requirements of the BFX have been identified, Reference [5];*
- ***Evidence 1.1.5****: The safety functional requirements of the BNX, BWX, BDA/BDB/BDC/BDU/BDV, BEJ, BPX, and BEX will be identified.*

2) ***Argument 1.2****: The classification & categorisation of the structures have been identified, described in Sub-chapter 16.3.2.*

- ***Evidence 1.2.1****: The methodology of classification & categorisation has been developed, Reference [6];*
- ***Evidence 1.2.2****: The classification & categorisation of civil structures have been identified based on the methodology, described in Sub-chapter 16.3.2.*

3) ***Argument 1.3:*** *The structure design requirements have been derived, described in Sub-chapter 16.3.3.*

- ***Evidence 1.3.1****: The design requirements of internal and external*

containment have been identified, Reference [2];

- ***Evidence 1.3.2****: The design requirements of the BRX internal structures have been identified, Reference [3];*
- ***Evidence 1.3.3****: The design requirements of the safeguard buildings have been identified, Reference [4];*
- ***Evidence 1.3.4****: The design requirements of the BFX have been identified, Reference [5];*
- ***Evidence 1.3.5****: The design requirements of the BNX, BWX, BEJ, BPX, BDA/BDB/BDC/BDU/BDV, and BEX will be identified.*

b) ***Sub-claim 3.3.9.2:*** *The design of civil structures satisfies the safety functional requirements;*

1) ***Argument 2.1****: Appropriate design codes and standards have been identified, described in Sub-chapter 16.4.*

- ***Evidence 2.1.1****: Approach to codes and standards on civil structures have been developed, Reference [7];*
- ***Evidence 2.1.2****: Applicability of codes and standards on civil structures design will be developed.*

2) ***Argument 2.2****: Methodology for civil structures analysis and design has been developed according to the codes and standards, described in Sub-chapter 16.5-16.7.*

- ***Evidence 2.2.1****: Structural analysis and design method statement has been developed, Reference [8];*
- ***Evidence 2.2.2****: Raft foundation analysis and design method statement has been developed, Reference [9];*
- ***Evidence 2.2.3****: Internal containment analysis and design method statement has been developed, Reference [10];*
- ***Evidence 2.2.4****: Overall seismic analysis method statement has been developed, Reference [11];*
- ***Evidence 2.2.5****: Aircraft impact evaluation method statement will be developed.*

3) ***Argument 2.3****: Analysis and design of the structures will be conducted according to the methodology to ensure the safety functional requirements will be achieved, described in Sub-chapter 16.5-16.7.*

- ***Evidence 2.3.1****: Seismic analysis for structures will be conducted.*

- ***Evidence 2.3.2****: Structural analysis and design will be conducted.*
- ***Evidence 2.3.3****: Aircraft impact evaluation for structures will be conducted.*
- ***Evidence 2.3.4****: Ultimate capacity evaluation for internal containment will be conducted.*
- ***Evidence 2.3.5****: Seismic analysis of cliff-edge effect on civil structures will be conducted.*
- ***Evidence 2.3.6****: Structural performance evaluation by Probabilistic Safety Assessment (PSA) will be conducted.*

c) ***Sub-claim 3.3.9.3:*** *All reasonably practicable measures have been adopted to improve the design of the civil structures;*

1) ***Argument 3.1:*** *The civil structures meet the requirements of the relevant design principles and therefore of Relevant Good Practice (RGP), described in Sub-chapter 16.10.*
   - ***Evidence 3.1.1:*** *The consistency review against the RGP has been conducted, described in Sub-chapter 16.10.*
2) ***Argument 3.2:*** *Design improvements will be considered and any reasonably practicable changes are implemented, described in Sub-chapter 16.10.*
   - ***Evidence 3.2.1:*** *The potential improvements against the RGP have been identified, described in Sub-chapter 16.10;*
   - ***Evidence 3.2.2:*** *The potential improvements will be considered in the design of civil structures.*

d) ***Sub-claim 3.3.9.4:*** *The civil structures performance will be validated by commissioning and testing;*

1) ***Argument 4.1:*** *The civil structures have been designed to take benefit from a suite of pre-construction tests, to provide assurance of the initial quality of the manufacture, described in Sub-chapter 16.8.*
   - ***Evidence 4.1.1:*** *The pre-construction tests for the civil structure components and materials will be conducted.*
2) ***Argument 4.2:*** *The civil structures have been designed to take benefit from a suite of commissioning tests, to provide assurance of the initial quality of the build, described in Sub-chapter 16.8.*
   - ***Evidence 4.2.1:*** *The tests on civil structures before commissioning will be conducted.*

e) ***Sub-claim 3.3.9.5:*** *The ageing effects of civil structures have been addressed in the design and suitable EMIT specified.*

1) ***Argument 5.1:*** *The ageing effects have been considered in the design of the civil structures, described in Sub-chapter 16.9.*

- ***Evidence 5.1.1:*** *The detailed ageing effects consideration will be provided.*

2) ***Argument 5.2:*** *An initial EMIT strategy has been developed, described in Sub-chapter 16.9.*

- ***Evidence 5.2.1:*** *The detailed EMIT approach will be developed.*

16.2.3 Chapter Structure

The general structure of this Chapter is presented as the following:

a) Sub-chapter 16.1 lists the abbreviations and acronyms that are mentioned in this Chapter;

b) Sub-chapter 16.2 presents the Sub-claims, arguments and evidence of the civil structures design, and describes the scope of the PCSR and interfaces with other Chapters;

c) Sub-chapter 16.3 describes the safety functional requirements, classification and categorisation and design requirements of the civil structures;

d) Sub-chapter 16.4 presents the selection approach and list of the applicable codes and standards;

e) Sub-chapter 16.5 presents the seismic analysis;

f) Sub-chapter 16.6 describes design of nuclear safety-related structures which include loads and load combinations, structure description, structural analysis and design method;

g) Sub-chapter 16.7 presents beyond design basis conditions, which include ultimate capacity evaluation for internal containment, internal containment performance evaluation, aircraft impact evaluation, and seismic cliff-edge effects of civil structures;

h) Sub-chapter 16.8 summarises construction and testing;

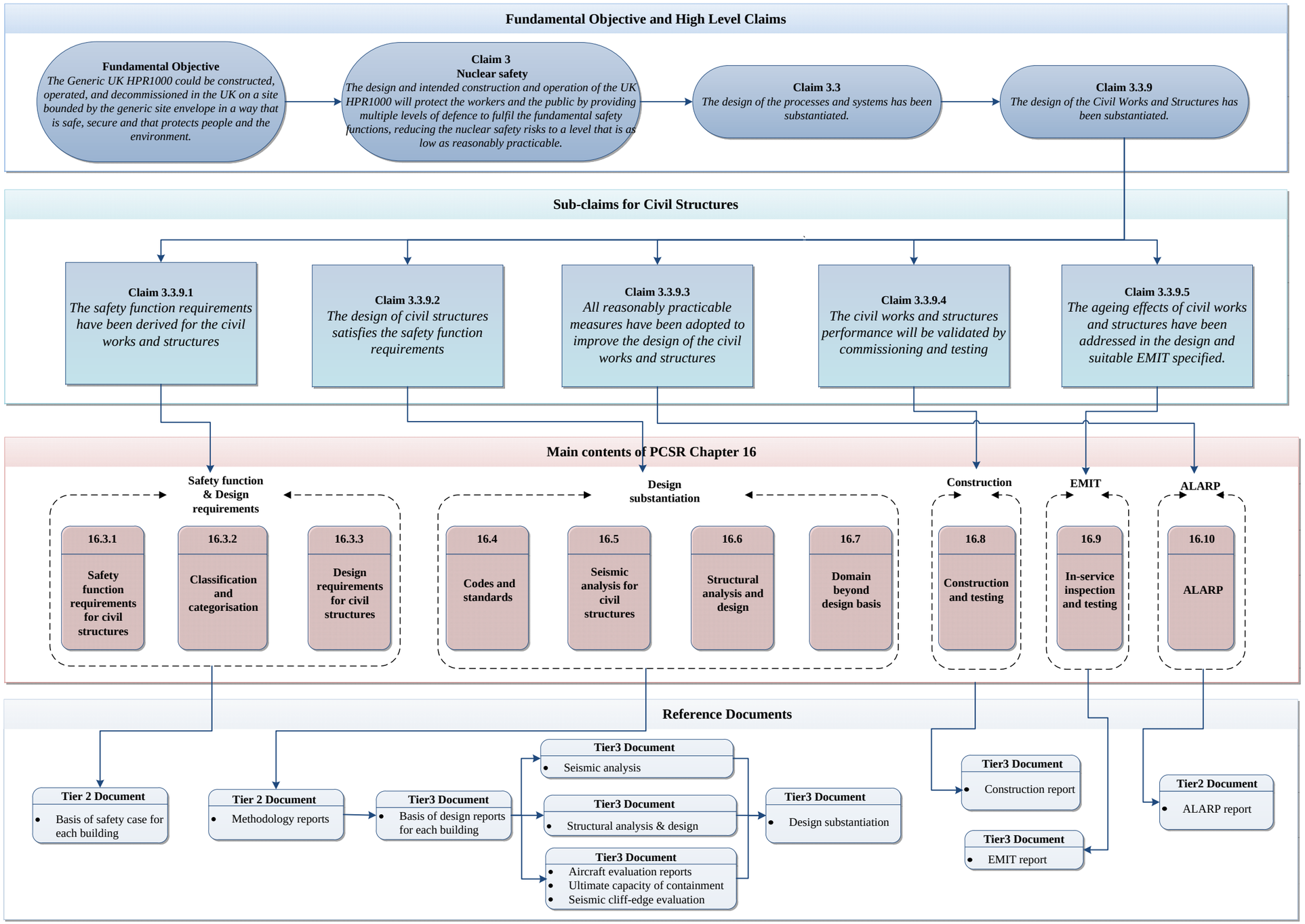
i) Sub-chapter 16.9 describes the initial strategy and forward plan of EMIT;

j) Sub-chapter 16.10 presents the approach of As Low As Reasonably Practicable (ALARP);

k) Sub-chapter 16.11 presents concluding remarks for this chapter;

l) Sub-chapter 16.12 lists the supporting references of this chapter.

This chapter and relevant reference documents form the complete safety case for civil structures. The PCSR presents the claims and sub-claims of civil structures (Tier 1 document). The basis of safety case reports and methodology reports present the arguments (Tier 2 documents), and design reports provide the evidence (Tier 3 documents). The main contents of this chapter are divided into four aspects which are safety function and design requirement, design substantiation, construction and EMIT. The clear traceability is developed based on the main contents as shown in F-16.2-3.



F-16.2-3 Structure of Chapter 16

16.2.4 Interfaces with Other Chapters

The interfaces with other chapters are listed in Table T-16.2-1.

T-16.2-1 Interfaces between Chapter 16 and Other Chapters

Chapter	Interface
Chapter 1 Introduction	Chapter 1 provides the fundamental objective, level 1 claims and level 2 claims. Chapter 16 provides chapter claims, arguments to support relevant claims that are addressed in Chapter 1.
Chapter 2 General Plant Description	Chapter 2 provides an introduction to the main civil structures and their layouts.
Chapter 3 Generic Site Characteristics	Chapter 3 provides generic site parameters for the design of the civil structures.
Chapter 4 General Safety and Design Principles	Chapter 4 provides general engineering substantiation principles, general principles for application of codes and standards, etc. These principles are applied to the design of the civil structures in Chapter16.
Chapter 6 Reactor Coolant System	The design output of civil structures is considered in the system and component design of the reactor coolant system presented in Chapter 6.
Chapter 7 Safety Systems	Chapter 7 presents the safety functions of internal containment and external containment.
Chapter 10 Nuclear Auxiliary Systems	The design output of civil structures is considered in the system and component design of auxiliary systems presented in Chapter 10.
Chapter 11 Steam and Power Conversion System	The design output of civil structures is considered in the system and component design of steam and power conversion system presented in Chapter 11.
Chapter 14 Probabilistic Safety Assessment	Internal containment performance evaluation for PSA is the part of the beyond design basis evaluation described in Chapter 16. The methodology of internal containment performance evaluation is described in Chapter 14.

Chapter	Interface
Chapter 17 Structural Integrity	Chapter 17 presents the structural integrity classification and demonstration of containment steel liner.
Chapter 18 External Hazards	Chapter 18 defines external hazards that lead to loads being placed on the civil structures.
Chapter 19 Internal Hazards	Chapter 19 defines internal hazards that lead to loads being placed on the civil structures.
Chapter 20 MSQA and Safety Case Management	The organisational arrangements and quality assurance arrangements set out in Chapter 20 are implemented in the design process and production of Chapter 16.
Chapter 23 Radioactive Waste Management	Chapter 23 presents the design of radioactive waste management systems which are housed in the civil structures described in Chapter 16.
Chapter 24 Decommissioning	Chapter 24 provides design measures relevant to civil structures to facilitate decommissioning and structure dismantling considerations.
Chapter 25 Conventional Safety and Fire Safety	Chapter 25 and Chapter 16 have an interface in terms of design safety of civil structures and protective barriers, and CDM requirements for building design risk management.
Chapter 28 Fuel Route and Storage	Chapter 28 presents the design of the fuel handling and storage system which is housed in the BRX and BFX described in Chapter16.
Chapter 29 Interim Storage of Spent Fuel	Chapter 29 presents the spent fuel interim storage operation related SSCs in the UK HPR1000, which includes the BFX building described in Chapter 16.
Chapter 33 ALARP Evaluation	Chapter 33 presents the overall ALARP evaluation which is supported by the ALARP demonstration for the civil structures in Chapter 16.

16.3 Safety Functional Requirements and Design Requirements

16.3.1 Safety Functional Requirements

According to the fundamental safety functional requirements and high level safety functions described in Chapter 4, safety functional requirements of civil structures are derived: housing, support and protection for Structures, Systems and Components (SSC), and confinement of radioactive materials as well as limitation of accidental radioactive releases.

These safety functional requirements have been further decomposed into the following detailed requirements.

a) F1: Function to provide structural support to SSC;

b) F2: Function to provide protection to SSC against external hazards;

c) F3: Function to provide protection to SSC against internal hazards;

d) F4: Function to confine the radioactive materials, shield radiation, and reduce radioactive release;

e) F5: Function to maintain specific internal building environment appropriate for SSC during normal operating and accident situations;

f) F6: Function to satisfy the requirements of decommissioning which include supporting SSC, providing a barrier and maintaining the radioactive materials.

These safety functional requirements in different design situations of the civil structures which correspond to UK HPR1000 design conditions described in Chapter 4 are listed in Tables T-16.3-2 and T-16.3-3.

The detailed information of safety functional requirements for internal and external containment, BRX internal structures, BSA/BSB/BSC, and BFX are shown in Reference [2], [3], [4], and [5]. The detailed information for the BNX, BWX, BEJ, BDA/BDB/BDC/BDU/BUV, BEX and BPX will be developed.

16.3.2 Classification and Categorisation

The safety category and safety classification are identified based on the safety function of the structures. According to the principles for the classification of SSC developed in Chapter 4，structures are classified by the highest classification and category of components housed in the building. The seismic category of structures is assigned depending on the required performance during and following a seismic event. The detailed process for the classification and categorisation of structures is described in the basis of safety case reports, Reference [2], [3], [4] and [5].

The classification and category of structures is listed in Table T-16.3-1.

T-16.3-1 Classification and Category of Structures

Building	Function Categorisation	Functional Classification	Seismic Category
BRX	FC1	F-SC1	SSE1
BSA/BSB/BSC	FC1	F-SC1	SSE1
BFX	FC1	F-SC1	SSE1
BNX	FC3	F-SC3	SSE1
BDA/BDB/BDC/ BDU/BDV	FC1	F-SC1	SSE1
BWX	FC3	F-SC3	SSE1
BEJ	FC3	F-SC3	SSE1
BEX	NC	NC	SSE2
BPX	NC	NC	SSE2

a) FC1: Category 1, FC3: Category 3, NC: Non-Categorised;

b) F-SC1: Functional Class 1, F-SC3: Functional Class 3, NC: Non-Classified;

c) SSE1: Seismic Category 1, SSE2: Seismic Category 2.

16.3.3 Design Requirements

The design requirements of civil structures are identified to ensure that the safety functional requirements can be achieved. The design requirements comprise the structural behaviour requirements and other design considerations.

16.3.3.1 Structural Behaviour Requirements

In order to meet the safety functional requirements F1-F4, several structural behaviour requirements are identified based on the safety functional requirements and classification & categorisation of the structures. These structural behaviour requirements will be ensured in design by reaching the relevant design criteria provided in the codes and standards.

The structural behaviour requirements include strength, stability, durability, serviceability, water tightness and air tightness.

a) D1: Strength---Structures are strong and robust. Structures and structural members are designed to have required strengths at all sections;

b) D2: Stability---Structures cannot collapse, and structures can maintain overall structural stability;

c) D3: Durability---Structural durability can satisfy the design life requirement;

d) D4: Serviceability---The deformation of the structure and structural members are

limited and compatible with the requirements of equipment;

e) D5: Water tightness---Structures are required to retain liquids;

f) D6: Air tightness---Structures are required to contain gases under pressure with a limited rate of gas leaks.

16.3.3.2 Other Design Consideration

Except for the structural behaviour requirements, other design considerations have arisen to satisfy the safety functional requirements F5-F6.

For safety functional requirement F5, the specific internal building environment can be maintained by heating, ventilation and air conditioning systems. For safety functional requirement F6, structural requirements consistent with the plant decommissioning described in the Chapter 24 are be derived and satisfied.

These structural behaviour requirements in different design situation of the civil structures are listed in Tables T-16.3-2 and T-16.3-3.

T-16.3-2 Safety Functional Requirements and Design Requirements for the Reactor Building and Typical Components

UK HPR1000 Design Condition	UK Context Terminology	Structural Design Situation	Safety Functional Requirements and Design Requirements	Buildings and Typical Components						
	Plant State			BRX Internal Containment	BRX External Containment	BRX Internal Structures	ASP Tank	IRWST Tank	Reactor Pool	IVR Tank
DBC-1	Normal operation	Normal operation	Safety functional requirements	F1,F4	F1,F4	F1,F4,	F1	F1,F4	F1,F4	F1,F4
DBC-2			Civil design requirements	D1,D2,D3, D4,D6	D1,D2,D3, D4	D1,D2,D3, D4	D1,D2,D3, D4,D5	D1,D2,D3, D4,D5	D1,D2,D3, D4,D5	D1,D2,D3, D4,D5
DBC-3	Frequent faults	Fault	Safety functional requirements	F1,F4	F1,F2,F4	F1,F3,F4	F1,F2,F3	F1,F3,F4	F1,F3,F4	F1,F3,F4
DBC-4	Infrequent faults		Civil design requirements	D1,D2,D6	D1,D2,D6	D1,D2,D4	D1,D2,D4, D5	D1,D2,D4, D5	D1,D2,D4, D5	D1,D2,D4, D5
DEC-A	Frequent fault + failure of 1st line of protection									
	Beyond design basis (including severe accident)	Beyond design basis	Safety functional requirements	F1, F4	F1,F2	F1,F3	/	F1,F3	/	F1,F3
DEC-B			Civil design requirements	D1,D2,D6	D1,D2	D1,D2	/	D1,D2,D5	/	D1,D2,D5

T-16.3-3 Safety Functional Requirements and Design Requirements Applicable to the Buildings excluding the Reactor Building

UK HPR1000 Design Condition	UK Context Terminology Plant State	Structural Design Situation	Safety Functional Requirements and Design Requirements	Buildings and Typical Components							
				BSA/BSB /BSC	BFX	BNX	BWX	BDA/BDB/BDC /BDU/BDV	BEJ	Raft Foundation	Spent Fuel Pool
DBC-1	Normal operation	Normal operation	Safety functional requirements	F1,F4	F1,F4	F1,F4	F1,F4	F1	F1	F1,F4	F1,F4
DBC-2			Design requirements	D1,D2,D3, D4,D5	D1,D2,D3, D4	D1,D2,D3, D4	D1,D2,D3, D4	D1,D2,D3, D4	D1,D2,D3, D4	D1,D2,D3, D4,D5	D1,D2,D3, D4,D5
DBC-3	Frequent faults	Fault	Safety functional requirements	F1,F2,F3, F4	F1,F2,F3, F4	F1,F2,F3, F4	F1,F2,F3, F4	F1,F2,F3	F1,F2,F3	F1,F3,F4	F1,F3,F4
DBC-4	Infrequent faults		Design requirements	D1,D2,D4, D5	D1,D2,D4	D1,D2,D4	D1,D2,D4	D1,D2,D4	D1,D2,D4	D1,D2,D4, D5	D1,D2,D4, D5
DEC-A	Frequent fault + failure of 1st line of protection										
	Beyond design basis (including severe accident)	Beyond design basis	Safety functional requirements	F1,F2	F1,F2	F1	F1	/	/	F1	F1,F2
DEC-B			Design requirements	D1,D2	D1,D2	D1,D2	D1,D2	/	/	D1,D2	D1,D2,D5

16.4 Applicable Codes and Standards

The applicable codes and standards are selected based on the *General Principles for Application of Laws, Regulations, Codes and Standards*, Reference [12]. During the UK HPR1000 design, UK regulations need to be followed, which include *Construction (Design and Management) (CDM) Regulations*, Reference [13], and *Building Regulations*, Reference [14]. The codes and standards which are recognised as RGP are considered.

In order to select applicable codes and standards, an approach to codes and standards for civil structures which reflects the ALARP principle is carried out. More details about the approach to codes and standards are specified in Reference [7].

Strategy on application of codes and standards for the UK HPR1000 is as following:

a) Adoption of American codes and standards for strength design;

b) Adoption of a combination of American and European codes for serviceability design;

c) Material specification is in accordance with European and British codes.

The codes and standards listed below are either the latest version at the time of production of this report or the most compatible to the primary code. The primary codes and standards are supported by a series of supplementary documents and will be listed in its relevant sections or reports.

16.4.1 Seismic Analysis

a) ASCE/SEI 4-16, Seismic Analysis of Safety-Related Nuclear Structures, American Society of Civil Engineers, 2017, Reference [15];

b) ASCE/SEI 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, American Society of Civil Engineers, 2005, Reference [16].

16.4.2 Structural Analysis and Design

a) Internal Containment Structure Design

   ASME Boiler & Pressure Vessel Code, Section III, Division 2, Subsection CC: Code for Concrete Containments, American Society of Mechanical Engineers, July 2013, Reference [17].

b) Other Nuclear Safety-related Structure Design

   1) ACI 349-13, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, American Concrete Institute, August 2013, Reference [18];

2) ANSI/AISC-N690s1-15, Specification for Safety-Related Structures for Nuclear Facilities, incl. Supplement No. 1, American National Standards Institute/American Institute of Steel Construction, August 2015, Reference [19].

3) BS EN 1992, Eurocode 2, Design of Concrete Structures and its UK National Annex, December 2004, Reference [20].

c) Foundation Design

NUREG-0800, US NRC Standard Review Plan for Review of Safety Analysis Reports for Nuclear Power Plants-LWR Edition

Section 3.8.5: Foundations, Revision4, September 2013, Reference [21].

16.4.3 Materials

a) BS EN 206: 2013, Concrete - Specification, Performance, Production and Conformity, Reference [22];

b) BS EN 10080:2005, Steel for the Reinforcement of Concrete - Weldable Reinforcing Steel –General, December 2005, Reference [23];

c) BS 4449:2005, Specification for Carbon Steel Bars for the Reinforcement of Concrete, November 2005, Reference [24];

d) Pr EN10138:2009, Prestressing Steels, August 2009, Reference [25].

16.4.4 Metrication

The design and construction of the UK HPR1000 is carried out based on the international metric system. However, if the reference code or standard is only in the form of imperial system, there are two available options for applying UK HPR1000 design according to the specific conditions:

a) Conversion of the code or standard to international metric system for carrying out UK HPR1000 design;

b) Conversion of the design input from metric to imperial unit, and then carrying out the design according to the imperial code, finally conversion of the design output from imperial to metric system.

16.5 Seismic Analysis

16.5.1 Seismic Input for SSE1 and SSE2 Structures

16.5.1.1 Design Response Spectra

For the GDA phase, certified seismic design response spectra are adopted as the Design Basis Earthquake (DBE) input motion for the seismic analysis of SSE1 and SSE2 structures. The peak horizontal and vertical ground accelerations are 0.30 g and

0.20 g respectively. The design response spectra are applied at the bottom of the foundation.

In the site-specific design phase, site-specific design response spectra will be developed and used for the seismic analysis and design.

16.5.1.2 Design Time Histories

A single set of time histories consisting of two horizontal components and one vertical component is generated to perform time history analysis of civil structures.

The set of time histories is compatible with the design response spectra and satisfies the requirements defined in Reference [16], such as requirements about time increment and duration, amplitude, directional correlation, power spectral densities, etc.

16.5.1.3 Subgrade Properties

In order to envelop the characteristics of potential sites in the UK, the generic subgrade site conditions are defined in Chapter 3 and the specific subgrade parameters are described in Reference [11].

16.5.2 Modelling of Structures

The structures are simulated using 3D finite element models that can represent the properties of mass and stiffness appropriately. The mass of the structure includes self-weight, equipment, distribution systems, effective live load, etc. The stiffness of the structural component is represented based on the material properties and the geometric features.

The structural components are modelled as appropriate element types such as beam elements, shell elements, etc. A reasonable element mesh size of elements is adopted to achieve results of an acceptable accuracy, taking into account the different analysis purposes of finite element models.

The detailed modelling method of structures is described in Reference [11].

16.5.3 Seismic Analysis of SSE1 Structures

Appropriate analysis methods are adopted to carry out seismic analysis of SSE1 structures to ensure that the structures can fulfil their safety functional requirements during an earthquake. Soil-Structure Interaction (SSI) effects are considered in the seismic analysis and performed by the substructuring method with computer program SASSI.

The Floor Response Spectra (FRS) and seismic member demands are developed to design the subsystems and structures.

16.5.3.1 Development of FRS

The FRS are developed using the time series acceleration responses which are determined by seismic analysis of the structures.

The FRS are enveloped over the generic subgrade site conditions. To account for the uncertainties in the dynamic behaviour of the soil and structures, the approach of peak broadening is adopted and the broadening used is ±15% at each peak frequency in the amplified region.

The procedure of developing the FRS is described in Reference [11].

16.5.3.2 Development of Seismic Member Demands

Seismic member demands are calculated using a quasi-one-step analysis method and will be combined with other loads as shown in Sub-chapter 16.6.2.

In the quasi-one-step analysis, dynamic response analysis is performed as the first step to establish overall responses, including acceleration time series and displacement histories. Calculations of member demands are performed in the subsequent step with boundary conditions consistent with the model used for the first step. The dynamic responses obtained from the first step are used as the analysis input for the second step.

The detailed information about calculations of seismic member demands is described in Reference [11].

16.5.4 Seismic Analysis of SSE2 Structures

SSE2 structures are designed to ensure that the DBE action could not cause unacceptable impact on adjacent SSC of SSE1. SSE2 structures are evaluated under the DBE with the same methods of SSE1 structures.

16.5.5 Analysis of Non-nuclear Seismic Structures

Non-nuclear seismic structures are outside the scope of GDA. The design of these structures adopts the normal industrial codes and standards.

16.6 Design of Nuclear Safety-Related Structures

This Sub-chapter mainly introduces the design of nuclear safety-related structures, which includes loads and load combinations, structure descriptions, analysis and design methods.

This Sub-chapter provides the description of the BRX, BSA/BAB/BSC, BFX, BNX, BDA/BDB/BDC/BDU/BDV, BWX and BEJ. The description of the BEX and BPX will be provided in the basis of safety case reports.

16.6.1 Design Principle

Sub-chapter 16.3.3 presents the design requirements of the civil structures under different operating conditions. In order to achieve these design requirements, the following design principles are followed in the design process.

The plant design life is 60 years which is determined in Chapter 2. The aging mechanism of the structures is considered in the design to ensure the safety functional requirements can be achieved throughout the design life.

The principal construction materials for civil structures are concrete, reinforcing steel, structural steel, prestressing tendon, etc. The materials widely used in the UK are adopted preferentially.

Based on the design codes and standards listed in Sub-chapter 16.4, a conservative method and complete load list is adopted to analyse and design in order to ensure that a reliable result achieved can satisfy the design requirements. The durability design is also taken into consideration in the normal operation.

a) BRX internal containment

   For normal and fault conditions, the structures can satisfy their Strength (D1) and Stability (D2) requirements by design in accordance with the code requirements for strength identified in Reference [17]. Complying with the provisions specified in Reference [17] and [20] about durability and serviceability, the structures can satisfy Durability (D3) and Serviceability (D4) behaviour requirements.

   For beyond design conditions, the detailed structure analysis will be developed in *Ultimate Capacity Evaluation for Internal Containment* and *Cliff-edge Effect of Extreme Environmental Hazard for Civil Engineering Structure*.

   The first barrier for Air Tightness (D6) is achieved by an internal steel liner. The structures are used as the second barrier by controlling the concrete stress to limit the development of cracks and adding structural inspection measures.

b) Other nuclear structures

   For normal and fault conditions, the structures can satisfy their Strength (D1) and Stability (D2) requirements by design in accordance with the code requirements for strength identified in Reference [18]. Complying with the provisions specified in Reference [18] and [20] about durability and serviceability, the structures can satisfy Durability (D3) and Serviceability (D4) behaviour requirements.

   For beyond design conditions, the detailed structure analysis will be developed in *Structural Evaluation for Aircraft Impact* and *Cliff-edge Effect of Extreme Environmental Hazard for Civil Engineering Structure*.

   The first barrier for Water Tightness (D5) and Air Tightness (D6) are achieved by

an internal stainless steel liner. The structures are used as the second barrier by controlling concrete cracks and adding structural inspection measures.

The design methodology is provided in Reference [8] and [9].

Detailed implementation of design requirements for internal and external containment, BRX internal structures, BSA/BSB/BSC, and the BFX are shown in Reference [2], [3], [4], and [5]. The detailed information for the BNX, BWX, BEJ, BEX, BPX and BDA/BDB/BDC/BDU/BUV will be developed.

The software used in the analysis and design for the civil structures in the UK HPR1000 are listed below:

a) ACS SASSI: A commercial Windows software for linear and non-linear 3D seismic soil-structure interaction analysis;

b) ANSYS: A commercial finite element software which is used to undertake modelling and analysis of the civil structures;

c) ABAQUS: A commercial finite element software which is used to undertake the analysis of beyond design basis of the containment;

d) SAP2000: A commercial software which is used to undertake structural analysis and design, steel structural analysis and design;

e) LS-DYNA: A commercial software which is used to undertake nonlinear analysis against intentional aircraft impact, dropped loads analysis, etc.

f) REINCAL: A custom software, internally-developed by the RP, which determines the section and reinforcement of structural members;

The verification and validation of the custom software REINCAL will be conducted.

16.6.2 Loads and Load Combinations

The loads used in the design of the civil structures are derived from the normal operation, internal hazards and external hazards. Normal loads conservatively reflect the maximum loads encountered during normal plant operation and shutdown. The external hazards are presented in Chapter 18 and the internal hazards are presented in Chapter 19.

16.6.2.1 Normal Loads

Normal loads include dead loads (D), live loads (L), liquid loads (F), static earth pressures (H), prestressing loads (F_p), normal operating thermal loads (T_o) and normal operating equipment reactions (R_o).

a) Dead Loads (D)

Dead loads include the weight of the structure and the weight of the fixed piping

and equipment during the normal operation of the plant.

b) Liquid Loads (F)

For the water pools within the nuclear island, hydrostatic loads caused by a depth of water in the pools are treated as liquid loads (F).

c) Live Loads (L)

Live loads are divided into live loads during construction and during normal operation. Live loads during construction (carried loads, support imposed loads, etc.) are confirmed according to the construction conditions. Live loads during normal operation are produced by the use and occupancy of the buildings.

d) Static Earth Pressures (H)

Static earth pressures are derived from the effect of backfilled soil.

e) Prestressing Loads (F_p)

Prestressing loads are the loads resulting from the application of prestressing which is used in the design of the prestressed concrete containment.

f) Normal Operating Thermal Loads (T_o)

Normal operating temperature loads are thermal effects and loads during normal operating or shutdown conditions, based on the most critical transient or steady-state condition.

g) Normal Operating Equipment Reactions (R_o)

Normal operating equipment reactions are piping and equipment reactions, or related internal moments and forces that occur under normal operating and shutdown conditions, excluding dead loads and earthquake reactions.

16.6.2.2 Loads from Internal Hazards

Loads arising from internal hazards include internal flooding, postulated high energy pipe failures, dropped loads, internal missiles and internal explosion.

a) Internal Flooding

Internal flooding is assumed in a deterministic way to occur as a failure of the pressurised pipes, except those pipes designed with high integrity component standards.

For compartments within the nuclear island, the potential internal flooding is treated as dead loads (D).

b) Postulated High Energy Pipe Failures

The effects caused by the failures of high energy pipes include overpressure, high

temperature, pipe whip and jet impingement.

1) Accident Pressure Load (P_a)

The design of the civil structures considers a differential pressure across the compartment or building components (such as walls or slabs).

2) Accident Temperature Load (Ta)

The accident temperature load is caused by temperature distributions within the concrete structure occurring as a result of accident conditions generated by a postulated pipe break and including To.

3) Accident Pipe Reactions (Ra)

The accident pipe reactions are considered under thermal conditions generated by a postulated pipe break and including Ro.

4) Local Effects (Rr)

The local effects generated by the postulated pipe breaks include: jet impingement load due to pipe rupture (Yj), missile impact load due to pipe rupture (Ym), and reaction forces due to pipe rupture (Yr).

c) Dropped Loads

A dropped load occurs if the lifting device can no longer control the load on the hook. Moreover, the lifting devices have the potential to fall or collapse according to the standards applicable to the lifting devices.

d) Internal Missiles

Internal missiles may be generated by high energy fluid system components and rotating machinery (i.e., component over speed failures).

e) Internal Explosion

Main potential sources of internal explosion include explosive gases released from a regular operational process, explosive gases released from a pipe failure and high energy arcing faults.

16.6.2.3 Loads from External Hazards

Loads from external hazards include earthquake, aircraft impact, wind and tornado, temperature, snow and icing, and external explosion.

a) Earthquake (E_{ss})

E_{ss} is defined as a Safe Shutdown Earthquake (SSE) for which certain SSC in the plant are designed to remain functional.

b) Aircraft impact

Aircraft impact considered in GDA is divided into two types, accidental aircraft and intentional aircraft. The accidental aircraft is considered as a design basis event. The intentional aircraft is considered as beyond design basis condition.

c) Wind (W)

The wind load is determined using the wind speed value (3-second gust).

d) Tornado Load (W_t)

Tornado load including the effects of missile impact are as following:

1) The tornado generated missile impact effects (W_{tm});

2) The differential pressure loads due to rapid atmospheric pressure change (W_{tp});

3) The loads due to tornado wind pressure (W_{tq}).

e) Temperature

Extreme ambient temperatures include extreme high or low temperatures. These temperature values are used to calculate the thermal effect on the civil structures based on the temperature gradient.

f) Snow and Icing (S)

The snow and icing loads are considered to be live loads. The design basis for snow and icing are determined in the UK HPR1000 generic site report.

g) External Explosion

An external explosion may take the form of a deflagration, which generates moderate pressures, heat or fire, or a detonation which generates high pressures and thermal effects.

16.6.2.4 Test Loads

Test loads are loads which are applied during structural integrity or leak rate tests of prestressed concrete containment, which include:

a) Pressure during the structural integrity and leak rate tests (Pt);

b) Thermal effects and loads during the test (Tt).

16.6.2.5 Load Combinations

To achieve the design requirements introduced in Sub-chapter 16.3, the civil structures are analysed and designed under the loads arising from normal operation, internal hazards and external hazards. The individual loads applied to the buildings are listed in Table T-16.6-1.

The individual loads are combined under different design situations by multiplying the loads by a factor and combining them with other factored loads. The load combinations considered in the design of concrete structures comply with Reference [18]. The load combinations considered in the design of prestressed concrete containment comply with Reference [17]. The detailed load combinations for the civil structures are specified in method statement reports, Reference [8], [9], and [10].

T-16.6-1 Loads Applied to Buildings

Building		**BRX Internal Structures**	**Internal Containment**	**External Containment**	**BFX**	**BSA/BSB/ BSC**	**BNX**	**BWX**	**BDA/BDB/BDC/ BDU/BDV**
Normal operational loads	Dead loads (D)	×	×	×	×	×	×	×	×
	Live loads (L)	×	×	×	×	×	×	×	×
	Liquid loads (F)	×		×	×	×			
	Static earth pressure (H)				×	×	×	×	×
	Prestress loads (Fp)		×						
	Normal operating thermal loads (To)	×	×	×	×	×	×	×	×
	Normal operating equipment reactions (Ro)	×	×	×	×	×	×	×	×
Loads from internal hazards	Internal flooding	×		×	×	×	×	×	
	Accident pressure load (P_a)	×	×	×	×	×			
	Accident temperature load (Ta)	×	×	×	×	×			
	Accident pipe reactions (Ra)	×	×	×	×	×			
	Local effects (R_r)	×	×	×	×	×			
	Dropped loads	×			×		×	×	
	Internal missiles	×				×			

Building		BRX Internal Structures	Internal Containment	External Containment	BFX	BSA/BSB/ BSC	BNX	BWX	BDA/BDB/BDC/ BDU/BDV
	Internal explosion	×	×		×	×			
Loads from external hazards	Snow and icing (S)			×	×	×	×	×	×
	Wind (W)			×	×	×	×	×	×
	Tornado load (W_t)			×	×	×	×	×	×
	Earthquake (E_{ss})	×	×	×	×	×	×	×	×
	Temperature	×	×	×	×	×	×	×	×
	External explosion			×	×	×	×	×	×
	Aircraft impact	{							}
Test loads	Pressure (P_t)		×						
	Thermal effects (T_t)		×						

a) The symbol "×" means that the load is included as a design input for the structure;

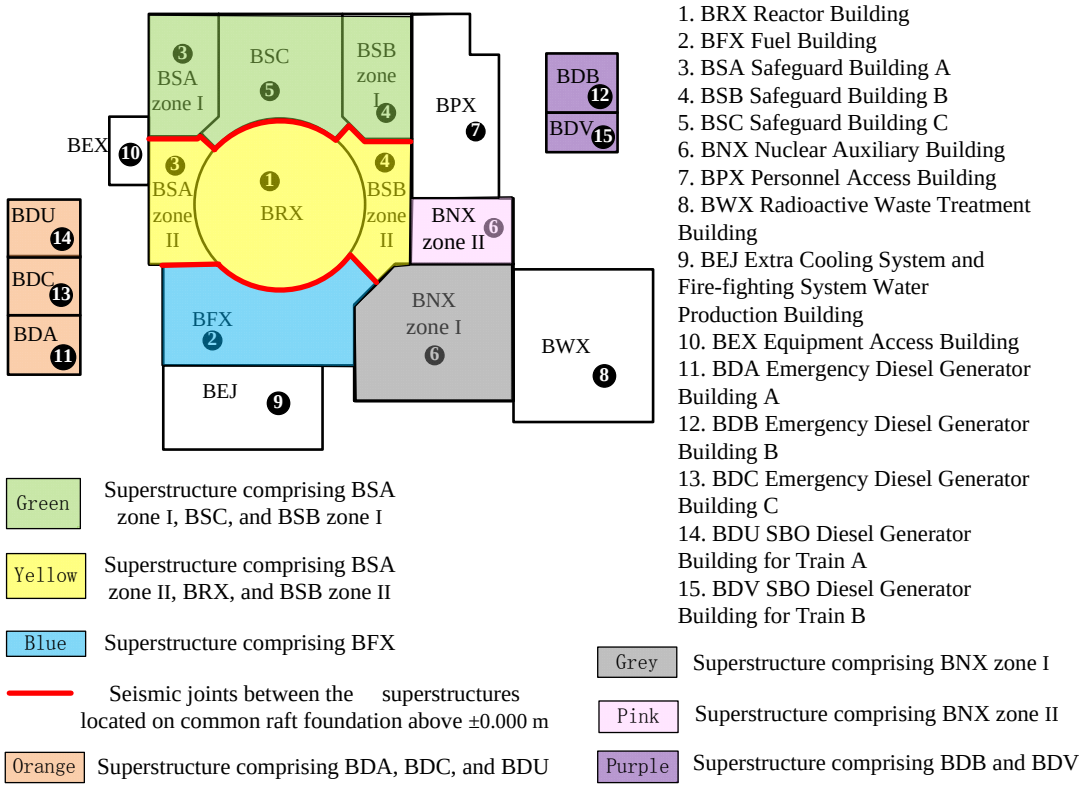
b) This table will be updated during the GDA progress.

16.6.3 Nuclear Safety-Related Structures Layout

The BRX, BSA/BSB/BSC and BFX are located on the common raft foundation. The part of the structures below ±0.000m level (including ±0.000m level) form an integral structure and the part of the structures above ±0.000m level are divided into three parts: superstructure comprising BSA zone I, BSC and BSB zone I, superstructure comprising BSA zone II, BRX and BSB zone II, and superstructure comprising the BFX. These superstructures are separated by seismic joints (which also serve as expansion joints) above ±0.000m level.

The BNX is divided in two parts which are separated from each other. The BDA, BDC and BDU are located on the same raft foundation and the superstructures form an integral structure. The same is for the BDB and BDV.

The layout of nuclear safety-related structures is shown in F-16.6-1. The detailed layout information of the structures is provided in Reference [26].



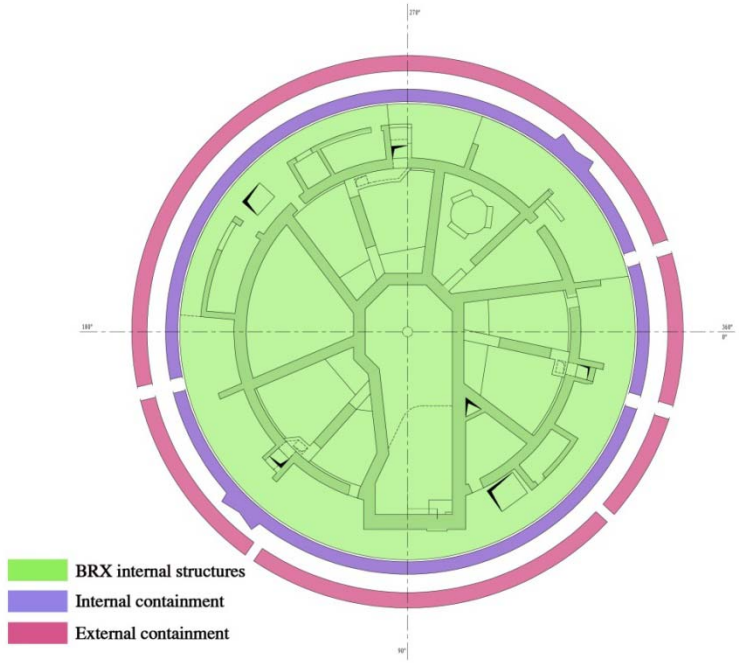
F-16.6-1 Nuclear Safety-related Structures Layout

16.6.4 Reactor Building

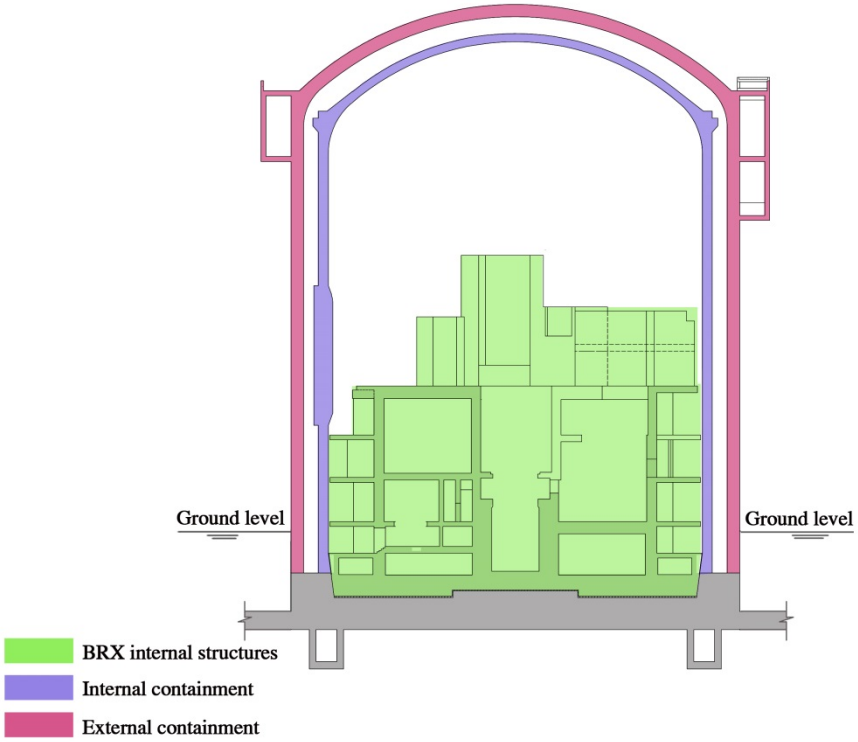
The reactor building consists of the internal containment, external containment and internal structures. It is located in the centre of the common raft foundation.

The external containment is located outside of internal containment; an annulus is set between them. The internal structures are housed by the internal containment.

The typical plan and typical section of the reactor building are shown in F-16.6-2 and F-16.6-3 respectively.



F-16.6-2 Typical Plan of the Reactor Building



F-16.6-3 Typical Section View of the Reactor Building

16.6.4.1 Internal Containment

a) Structural Form

The internal containment is a prestressed concrete structure, the inner surface of which is covered with a steel liner. It comprises of a cylindrical wall, dome, ring belt which connects the cylindrical wall and dome, ribs, equipment hatch, etc. Two vertical ribs are located on the cylindrical wall symmetrically. A prestressing gallery is set below the common raft foundation for the tensioning of prestress tendons.

The main geometry of the internal containment is as follows:

1) The internal diameter is about 45m;

2) The height is about 68m;

3) The thickness of the cylindrical wall and dome are 1.2m and 1.0m respectively;

4) The elevation of equipment hatch centre is +20.800m;

5) The elevation of ring belt is about from +45.000m to +51.000m.

The typical plan of components in the reactor building is shown in F-16.6-4 and the typical section of components in the reactor building is shown in F-16.6-5.

The internal containment prestressing systems adopt bonded tendons, which include the horizontal tendons and vertical tendons. The horizontal tendons surround the cylinder wall and are anchored to the ribs. The vertical tendons are anchored to the bottom of the raft foundation at one end and anchored to the ring belt at the other end.

The steel liner is anchored to the internal concrete surface of the internal containment and at the top of the reactor building foundation. The anchoring system of the steel liner is buried in to the concrete structure and welded to the steel liner plate. It is composed of grids at right angles. The anchoring system is used to reinforce the steel liner and ensure the stability of the steel liner during the construction and operation periods. It can also serve as the construction formwork of the internal containment wall.

The inspection system is embedded in the internal containment, which will monitor the structural behaviour of the internal containment throughout the service life. More detailed information is described in Sub-chapter 16.9.

In order to allow for the passage of equipment, personnel and pipes, an equipment hatch, two personnel access airlocks and other small penetrations are equipped through the internal containment and external containment.

b) Analysis and Design Method

The analysis and design of the internal containment are divided into four parts which are prestressing system analysis and design, current zones analysis and design, singular zones analysis and design, other areas analysis and design.

The aim of the analysis and design is to satisfy that the structural behaviour requirements described in Sub-chapter 16.3.1 can be achieved.

1) Prestressing Analysis and Design

Prestressing system is analysed and designed to provide enough pre-stress for ensuring the leak-tightness of internal containment.

The stress stage of containment concrete is determined based on recognised codes and standards and the thin membrane theory which provides the relationship between internal pressure and membrane stress in the containment. The main parameters of prestressing including the type, number and spacing of prestressing are calculated based on the effective prestress which is calculated by considering recognised codes and standards of prestress loss and geometry information of containment.

2) Current Zones Analysis and Design

The current zone analysis and design include modelling of the structural system, load application to model, load combinations, allowable stresses design for service loads, and allowable stresses design for factored loads.

The above analysis and design process is based on Reference [17]. The structure is modelled and analysed in ANSYS.

3) Singular Zones Analysis and Design

Singular Zones mainly include ribs, ring belt, equipment hatch, etc. Unlike regular geometry conditions of current zones, singular zones contain irregular and discontinuity geometry conditions. Different path of force determination is conducted during the design process. In global model, some local load effects of singular zones such as the tensioning effect are not incorporated. The supplementary local effect calculation thus is carried out.

4) Other Areas Analysis and Design

For global model of current zones, some small penetrations in the current zones which would require an increase in discretisation for explicit representation need to be neglected. Hence, the local models need to provide a more accurate representation of the penetrations layouts to provide better resolution of the local stresses. Detailed design of these zones therefore needs be conducted by combining the local model and global analysis result.

The detailed design methodology is provided in Reference [8].

16.6.4.2 External Containment

a) Structural Form

The external containment is located outside of internal containment. It is a reinforced concrete structure composed of a cylindrical wall and dome. A passive water tank (ASP tank) is located on the top of the cylindrical wall.

The main geometry of the external containment is the following:

1) The internal diameter is about 51m;

2) The height is about 70m;

3) The thickness of the cylindrical wall and dome is 1.5m.

The typical plan of components in the reactor building is shown in F-16.6-4 and the typical section of components in the reactor building is shown in F-16.6-5.

b) Analysis and Design Method

The design and analysis of the external containment mainly comprises of modelling, the load applied, internal force analysis and member section design. The design methods of the external containment are same as the methods described in Sub-chapter 16.6.5.

The aircraft impact evaluation is described in Sub-chapter 16.7.3.

16.6.4.3 BRX Internal Structures

a) Structural Form

The BRX internal structures are located in the centre of the BRX. The plan view of the internal structure is a circle with a radius of 22.5m. The total height is about 41m and the height above the ground is 33.2m.

The BRX internal structures are comprised of three main functional levels:

1) +1.200m (main equipment floor);

2) + 5.660/+7.160m (reactor pool);

3) + 17.500m (service floor);

4) Other auxiliary levels (served by stairs and a lift).

The typical plan of components in the reactor building is shown in F-16.6-4 and the typical section of components in the reactor building is shown in F-16.6-5.

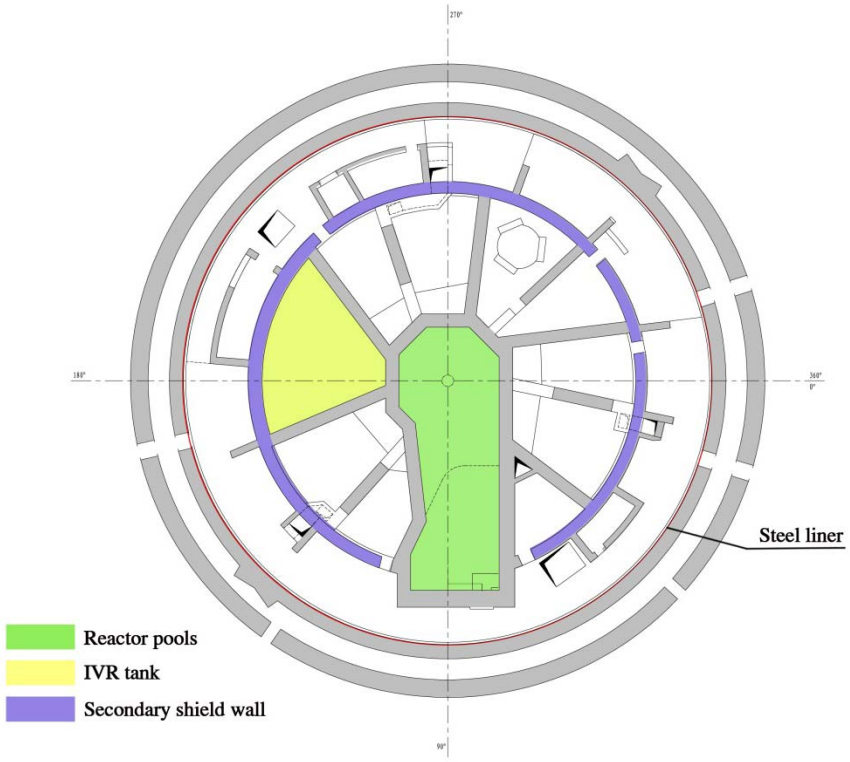
The BRX internal structures mainly comprise of the reactor cavity, secondary shield wall and reactor pools.

The reactor cavity is composed of a cylinder which shares an axis with the reactor building. The cavity supports the reactor pressure vessel and acts as radiation shielding to protect personnel and equipment. The secondary shield walls consist of walls, support slabs and floors. The walls and the reactor cavity form the compartments that enclose all the main reactor cooling systems and equipment.

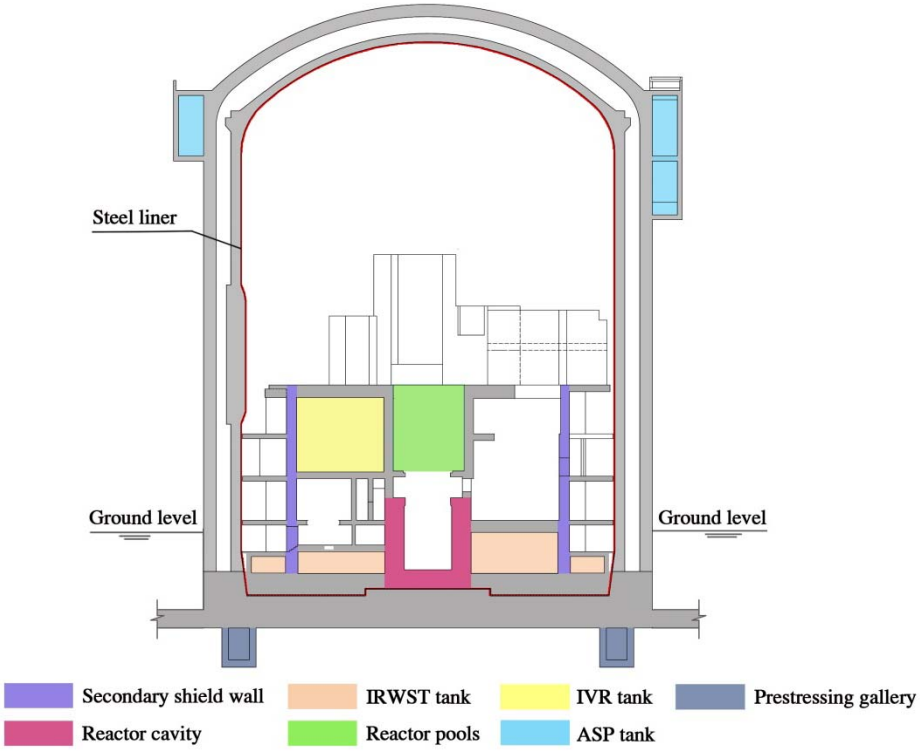
The reactor pool is composed of two parts, the cavity pool and the reactor internal component pool. The pool is lined internally with a stainless steel liner. The liner forms the primary barrier to potential leakage and the concrete walls and slabs form the second barrier.

The BRX internal structures are reinforced concrete walls and slab structures. The horizontal loading is transferred by the slabs to the walls. The vertical loading is supported by the slabs and is transferred by walls of the secondary shield wall, reactor cavity and reactor pools to the common raft foundation.

Detailed design requirements and the layout of the BRX internal structures are provided in Reference [3].



F-16.6-4 Typical Plan of Components in the Reactor Building



F-16.6-5 Typical Section of Components in the Reactor Building

b) Analysis and Design Method

The analysis and design of the BRX internal structures mainly comprises of modelling, the load applied, internal force analysis and member design.

The main design processes include input data, finite element modelling, analysis, and results evaluation.

The input data are derived from the building layout, the general site design parameters, internal hazards and external hazards, etc. The structural system is simplified and used for the modelling. The loads are identified and combined in accordance with the applicable design codes.

Two main different types of finite element model are adopted to perform the design analysis of the internal structures: a global 3D nuclear island finite element model which represents all structures on the common raft foundation, and a 3D internal structures refined mesh finite element model.

Loads and the boundary constraint are applied to the finite element model. Two sets of analysis are undertaken which include overall finite element analysis and local detailed analysis (for special areas).

The in-structure forces and displacements are obtained from the analysis. The member section is revised, and the quantity and allocation of reinforcements are determined based on the refined model results of the BRX internal structures.

Meanwhile, the additional requirements prescribed in the relevant codes are considered, for example, the minimum reinforcement requirement.

16.6.5 Other Structures

16.6.5.1 Structural Form

a) Safeguard Buildings

The safeguard buildings which include the BSA, BSB and BSC are located around the BRX. The main geometry of the safeguard buildings is as follows:

1) The length and width of the safeguard buildings are about 78.2m and 81.4m respectively;

2) The length, width and height of the BSA are about 78.2m, 20.6m and 39.6m respectively (including the raft foundation), including two floors below ±0.000m and six floors above ±0.000m. The BSB is basically the same as BSA;

3) The length, width and height of the BSC are about 40.2m, 38.45m and 43.4m respectively (including the raft foundation), including two floors below ±0.000m and seven floors above ±0.000m.

The typical plan of the safeguard buildings is shown in F-16.6-6. The typical section of the safeguard buildings is shown in F-16.6-7.

The major functional areas housed by the safeguard buildings are as follows:

1) Main control room;

2) Main stream and feed water piping area;

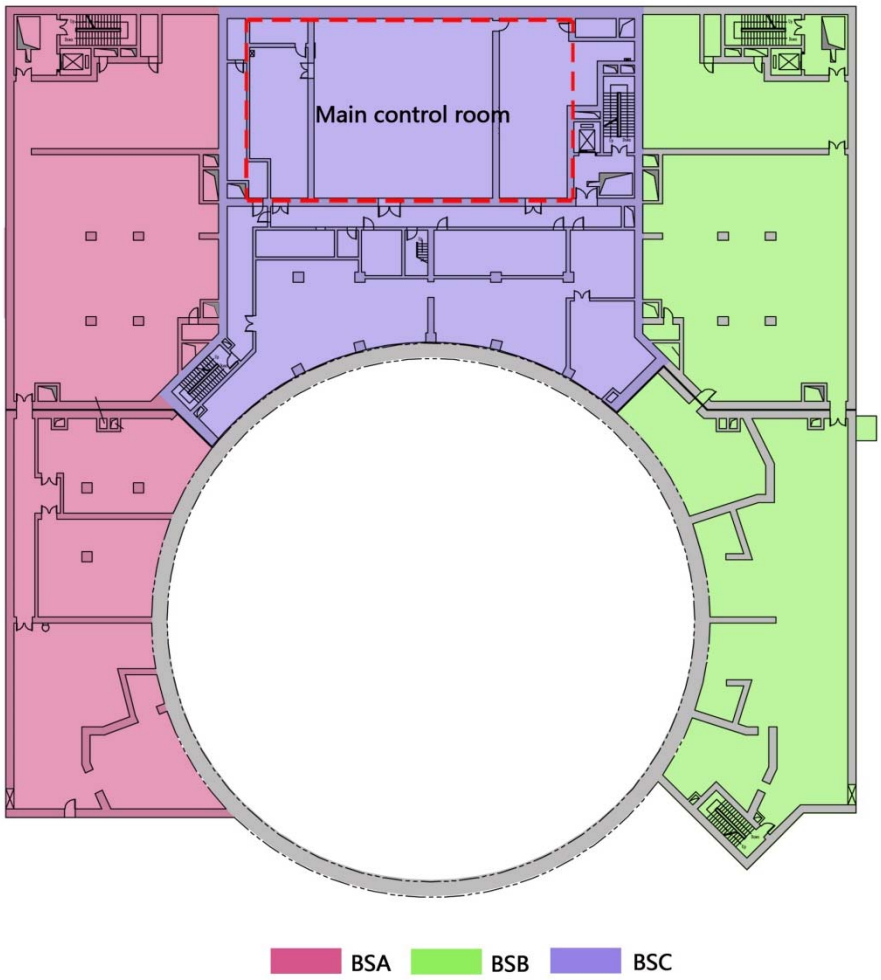
3) Safety-related mechanical and electrical systems area;

4) Instrumentation & control systems area.

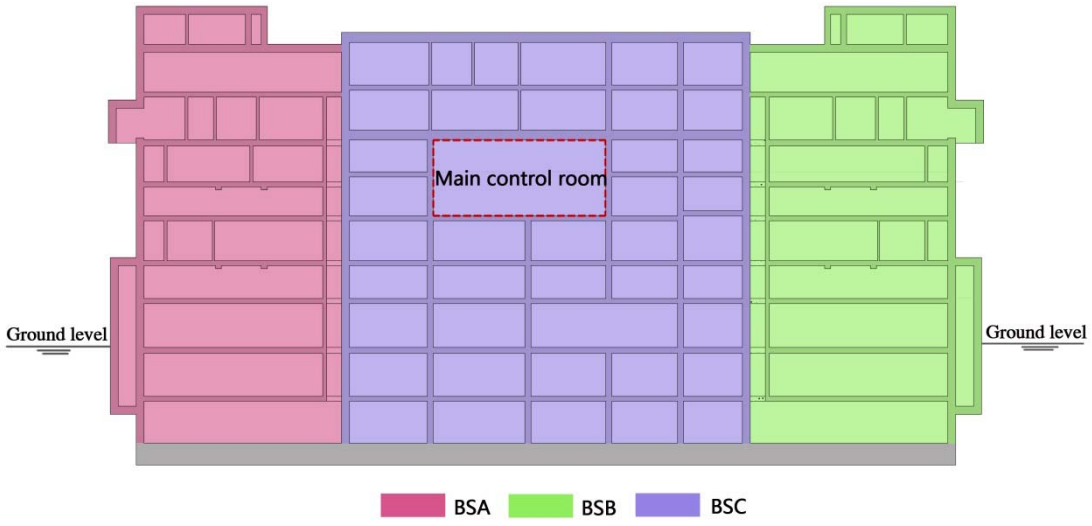
The safeguard buildings are a reinforced concrete structure consisting of cast in-situ walls and slabs, which consist of some reinforced columns and beams in local areas. The thickness of walls is from 0.6m to 1.0m. The thickness of slabs is from 0.5m to 1.0m.

The horizontal loading is transferred by the roofs and slabs to the walls and columns. The vertical loading is transferred by the walls and columns to the common raft. The reinforced concrete walls on the common raft provide stiffness for the common raft and transfer the final loading to the common raft foundation.

Detailed design requirements and the layout of safeguard buildings are provided in Reference [4].



F-16.6-6 Typical Plan of the Safeguard Buildings



F-16.6-7 Typical Section of the Safeguard Buildings

b) BFX

The BFX has ten main levels with eight floors above ±0.000m and two floors below ±0.000m. The main geometry of the BFX is as follows:

1) The length of the BFX is about 59.8m;

2) The width of the BFX is about 23.7m;

3) The height of the BFX is about 39m.

The typical plan of the BFX is shown in F-16.6-8. The typical section of the BFX is shown in F-16.6-9.

The major functional areas housed by the BFX are listed below:

1) The mechanical equipment area;

2) Preliminary mechanical component area;

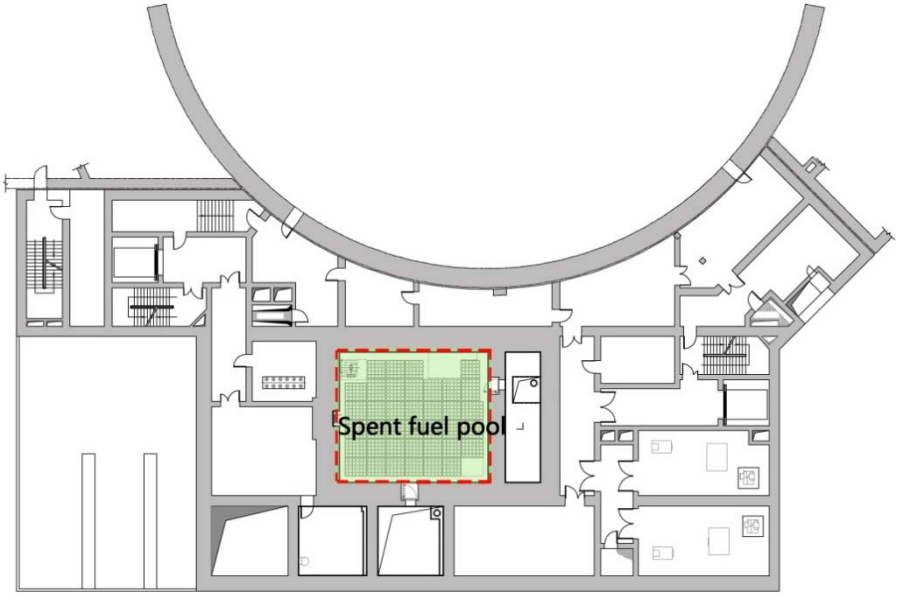
3) The area for ventilation and air conditioning equipment.

The BFX is a reinforced concrete structure consisting of cast in-situ walls and slabs. The thickness of walls is from 0.3m to 1.2m. The thickness of slabs is from 0.4m to 0.7m. The thickness of the roof is 1.0m.

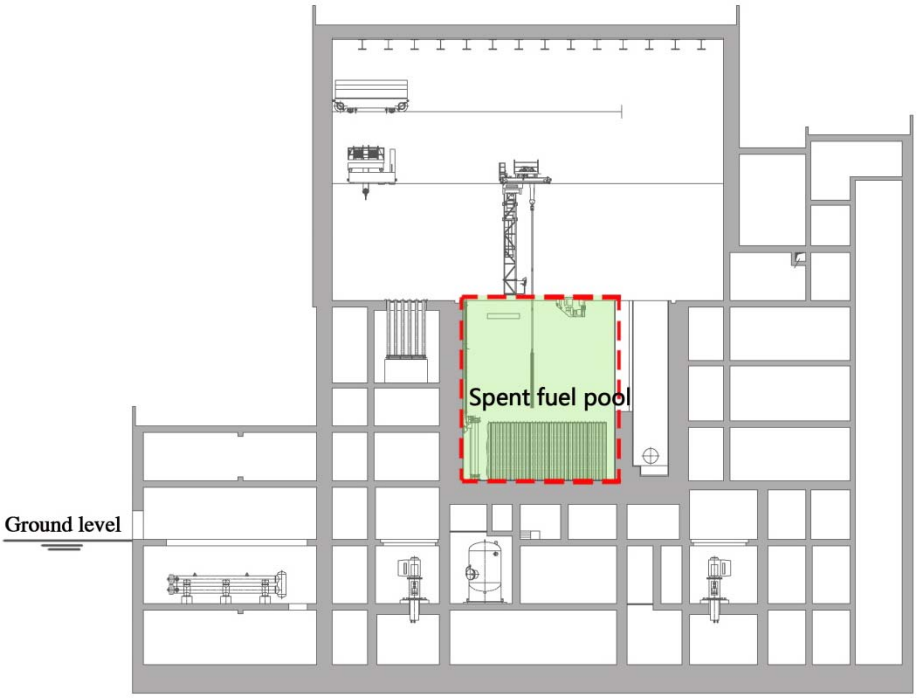
The spent fuel pool is a reinforced concrete structure which is lined with stainless steel plates to ensure leak-tightness. The liner is anchored to the concrete walls of pool and has no structural function. The pool is located at the middle of the structure and the thickness of the walls and floor are at least 1.8m. The walls of the spent fuel pool also act as the structure bearing wall. The thickness of walls is designed to meet the requirements of radiation shielding and structure bearing.

The horizontal loading is transferred by the roofs and slabs to the walls. The vertical loading is transferred by walls to the common raft foundation. The reinforced concrete walls on the common raft foundation provide stiffness for the raft foundation and transfer the final loading to raft foundation.

Detailed design requirements and the layout of the BFX are provided in Reference [5].



F-16.6-8 Typical Plan of the BFX



F-16.6-9 Typical Section of the BFX

c) BNX

The raft foundation and superstructure of the BNX are divided into zone I and zone II which are isolated by a structural joint with a 200mm width. The main geometry of the BNX is as follows:

1) The length and width of BNX zone I are about 43.2m and 50.2m respectively, including three floors below ±0.000m and seven floors above ±0.000m. The height of the superstructure of zone I is about 31m;

2) The length and width of BNX zone II are about 20.8m and 32.1m respectively, including two floors below ±0.000m and four floors above ±0.000m. The height of the superstructure of zone II is about 20.45m, while part of it is 11.25m.

The typical plan of the BNX is shown in F-16.6-10. The typical section of the BNX is shown in F-16.6-11.

The major functional areas housed by the BNX are listed below:

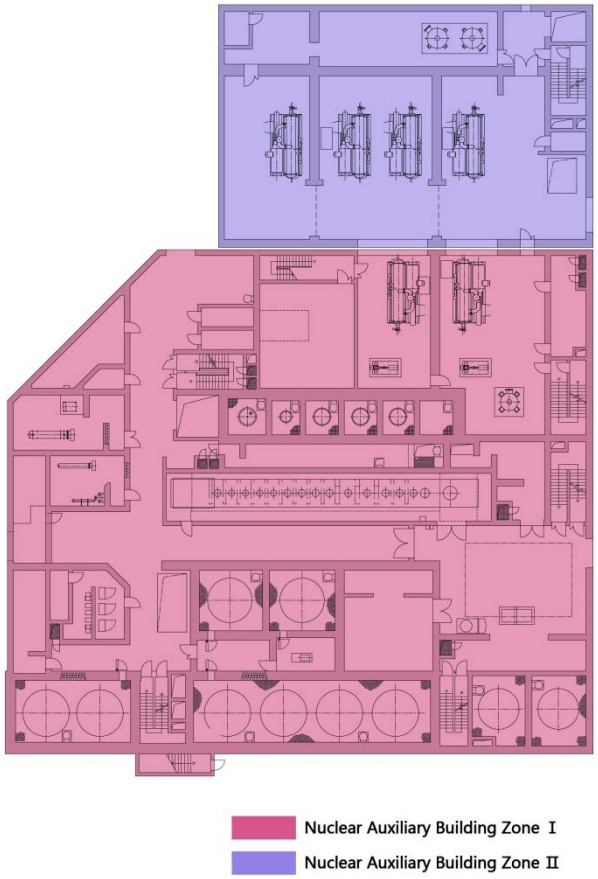
1) Coolant storage and treatment system area;

2) Gaseous waste treatment system area.

The BNX is a reinforced concrete structure consisting of cast in-situ walls and slabs. The thickness of walls is from 0.3m to 1.1m. The thickness of slabs and roofs is from 0.3m to 1.65m.

The horizontal loading is transferred by the roofs and slabs to the walls. The vertical loading is transferred by walls to the raft foundation. The reinforced concrete walls on the raft provide stiffness for the raft and transfer final loading to the raft foundation.

Detailed safety requirements and the layout of the BNX will be provided.



F-16.6-10 Typical Plan of the BNX

F-16.6-11 Typical Section of the BNX

d) Diesel Generator Buildings

The diesel generator buildings comprise of the BDA/BDC/BDU and BDB/BDV. The BDA, BDC and BDU are located on the same raft foundation, while the superstructure forms an integral structure. The same applies for the BDB and BDV. The BDA/BDC/BDU and BDB/BDV are geographical separated by a specified distance to ensure redundancy.

The main geometry of the BDA/BDC/BDU and BDB/BDV is as follows:

1) The length and width of the BDA/BDC/BDU are 44.75m and 26.0m respectively, including five floors above ±0.000m and two floors below ±0.000m;

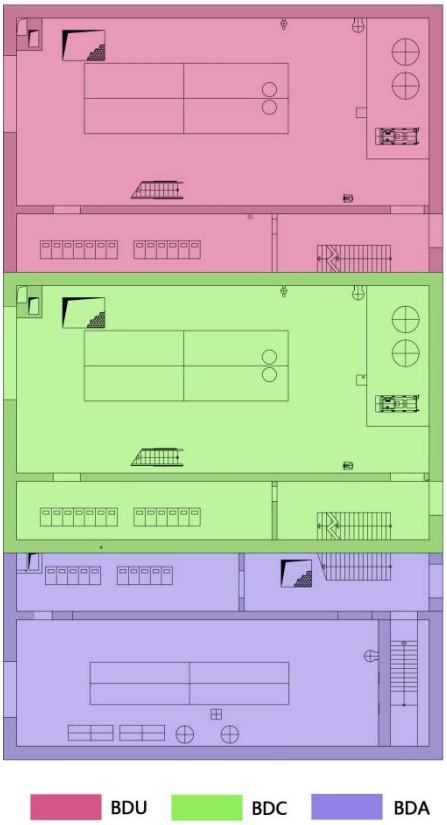
2) The length and width of the BDB/BDV are 28.9m and 26.0m respectively, including five floors above ±0.000m and two floors below ±0.000m.

The typical plan of diesel generator buildings is shown in F-16.6-12. The typical section of diesel generator buildings is shown in F-16.6-13.

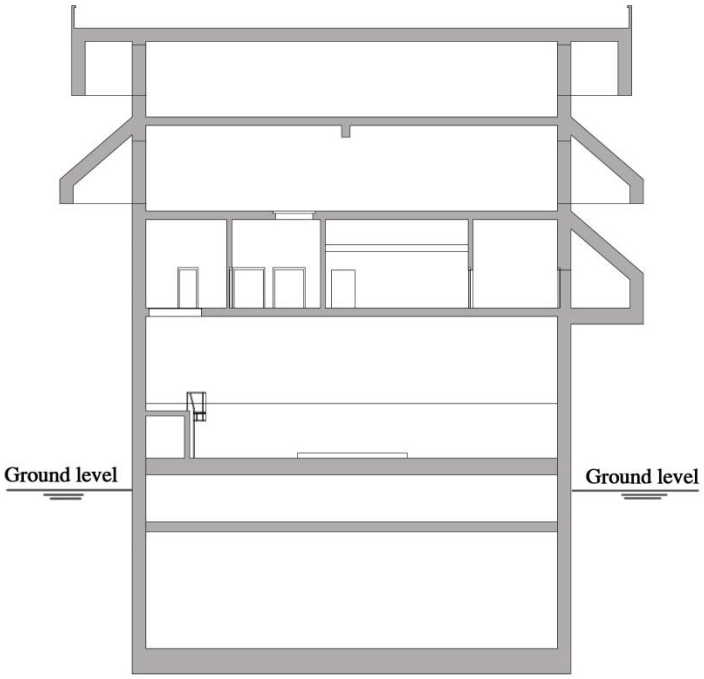
The BDA/BDC/BDU and BDB/BDV are reinforced concrete structures consisting of cast in-situ walls and slabs. The thickness of walls is from 0.3m to 0.8m. The thickness of the slab for supporting the diesel generator is 1.0m.

The horizontal loading is transferred by the roofs and slabs to the walls. The vertical loading is transferred by walls to the raft foundation. The reinforced concrete walls on the raft provide stiffness for the raft and transfer the final loading to the raft foundation.

Detailed safety requirements and the layout of the diesel generator buildings will be provided.



F-16.6-12 Typical Plan of Diesel Generator Buildings



F-16.6-13 Typical Section of Diesel Generator Buildings

e) BWX

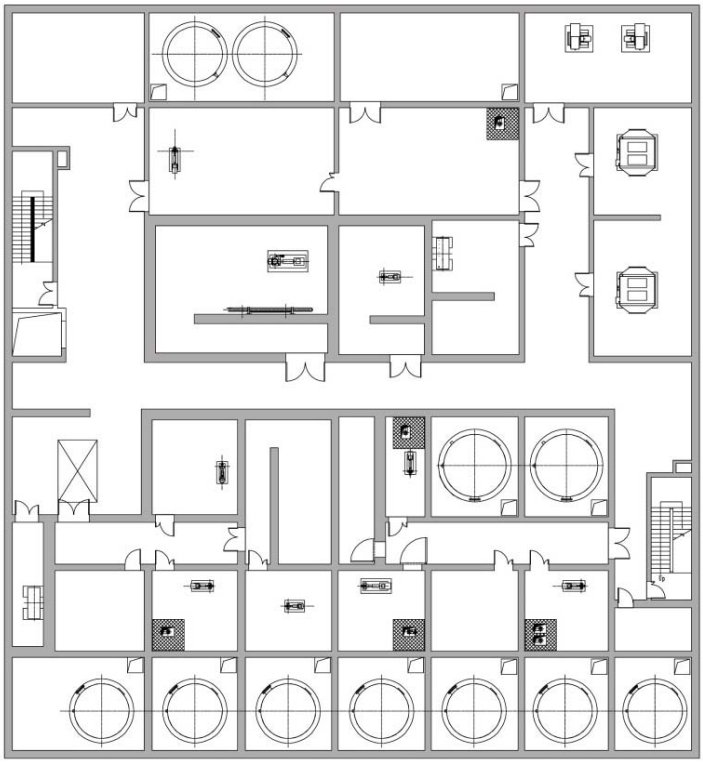
The length and width of BWX are about 48.5m and 44.7m respectively. It has four main levels with two floors above ±0.000m and two floors below ±0.000m.

The typical plan of the BWX is shown in F-16.6-14. The typical section of the BWX is shown in F-16.6-15.

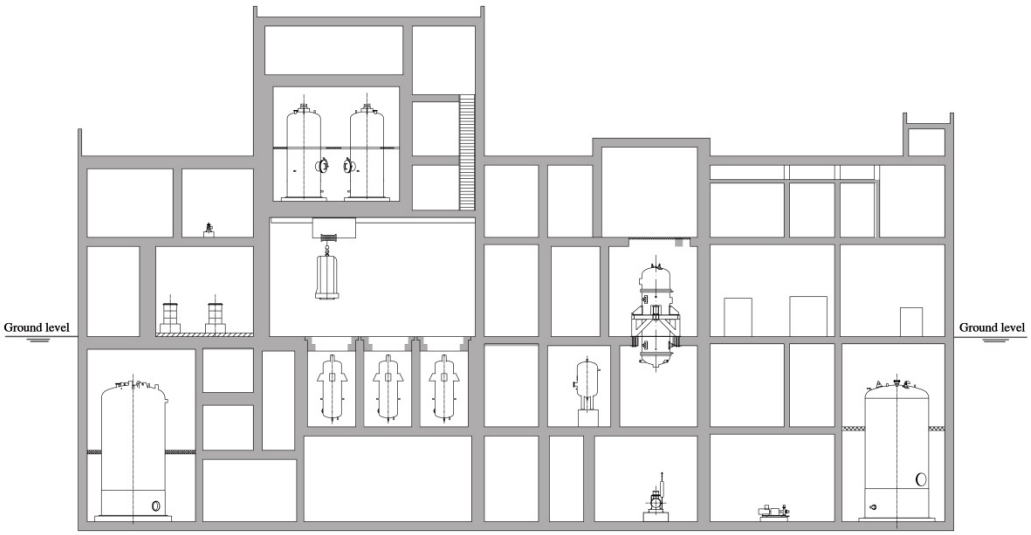
The BWX is a reinforced concrete structure consisting of cast in-situ walls and slabs. The thickness of walls is from 0.3m to 0.9m. The thickness of slabs and roofs is from 0.4m to 0.9m.

The horizontal loading is transferred by the roofs and slabs to the walls. The vertical loading is transferred by walls to the raft foundation. The reinforced concrete walls on the raft provide stiffness for the raft and transfer the final loading to the raft foundation.

Detailed safety requirements and the layout of the BWX will be provided.



F-16.6-14 Typical Plan of the BWX



F-16.6-15 Typical Section of the BWX

f) BEJ

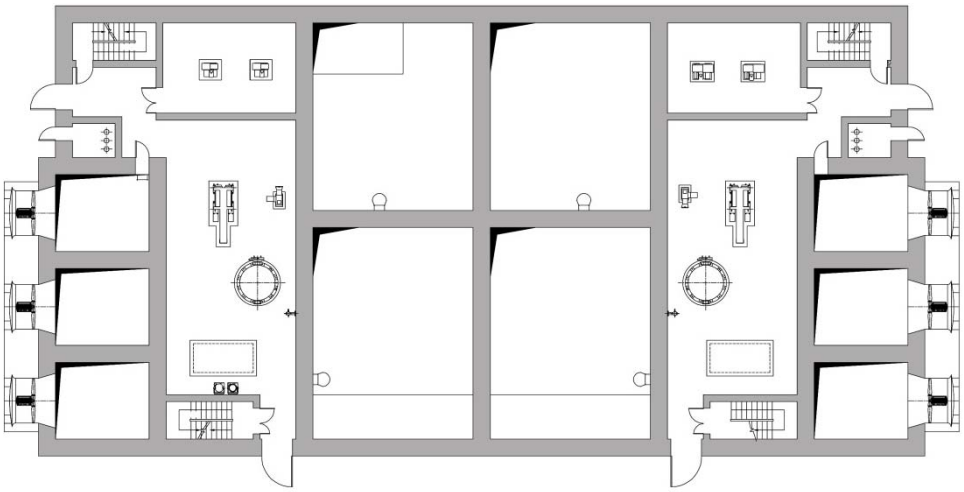
The length and width of the BEJ are about 50m and 26.4m respectively. It has three main levels with two floors above ±0.000m and one floor below ±0.000m.

The typical plan of the BEJ is shown in F-16.6-16. The typical section of the BEJ is shown in F-16.6-17.

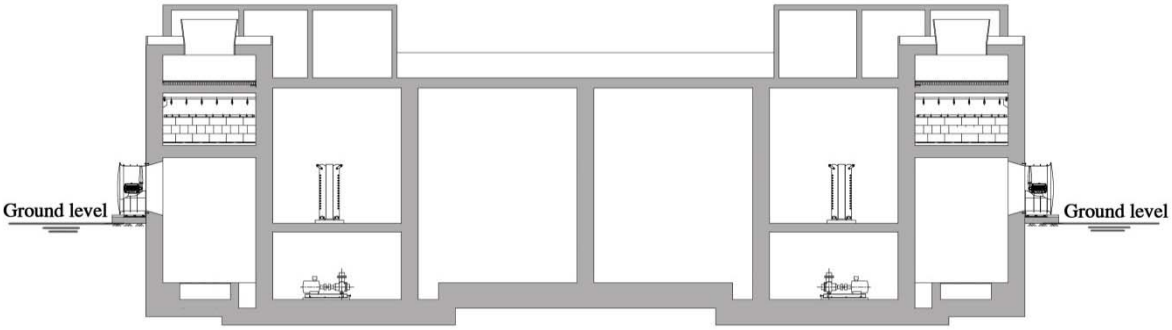
The BEJ is a reinforced concrete structure consisting of cast in-situ walls and slabs. The thickness of outer walls and pool walls are 1.0m. The thickness of slabs at level ±0.000m is 0.5m. The thickness of the roof is 0.6m.

The horizontal loading is transferred by the roofs and slabs to walls. The vertical loading is transferred by the walls to the raft foundation. The reinforced concrete walls on the common raft provide stiffness for the raft and transfer the final loading to the raft foundation.

Detailed safety requirements and the layout of the BEJ will be provided.



F-16.6-16 Typical Plan of the BEJ



F-16.6-17 Typical Section of the BEJ

16.6.5.2 Analysis and Design Method

The design of the structures described in this sub-chapter complies with the appropriate standards and codes. The design process mainly includes input data, loads and load combinations, analysis and design, and results evaluation, etc.

Structures shall be analysed for the loads and load combinations outlined in Sub-chapter 16.6.2 to get the stress, strain and displacement. A computerised program is used to build 3D finite element models for the structural system analysis and dynamic analysis. The results of the analysis are summarised and used in the design of individual members and connections.

Overall analysis is carried out for the structure, and more detailed analysis for complex areas in the structure is implemented when needed. The information such as stress, strain and deformation is obtained from analysis of the structure and members.

The limit state design method adopted in the design comprises of strength design

including calculations of section and reinforcement, and serviceability design including calculations of deformation, cracks, etc.

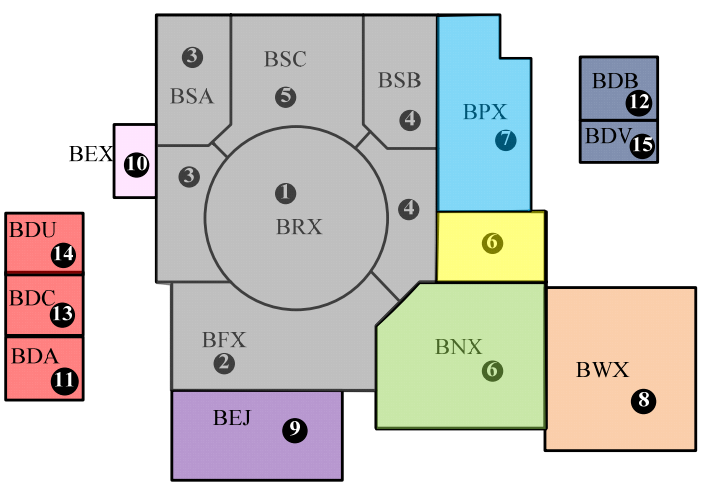
The detailed design methodology is provided in Reference [8] and [9].

16.6.6 Foundation

16.6.6.1 Description

The BRX, BFX and BSA/BSB/BSC are located on a common raft foundation. The BNX, BWX, BEJ, BPX, BEX, BDA/BDC/BDU and BDB/BDV are separately located on the independent raft foundation.

Considering that the foundations contact the soil or rocks directly, a waterproof layer is provided surrounding the external surface of the outer walls and the bottom of the foundations. The raft foundations of the buildings are shown in F-16.6-18.



F-16.6-18 Raft Foundations

a) Common Raft Foundation

The main geometry of the common raft foundation is as follows:

1) The length and width of foundation are about 110m and 82m respectively;

2) Thickness of the raft foundation under the BRX is about 4m;

3) Thickness of the raft foundation under the BFX and BSA/BSB/BSC is about

2.2m.

The bottom level of the common raft foundation is -11.800m. There are some pits located in the common raft foundation.

b) Independent Raft Foundation

The BNX is located on an independent raft foundation of which the main geometry is as follows:

1) The length and width of the zone I foundation are about 43.2m and 50.2m respectively;

2) The thickness of the zone I foundation is from 1.8m to 2.5m, and part of it is from 1.7m to 2.45m;

3) The length and width of the zone II foundation are 20.8m and 32.1m respectively;

4) The thickness of the zone II foundation is 2.0m.

For the BNX, the bottom level of the zone I foundation is -12.750m. The bottom level of the foundation of zone II is -9.250m.

The diesel generator buildings are separately located on two independent raft foundations. The length and width of the BDA/BDC/BDU foundation are about 44.75m and 31.0m respectively. The length and width of the BDB/BDV foundation are about 31.9m and 33m respectively. The thickness of the foundation is about 1.5m and the bottom level of the foundation is -12.800m.

The BWX is located on an independent raft foundation. The length and width of the BWX foundation are about 48.5m and 44.7m respectively. The thickness of the foundation is about 1.8m. The bottom level of the foundation is -12.050m.

The BEJ is located on an independent raft foundation. The length and width of the BEJ are about 26m and 52m respectively. The thickness of the foundation is about 1.5m. The bottom level of the foundation is -4.000m.

16.6.6.2 Analysis and Design Method

The design of the raft foundation is based on the American codes and standards, relevant Euro codes and BS codes as listed in Sub-chapter 16.4.

A global finite element model with the raft and superstructures is used to design the raft foundation. The overall stability analysis is checked for resistance against sliding, overturning and flotation.

The analysis and design of the raft foundation includes strength, stability, durability, serviceability. The wind, tornado or seismic loads are considered in the anti-sliding and anti-overturning analysis, and different safety factors are required. The flotation

analysis is taken into account for both static and seismic loads, and the flotation analysis is not considered during the construction.

The detailed design methodology of the raft foundation is provided in Reference [9].

16.7 Beyond Design Basis Conditions

Beyond design basis is identified according to the fault sequences that have lower frequencies than that of the design basis. The beyond design basis evaluation includes the ultimate capacity evaluation for internal containment, PSA for internal containment, intentional aircraft impact evaluation and seismic cliff-edge effects evaluation.

16.7.1 Ultimate Capacity Evaluation for Internal Containment

16.7.1.1 Purpose

The purpose of containment ultimate capacity evaluation is to evaluate the limit of containment structure capacity under the beyond design basis pressure.

16.7.1.2 Evaluation Method

This evaluation is carried out through a nonlinear analysis methodology by using 3D finite element simulation, which includes modelling, establishing the constitutive relations of materials, loading, global analysis of structural reactions, analysis of typical locations of containment, determination of failure modes and criteria, and evaluation of the ultimate capacity of containment according to the failure criteria.

a) Modelling

   The finite element analysis software is used to establish an overall model of the containment. The model includes prestressing, steel liner, rebars, concrete, typical members and discontinuity parts, such as the equipment hatch and personnel hatches, ribs, etc. Appropriate elements are used to simulate different materials. Concrete is simulated by solid elements, steel liner is simulated as a skin covering the surface of a concrete solid element, reinforcement is simulated by surface elements, and prestressing is simulated by beam elements.

b) Establishing the Materials Constitutive Relations

   Establishing the constitutive relations of materials by considering their nonlinear characteristics is carried out according to UK materials, which is then used as the input data in the model.

c) Loadings

   When the model is established, a series of loadings are applied. The permanent loading and prestressing loading are set in the first analysis step, and then a step-by-step analysis applying pressure loading is carried out in the second

analysis step. In the last step, the thermal effect is taken into consideration.

d) Analysis

In accordance with the calculation results, a global analysis of structural reactions and an analysis of typical locations of containment are carried out to evaluate the structural behaviour and performance.

e) Criteria and Evaluation

Based on Reference [27], failure modes and criteria are determined. The ultimate capacity of the containment can be evaluated according to the calculation results and failure criteria.

The ultimate capacity evaluation will be carried out.

16.7.2 Internal Containment Performance Evaluation for PSA

16.7.2.1 Purpose

Internal containment performance evaluation for PSA is an input for PSA in Chapter 14. The objective of the containment performance evaluation is to develop a probabilistic fragility curve of containment failure which presents the link between the failure probability and the containment pressure. This curve is a key element of Level 2 PSA.

16.7.2.2 Evaluation Method

The containment performance is evaluated using the reliability analysis method. The main content of this evaluation is to quantify the probability of failure in the containment structure at different overpressure conditions by considering the associated uncertainties.

The reliability analysis method is based on a Monte Carlo approach to approximate the probability distribution function for the strength of a structure. A Latin Hypercube Simulation technique is applied to generate random variables.

The probability analysis is carried out and the containment performance is evaluated according to relevant criteria.

The methodology of containment performance evaluation is described in Chapter 14.

16.7.3 Aircraft Impact Evaluation

The civil structures are designed to meet the requirements of protection against intentional aircraft impact. The detailed protection principles are described in reference [28].

16.7.3.1 Safety function

The following functional requirements are incorporated in the plant design:

a) The reactor core remains cooled, or the containment remains intact;

b) Spent fuel cooling or spent fuel pool integrity is maintained.

16.7.3.2 Scope of Protection

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16.7.3.3 Evaluation Method

For intentional aircraft impact, the global effects, local effects, vibration effects and fire effects of the aircraft impact are mainly considered.

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16.7.4 Seismic Cliff-edge Effects of Civil Structures

The primary purpose of seismic cliff-edge effects evaluation of civil structures is to demonstrate that the structures have sufficient margin over the DBE. The seismic cliff-edge effects of civil structures will be considered in the GDA process.

16.8 Construction and Testing

The design of the civil structures must be transferrable into real structures through construction. The final structural performance will be validated and shall comply with the design intent.

Detailed consideration of the construction phase of the UK HPR1000 design is not considered within the scope of the GDA. Aspects that are fundamental to underpinning the safety case for construction and testing of the civil structures are taken into consideration, including requirements for materials, testing and/or inspections. CDM regulations are also considered appropriately in the design and construction.

The construction materials selected comply with the applicable codes and standards and are suitable to enable the design to be constructed, operated, inspected and maintained throughout the life of plant. Provision for inspection and testing during construction will be made to demonstrate that appropriate standards of workmanship are achieved.

In terms of approach to construction, the steel liner of the internal containment cylinder and dome are used as the internal formwork for the concrete. The steel liner welds will be fully inspected before concreting. The internal containment structure

will be instrumented to allow monitoring of its structural behaviour and the monitoring system will be developed during the design.

All structures will be inspected and tested during construction to confirm their compliance with the design intent and construction specifications. The inspection and test methodologies are proportionate to the safety categorisation of each structure. Once significant structural defects are identified, their effects on the safety functional requirements are assessed and remedial measures are applied when necessary.

Preliminary test of the containment system will be completed before commissioning. The objective of the test is to verify that the containment system can withstand the applied pressure in an essentially elastic manner with acceptable leakage.

The installation, tensioning and grouting of the internal containment bonded tendons will be fully trialled and/or tested during construction to ensure that the required tendon preload is achieved and that the tendon duct is completely filled with acceptable grout materials.

The stainless steel liner of the pool shall be subject to leakage test before commissioning.

16.9 In-Service Inspection and Testing

In-service examination, maintenance, inspection and testing procedures of the civil structures will be undertaken to:

a) Demonstrate that the structures continue to meet their safety functional requirements;

b) Confirm that the structures retain or prevent leakage and are leak tight;

c) Identify any significant defects, including ageing and degradation that could compromise the safety functional requirements of structures;

d) Check the validity of predictions of performance made during the design, e.g. the settlement of structures.

All nuclear safety-related structures will be visually inspected at regular intervals as required, appropriate to their operating conditions and demands. The inspection interval will be selected according to the anticipated ageing and degradation mechanisms and the safety categorisation of each structure, appropriate to their operating conditions and demands.

The sealing performance monitoring program for containment is based on the following basic principles:

a) Periodic tests including comprehensive and local tests will be conducted;

b) The bonded tendons will be directly or indirectly monitored throughout the

service life to demonstrate that their integrity and behaviour is acceptable. A number of unbound tendons will be provided in the internal containment structure to allow more detailed testing and visual inspection throughout the service life. The effectiveness of the tendon monitoring program will be demonstrated and validated prior to operation.

In-service inspection and monitoring of the foundations will be undertaken. The settlement of the foundations will be measured at regular intervals and will be compared to design predictions and acceptance limits.

16.10 ALARP

As part of the ALARP strategy presented in Chapter 33, a holistic review of the UK HPR1000 design against RGP is required to identify potential enhancements.The civil structures are part of the overall PSA of the plant and contribute to the overall PSA. If the civil structures critically affect the overall PSA aim and are sensitive, the appropriate actions will be undertaken to add margin of civil structures.

These potential improvements and appropriate actions will demonstrate that risks for the civil structures of UK HPR1000 are ALARP.

16.10.1 Sources of RGP

The following are sources of RGP for civil structures:

a) International Atomic Energy Agency (IAEA) safety standards;

   1) IAEA, Safety Requirements: Safety of Nuclear Power Plant: Design, No.SSR-2/1, Revision 01, 2016.

b) SAPs and TAGs;

   2) ONR, Safety Assessment Principles for Nuclear Facilities, Revision 0, 2014;

   3) ONR, Civil Engineering, NS-TAST-GD-017, Revision 3, 2013;

   4) ONR, Civil Engineering Containments for Reactor Plants, NS-TAST-GD-020, Revision 3, 20134.

c) Codes and Standards;

The RGP codes and standards are recognised and listed in Sub-chapter 16.4.

16.10.2 Potential improvements Identification

The preliminary consistency review work is carried out based on the requirements from RGPs for the overall design of civil structures. The result shows that the safety functional requirements and the design requirements of civil works comply with the RGPs. Meanwhile, there are some potential improvements which are identified during the consistency review. These potential improvements will be enhanced during the

step 3 and step 4 of GDA process.

16.11 Concluding Remarks

This Chapter presents the contents of the civil structures design to underpin the fundamental objective of the UK HPR1000 plant. The chapter is one of the overall PCSR documents and will be updated during the GDA progress.

The complete safety case is established in this chapter and relevant reference documents. The detailed arguments and evidence are provided for the sub-claims to ensure the safety case is valid, complete and evidential.

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