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General Nuclear System Ltd.

UK HPR1000 GDA Project

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Preliminary Safety Report

Chapter 16

Civil Works & Structures

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SENSITIVE INFORMATION RECORD

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16.1 List of Abbreviations and Acronyms

BDA	Emergency Diesel Generator Building A
BDB	Emergency Diesel Generator Building B
BDC	Emergency Diesel Generator Building C
BDU	Station Black Out Diesel Generator Building U
BDV	Station Black Out Diesel Generator Building V
BEJ	Extra Cooling System And Firefighting 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
BGL	Essential Service Water Drain Gallery L
BGM	Essential Service Water Drain Gallery M
BGN	Essential Service Water Drain Gallery N
BGT	Liquid Waste Transfer Gallery
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
BSX	Safeguard Buildings
BWX	Radioactive Waste Treatment Building

CDM	Construction (Design and Management) Regulations
DBA	Design Basis Accident
FRS	Floor Response Spectra
HPR1000(FCG3)	Hua-long Pressurized Reactor under construction at Fangchenggang nuclear power plant unit 3
IAEA	International Atomic Energy Agency
SAP	Safety Assessment Principles for Nuclear Facilities
SBO	Station Black Out
SDRS	Standard Design Response Spectra
SSE	Safe Shutdown Earthquake
SSE1	Seismic Category 1
SSE2	Seismic Category 2
SSI	Soil Structure Interaction
TAG	Technical Assessment Guides
UKHPR1000	The UK version of the Hua-long Pressurized Reactor

16.2 Introduction

This chapter supports the following high level objective: 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.

This chapter will demonstrate the following:

- The Civil Structures provide confinement of radioactive materials in the event of the failure of the reactor coolant system boundary
- The Civil Structures provide the environmental conditions to suit the SSCs
- The Civil Structures provide protection against internal and external hazards

During UK HPR1000 design, the codes and standards which are satisfied the UK safety requirements will be adopted, and the recognised sources of Civil Engineering relevant good practice will be considered, such as SAPs, TAGs, IAEA standards and other references. Moreover, the design will be compatible with UK construction practice and materials.

16.2.1 Layout of Main Buildings

The main block layout of the HPR1000 (FCG3) is described in PSR sub-chapter 2.6, the site layout will:

a) Enhance safety by taking account of potential internal and external hazards, including redundancy and segregation.

b) Define environmental zones for radiation and contamination control and personnel access and escape routes.

c) Provide access around the plant and equipment for installation, operation and maintenance.

d) Provide separation and segregation for the routing of services.

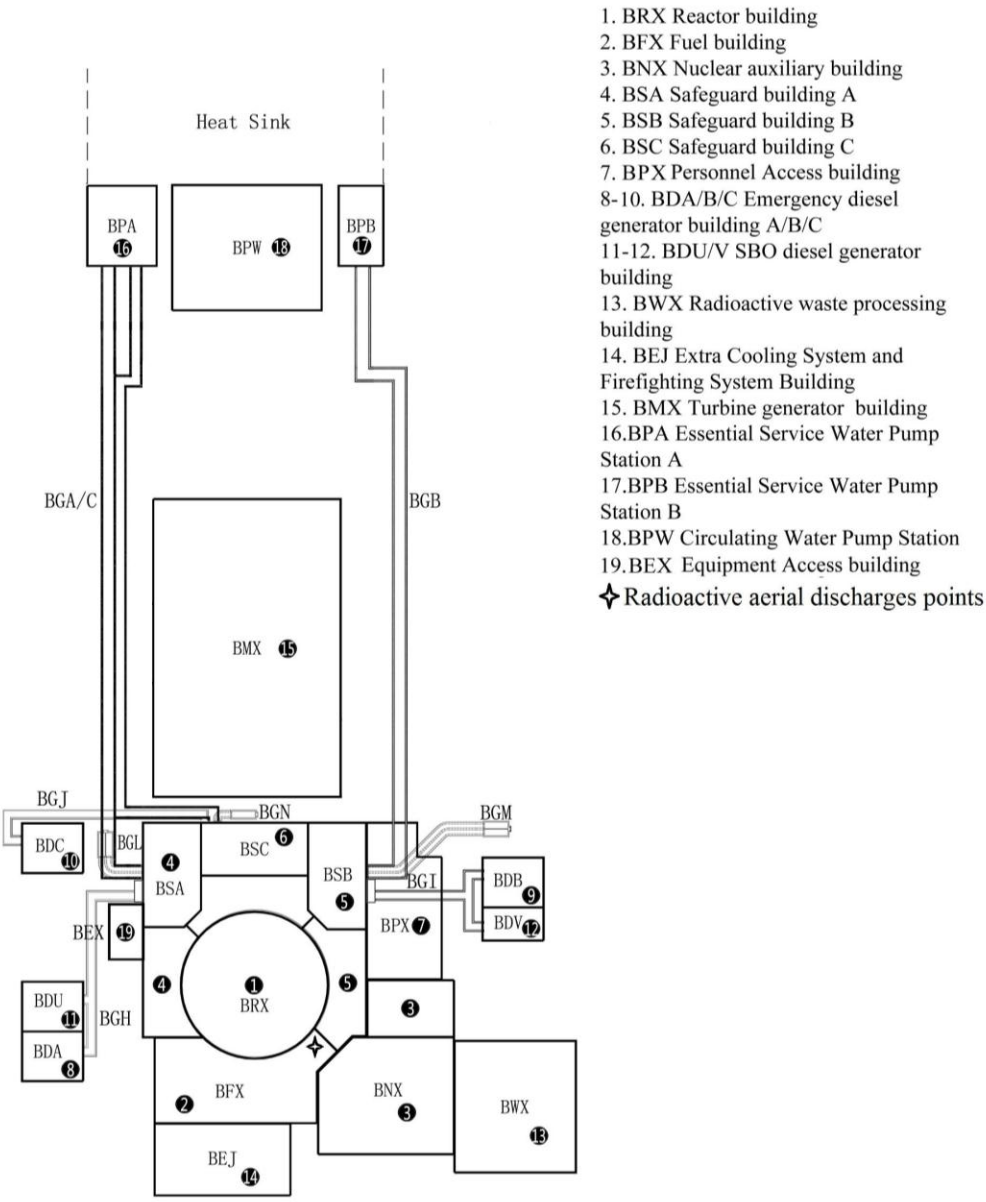
According to the seismic requirements presented in chapter 4, for HPR1000 (FCG3) buildings, Two seismic categories are defined: seismic category 1 (SSE1) and seismic category 2(SSE2). The buildings that are not categorised as seismic category 1 and seismic category 2 are assigned as non-nuclear seismic structures. The layout of main buildings is shown in F-16.2-1.

These buildings are divided into generic and site specific buildings according to their design parameters:

The generic buildings are those whose design is predominantly independent of the site specific condition. These buildings include the reactor building (BRX), safeguard buildings (BSX), fuel building (BFX), nuclear auxiliary building (BNX), emergency diesel generator buildings (BDA, BDB, BDC) and station black out (SBO) diesel generator buildings (BDU and BDV).

The site specific buildings, which design is related to the site specific condition, include the radioactive waste treatment building (BWX), essential service water pumping station (BPA/BPB), essential service water supply gallery (BGA/BGB/BGC), essential service water drain gallery (BGL/BGM/BGN), liquid waste transfer gallery (BGT), extra cooling system and firefighting system building (BEJ), equipment access building (BEX), personnel access building (BPX), turbine generator building (BMX) and other buildings.

The design methodology of SSE1, SSE2 and non-nuclear seismic buildings are introduced in sub-chapter 16.3.



F-16.2-1 Layout of main buildings

16.2.2 Classification of Civil Structures

The safety of the plant is dependent on the performance of its structures under all design conditions. Civil structures have achieved appropriate levels of reliability and integrity during the stages of design, manufacture, construction, commissioning (inspection and testing), operation and maintenance.

Safety-classified structures, systems and components are divided into different categories which are described in PSR chapter 4, depending on the safety functions to be fulfilled.

For structures supporting or protecting safety systems, the classification is same as that of the system which they protect.

T-16.2-1 provides the classification of main buildings.

T-16.2-1 Classification of Main Buildings

Identification code	Description	Design principles	Functional classification	Safety classification in terms of function	Seismic classification	Protection from aircraft crashes	Protection from external explosion
BRX	Reactor building	DPH	FC1	F-SC1	SSE1	Yes	Yes
BSX	Safeguard building A/B/C	DPM	FC1	F-SC1	SSE1	Yes	Yes
BFX	Fuel building	DPH	FC1	F-SC1	SSE1	Yes	Yes
BNX	Nuclear auxiliary building	DPL	FC3	F-SC3	SSE1	No	Yes
BDA/B/C	Emergency diesel generator building A/B/C	NC	FC1	F-SC1	SSE1	Yes	Yes
BDU/V	Station black out diesel generator building U/V	NC	FC3	F-SC3	SSE1	No	No
BWX	Radioactive waste treatment building	DPL	FC3	F-SC3	SSE1	No	No
BEJ	Extra cooling system and firefighting system building	NC	FC3	F-SC3	SSE1	No	No

Identification code	Description	Design principles	Functional classification	Safety classification in terms of function	Seismic classification	Protection from aircraft crashes	Protection from external explosion
BPA/B	Essential service water pumps station A/B	NC	FC1	F-SC1	SSE1	No	No
BGT	Liquid waste transfer gallery	DPL	NC	NC	SSE1	No	No
BGA/B/C	Essential service water supply gallery A/B/C	NC	FC1	F-SC1	SSE1	No	No
BGL/M/N	Essential service water drain gallery L/M/N	NC	FC1	F-SC1	SSE1	No	No
BEX	Equipment access building	NC	NC	NC	SSE2	No	No
BPX	Personnel access building	NC	NC	NC	SSE2	No	No
BMX	Turbine generator building	NC	NC	NC	NO/SSE2*	No	No
BPW	Circulating water pumping station	NC	NC	NC	NO	No	No
Other CI &BOP		NC	NC	NC	NO	No	No

Note: The descriptions of design principle, the definition of function classification, safety classification and seismic classification are described in chapter 4 of PSR.

*: BMX is designed complying with the normal industrial codes, and checked according to the requirements of codes for safety-related nuclear structures. It should be ensured that there has no influence on the SSE1 structures when it collapses.

16.3 Design Methodology

This section provides design methodology for the main civil structures of HPR1000 (FCG3), including the applied Regulations and Standards, design loads and load combinations, and seismic design.

16.3.1 Regulations Applied

The design of HPR1000 (FCG3) considered the relevant requirements from the following regulations:

- HAF101 Safety Regulations for Nuclear Power Plant Siting, Reference [1]
- HAF102 Safety regulations for Design of Nuclear Power Plants, Reference [2]

The design of UK HPR1000 will consider the relevant requirements from the following regulations:

a) Construction (Design and Management) Regulations (CDM), 2015: in particular, the requirement to take into account the general principles of prevention and any pre-construction information to eliminate, reduce or control, so far as is reasonably practicable, foreseeable risks to the health or safety of any person involved in the construction, operation, maintenance, decommissioning or demolition of the structure.

b) Building Regulations, 2010: in particular, the requirements of part A to avoid structural instability and disproportionate collapse.

16.3.2 Codes and Standards Applied

Design codes and standards for the SSE1 and SSE2 civil structures of HPR1000 (FCG3) are listed as following:

- NB/T 20303-2014 Design Requirements for Prestressed Concrete Containments for Pressurized Water Reactor Nuclear Power Plants, Reference [3]
- NB/T20012-2010 Design Requirements for Nuclear Related Concrete Structure for Pressurized Water Reactor Nuclear Power Plant, Reference [4]
- NB/T 20011-2010 Design Requirements for Nuclear Safety Related Steel Structure for Pressurized Water Reactor Nuclear Power Plant, Reference [5]
- GB50010-2010 Code for design of concrete structures, Reference [6]
- GB50017-2003 Code for design of steel structures, Reference [7]
- GB50267-97 Code for seismic design of nuclear power plants, Reference [8]

It can be ensured in design that the SSE1 civil structures have both the integrity and functional requirements.

The design of SSE2 civil structures ensure that the failure of SSE2 civil structures under the safe shutdown earthquake action are not result in an unacceptable interaction with SSE1 civil structures. The SSE2 civil structures are designed to fulfill integrity requirement but the functionality is not required.

The design of non-nuclear seismic civil structures of HPR1000 (FCG3) adopts the normal industrial Codes and Standards listed as following:

- GB50010-2010 Code for design of concrete structures, Reference [6]
- GB50017-2003 Code for design of steel structures, Reference [7]

- GB50009-2012 Load code for the design of building structures, Reference [9]
- GB50011-2010 Code for seismic design of buildings, Reference [10]

The design loads and load combination for SSE1 civil structures of HPR1000 (FCG3) are listed in the following sub-section.

UK HPR1000 civil structures will adopt the relevant good practice codes and standards. The design will be compatible with UK construction practice and materials.

16.3.3 Design Loads and Load Combinations

Design loads and load combinations for the design of HPR1000 (FCG3) SSE1 civil structures have been stated in this section.

16.3.3.1 Design Basis Loads

D—Permanent loads, including self-weight of the structures, weight of the fixed equipment under normal operating conditions, the fluid contained in the structures under normal operating conditions, shrinkage and creep effect of concrete, effect of the highest ground water level, effect of land subsidence, lateral soil pressure

L—Live loads, that occur under normal operating conditions

F—Loads resulting from the application of prestress

G—Loads resulting from relief valve or other high energy device actuation

T_0—Thermal effects and loads during normal operating or shutdown conditions

R_0—Pipe reactions during normal operating or shutdown conditions

P_v—External pressure loads resulting from pressure variation either inside or outside the containment

P_t—Pressure during the structural integrity and leak rate tests

T_t—Thermal effects and loads during the structural integrity and leak rate tests

E_2—Earthquake action caused by the ultimate safety ground motion

R_a—Pipe reaction generated by the Design Basis Accident (DBA), including R_0

T_a—Thermal effects and loads generated by the DBA including T_0

P_a—Design Pressure load within the containment generated by the DBA, based upon the calculated peak pressure with an appropriate margin

R_r—Local effects incurred by the DBA, the local effects shall include the following:

R_{rr}—Reaction produced by high energy pipe break under the DBA

R_{rj}—Jet impact load produced by high energy pipe break the DBA

R_{rm}—Impact load produced by high energy pipe break under the DBA

S_0—Snow load, or related internal moments and forces

W—Loads generated by the design wind specified for the plant site

W_t—Tornado loading including the effects of missile impact

A_1—Impact load incurred by the internal missile

A_2—Shock wave load caused by external explosion

A_3—Load incurred by external missiles

16.3.3.2 Beyond Design Basis Loads

Loads for beyond design basis events have been considered as discussed in PSR chapters 18. The approach for internal and external hazards has been determined on a case by case basis.

16.3.3.3 Load Combinations

The load combinations for HPR1000 (FCG3) have been based on those defined in the design codes and standards defined below. If necessary, additional loads and load combinations have been defined to accommodate coincidental and consequential external and internal hazards as defined in PSR chapters 18 and 19 respectively. Both design basis and beyond design basis loads will be considered. External and internal hazard loads have been combined with the most adverse normal operating conditions.

- NB/T 20303-2014 Design Requirements for Prestressed Concrete Containments for Pressurized Water Reactor Nuclear Power Plants, Reference [3]
- NB/T20012-2010 Design Requirements for Nuclear Related Concrete Structure for Pressurized Water Reactor Nuclear Power Plant, Reference [4]
- NB/T 20011-2010 Design Requirements for Nuclear Safety Related Steel Structure for Pressurized Water Reactor Nuclear Power Plant, Reference [5]

The load combinations for UK HPR1000 will comply with the relevant good practice codes and standards.

16.3.4 Seismic Design

This section will discuss the methods of analysis and the determination of design parameters for the design of SSE1 civil structures of HPR1000 (FCG3). The seismic design has considered the necessary loads and load combinations, including design basis earthquake actions, to enable the following functional requirements to be met:

a) Overall stability, to prevent the building or structural systems from collapsing;

b) Local stability, to prevent the collapse of structural components;

c) Reliable support for the plant or the equipment to enable it to operate during or after the earthquake;

d) Containment, to minimize the release of radioactive materials into environment, mainly defined by the sealing requirements for buildings and structures;

e) Interaction, to prevent adjacent buildings or structures from colliding under earthquake motions. Seismic gaps will be provided between structures to avoid adverse interactions.

16.3.4.1 Seismic Design Parameters

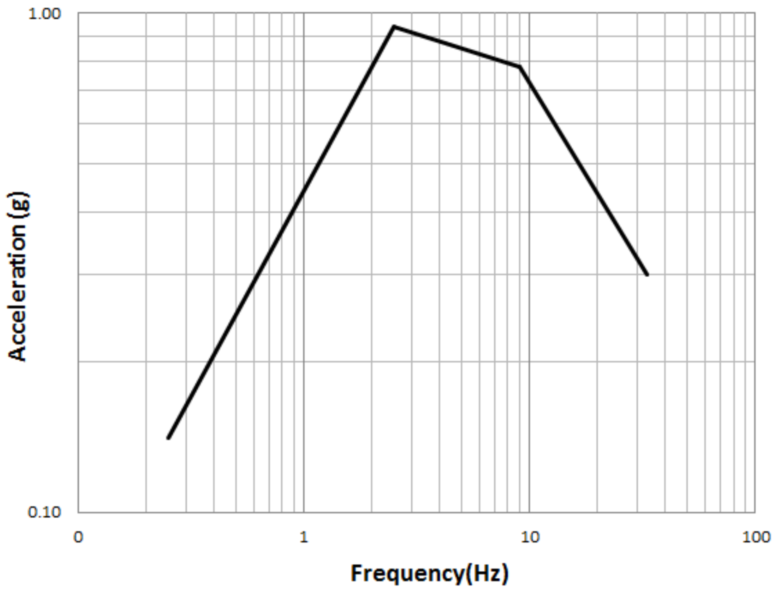
a) Design ground motion

The Standard Design Response Spectra (SDRS) is defined using NRC Regulatory Guide 1.60 as shown in F-16.3-1, according to Reference [11]. The excitation point is located at the bottom of the building foundations. For the design basis, the Safe Shutdown Earthquake (SSE) is defined for standard design buildings using the SDRS with peak horizontal and vertical ground accelerations of 0.30g and 0.20g respectively.

b) Damping values

For concrete structures, the damping values of prestressed concrete structure and reinforced concrete structures under SSE are 0.05 and 0.07 of critical, according to Reference [12].

For steel structures, the damping values of welded steel structures and bolted/riveted steel structures under SSE are 0.04 and 0.07 of critical, according to Reference [12].



F-16.3-1 Standard design response spectra used in HPR1000 (FCG3)

16.3.4.2 Seismic Analysis

The seismic analysis has been undertaken in compliance with GB50267, Reference [8]. Two orthogonal horizontal earthquake components and one vertical earthquake component are used.

Different methods have been adopted in the seismic analysis as appropriate to determine the seismic response of structures subjected to earthquakes. These include the equivalent static method, response spectrum method and time history analysis method. Floor Response Spectra (FRS) have been generated using time history analysis for the analysis and design of seismic subsystems.

The dynamic soil structure interaction (SSI) between the supporting soil/rock and the structure has been considered. Impedance functions are calculated by considering the ground as a semi-infinite space, modelling using spring and damper elements.

16.4 Design of SSE1 Structures

The safety requirements for SSE1 civil structures of HPR1000 (FCG3) are listed as following:

a) The civil engineering structures are required to provide support to the structures, systems, components in normal operation, internal hazards and external hazards through life to ensure the continuous normal operation of nuclear power plant.

b) The civil engineering structures are required to provide barrier function to protect the SSCs from external hazards to ensure the safety functions.

c) The civil engineering structures are required to provide barrier function to protect the SSCs from internal hazards including internal flooding, fire, high energy pipe break, internal missile etc. to ensure the safety functions.

d) The containment structure is required to provide seal tightness to contain radioactive materials.

e) The foundation structures are required to withstand the superstructures and keep stability.

It can be ensured in design that the safety requirements are fulfilled throughout the life of the structures.

16.4.1 Validation and Verification

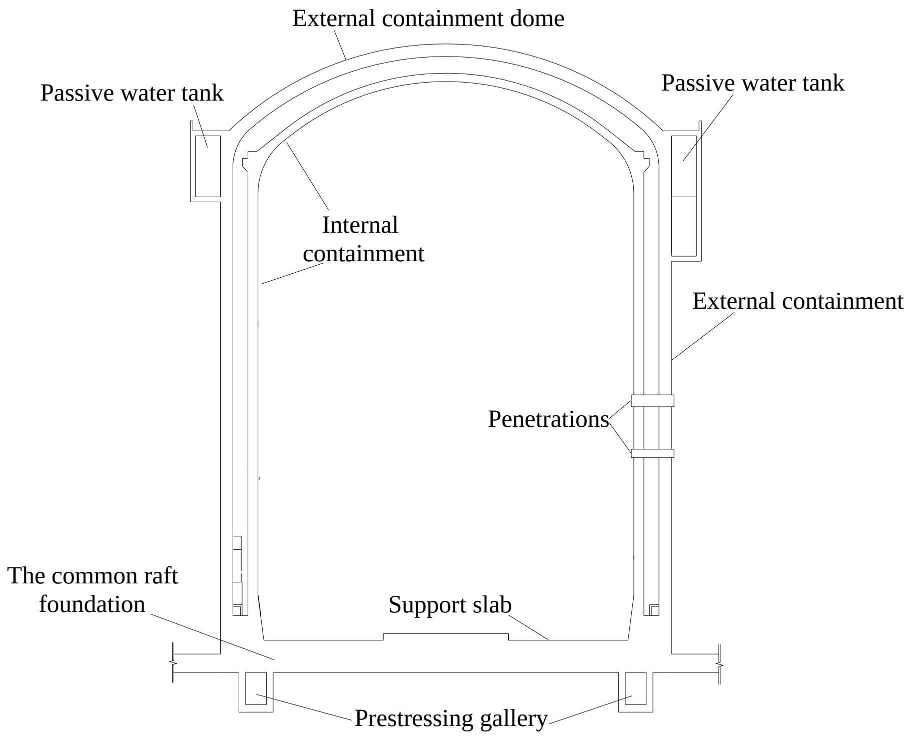
The following sub-chapters describe the analysis and design of the SSE1 structures. The computer analyses and calculation methods used have been validated and verified.

16.4.2 Reactor Building Containment Structure

16.4.2.1 Description

This section describes the considerations in the design of the reactor building containment structure. The containment system is the last barrier preventing releases of radioactive materials from the reactor into the environment. The containment provides effective radiation protection for the environment under all the postulated accidents, including the primary circuit coolant pipe breakage which will cause the rapid increase in pressure and temperature in the containment and the release of gaseous fission products.

The containment structure also protects the primary circuit from external hazards. The containment is a double-walled structure (internal and external) located on a common raft foundation of reinforced concrete, as shown in F-16.4-1. None of the leakage could be discharged to the environment without being filtered.



F-16.4-1 Concrete containment

16.4.2.1.1 Internal Containment Structure

The internal containment is a prestressed concrete structure, the inner surface of which is covered with a stainless steel liner to minimize the leakage of radioactive material. At the bottom, the steel liner is fixed to the concrete wall via continuous angled anchors and localised stud anchors, and located between the common raft foundation and the support slab for the reactor building internal structures, as shown in F-16.4.1. The internal containment structure has several penetrations which allow the passage of cables, pipes, personnel and equipment.

Prestressing has been provided by an arrangement of steel tendons. Instrumentation has been provided to monitor the tendon loads as discussed in sub-chapter 16.6.2.

16.4.2.1.2 External Containment Structure

The geometric form of the external containment structure is similar to that of the internal containment. The external containment is a reinforced concrete structure composed of a cylindrical wall and dome supported by the common raft foundation. The upper part of the cylindrical wall and dome is designed to protect the internal containment and internal structures from the impact of large commercial plane. This is achieved by the structural dimensions, concrete strength and steel reinforcement provision. The effects from the airplane impact, such as global response, local damage and vibration, have been analysed and assessed.

16.4.2.1.3 Penetrations

Various types of penetrations are provided in the containment, including mechanical penetrations, ventilation penetrations, electrical penetrations, instrumentation and control (I&C) penetrations, equipment hatch, personnel airlock, personnel emergency gate and a fuel transfer channel. Penetrations in the containment are located within the surrounding buildings, which provide protection from external hazards.

16.4.2.2 Design and Analysis

16.4.2.2.1 Design

The design flowchart is shown in F-16.4-2. The design of the internal containment covers the following contents:

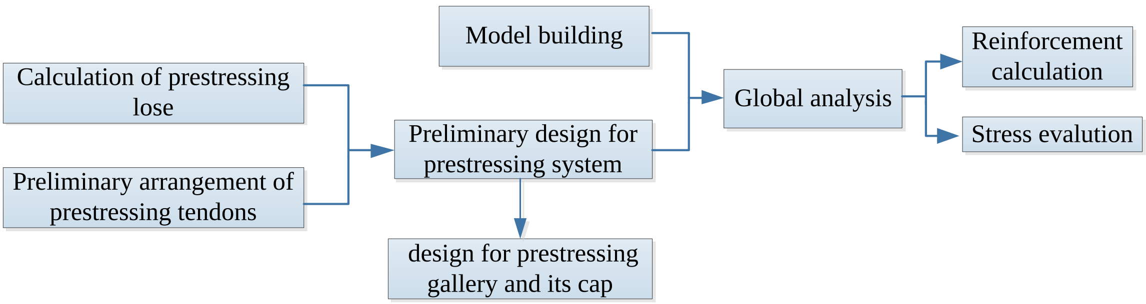
a) The design of the prestressing system;

b) The design of the steel liner;

c) The analysis of the structural performance with the thermal stress under the accident conditions;

d) The analysis of the structural performance under earthquake conditions;

e) The analysis and verification of leakage when the design pressure is exceeded.



F-16.4-2 Design flowchart of internal concrete containment

16.4.2.2.2 Analysis

a) Internal Containment

The structural analysis of the internal containment assumes that the structure remains essentially elastic during all design basis conditions. Static and dynamic finite element analyses have been conducted. The analysis includes the installation, tensioning and relaxation of the prestressing tendons over the service life.

b) Steel Liner

The material of steel liner is assumed to be ideally elastic-plastic. In the calculation, the steel liner and the internal containment concrete structure are assumed to have the same deformation, namely, no relative displacement or slippage has occurred. The analysis of steel liner includes three continuous stages:

Stage 1, the steel liner deformation and restraint are analysed to determine the plastic development zone;

Stage 2, the steel liner performance and anchorage system are further analysed;

Stage 3, the effect of the anchoring point failure is analyzed, and steel liner buckling is checked.

c) Penetration Sleeves

The penetration sleeves have been designed to have sufficient margin to avoid breaking and excessive plastic deformation. The penetration sleeves embedded in the concrete also satisfy the design requirements for the steel liner.

d) External Containment

The external containment analysis can use the methodology described in sub-chapter 16.4.4.2.2 for other SSE1 structures.

16.4.3 Reactor Building Internal Structures

16.4.3.1 Description

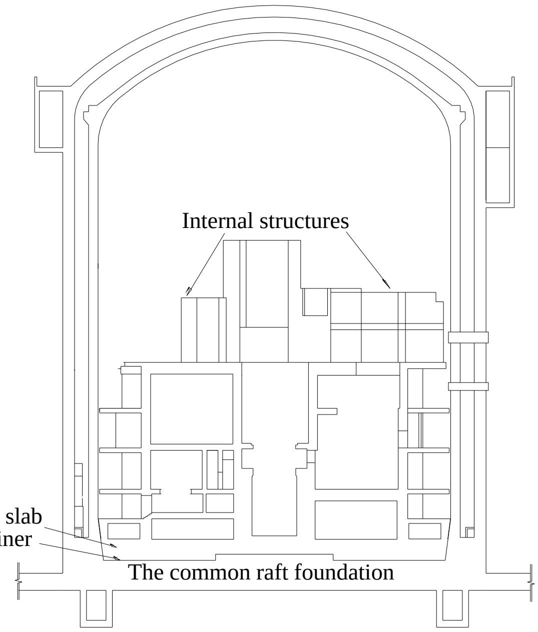
The main safety functions of the internal structures include:

a) Supporting the reactor container and relevant equipment;

b) Providing biological protection (shielding) for personnel and equipment;

c) Providing anti-pipe whip and missile protection for the containment, primary circuit, secondary circuit and protection system.

The internal structures comprise reinforced concrete walls and slabs located on the common raft foundation, as shown in F-16.4-3.

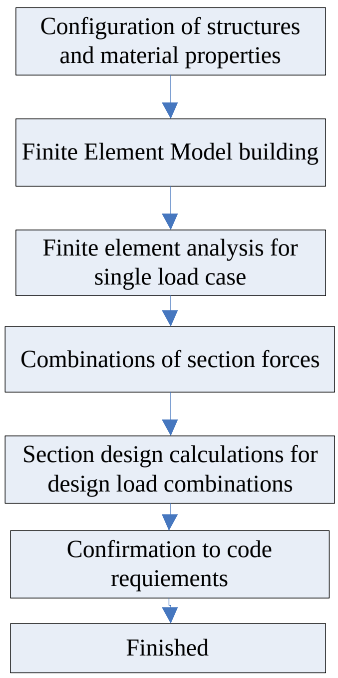


F-16.4-3 Internal structures

16.4.3.2 Design and Analysis

16.4.3.2.1 Design

The design and analysis of the reactor building internal structures are in compliance with the codes and standards as specified in sub-chapter 16.3.2.1. The design flowchart is shown in F-16.4-4.



F-16.4-4 Design flowchart for reactor building internal structures

16.4.3.2.2 Analysis

Finite element model has been used for the analysis of the internal structures, with static and dynamic calculations/analysis undertaken.

16.4.4 Other SSE1 Structures

16.4.4.1 Description

This section describes the arrangement, design and analysis of the other SSE1 structures.

a) Fuel building

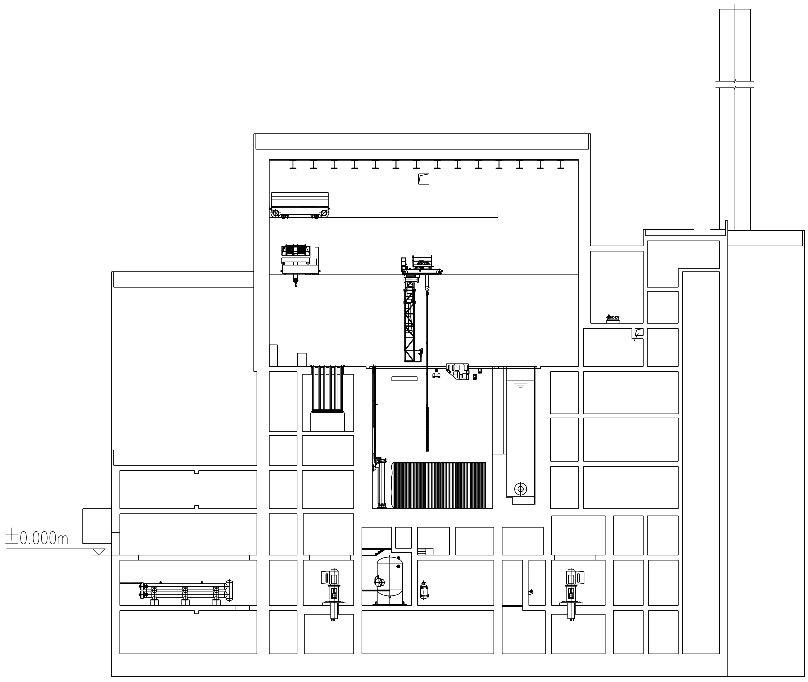
The fuel building, as shown in F-16.4-5, is divided into several zones according to the safety features and functions, i.e. the mechanical equipment zone, Preliminary Mechanical Component (PMC) zone, and zone for ventilation and air conditioning equipment. The floors below elevation 0.000m are the mechanical equipment deployment zones and floors at or above elevation 0.000m are zones for the PMC, ventilation and air conditioning equipment.

The fuel building is a robust reinforced concrete structure with structural loads withstood by the walls and floor/roof slabs. There are some special considerations for the fuel building. For instance, the outer walls and roof of the fuel building are designed with increased thickness to against certain externally-generated hazards by a large commercial airplane impact.

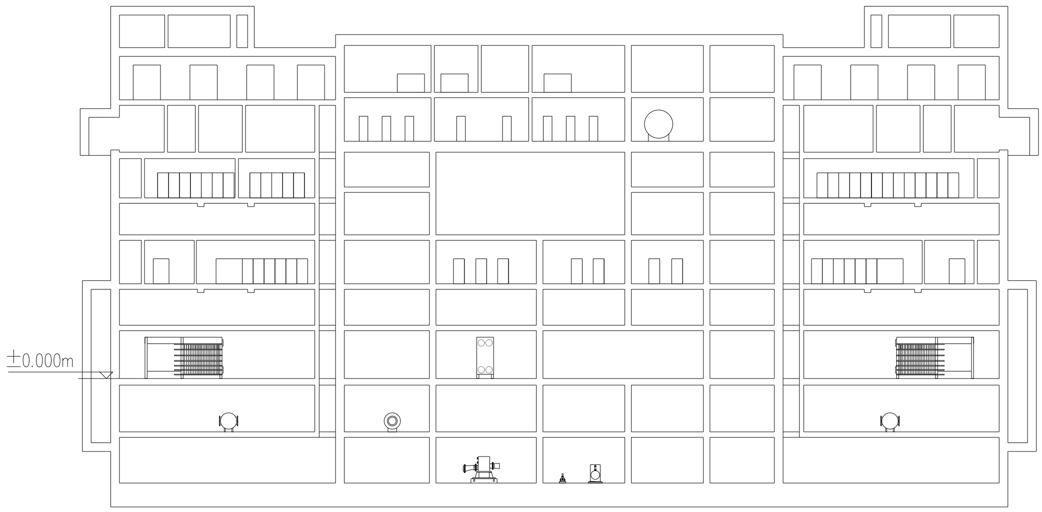
b) Safeguard buildings

BSA, BSB, and BSC are located around three sides of the reactor building. They house the electric pumps, the drain pump of Auxiliary Feed water system, the valve enclosure and low head safety injection pump, the ground water transfer tank, and so on.

The safeguard buildings structure consists of reinforced concrete walls and slabs as shown in F-16.4-6. In local areas, reinforced concrete slabs and columns are used. The outer walls and roof of BSC are designed for impact by a large commercial aircraft.



F-16.4-5 Fuel Building



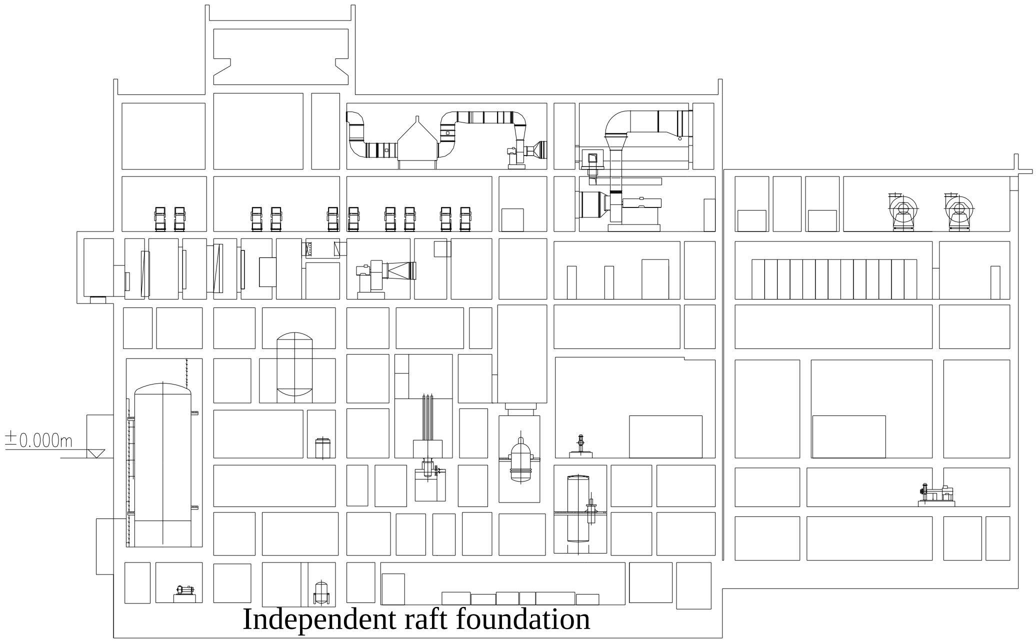
F-16.4-6 Safeguard buildings

c) Nuclear Auxiliary Building

As shown in F-16.2-1and F-16.4-7, the nuclear auxiliary building is adjacent to the fuel building, safeguard building B and personnel access building. It is located on a raft foundation independent from the common raft foundation, and separated from other buildings through the structural gaps on each floor (including the foundation).

The nuclear auxiliary building houses the coolant purification, separation, degas equipment, nuclear island waste gas processing system equipment, the main filter, desalt equipment , the ventilation and air conditioning equipment.

The nuclear auxiliary building structure consists of reinforced concrete walls and slabs.



F-16.4-7 Nuclear auxiliary building

d) Diesel generator buildings

The emergency diesel generator buildings house the main oil storage tank, fuel transfer pump, the diesel generator, foam tank, electric cabinet and battery, the oil tank for day use, lubricant tank, air compressor and starting air cylinder, the ventilation and air conditioning equipment and inlet filter, and air cooler and silencer.

The diesel generator building structure consists of reinforced concrete walls and slabs. In local areas, reinforced concrete slabs and columns are used.

The station blackout diesel generator buildings are similar to the emergency diesel generator buildings.

e) Radioactive waste treatment building

The radioactive waste treatment building is located near the nuclear auxiliary building. It is deployed with all the necessary devices for processing the radioactive liquid wastes and solid wastes in the plant. This building is mainly used to collect, store, and process the liquid and solid radioactive waste, including the treatment of waste water and concentrate, as well as the treatment and preparation of the wastes before they are released to the external environment or transferred to other places for storage. The BWX also includes the hot laundry. The structure of the BWX shall be able to contain the radioactive substance when the system, liquid waste storage tank and storage zone fail.

f) Essential service water pumping station

The function of the essential service water pumping system is to obtain water from the open channel; boost and transfer the sea water that has been processed by filtering and dosing equipment and meets the process requirements to the component cooling cater system (RRI)/ essential service water system (SEC) heat exchanger in the safeguard building. Each unit is equipped with two pumping stations (BPA/BPB), which are located at the two sides of the circulating water pumping station.

g) Essential service water supply gallery

The essential service water supply galleries connect the essential service water pumping station and the safeguard building, and transfer the essential service water through the mutually separate galleries to the safeguard buildings of the nuclear island. It also assumes the function of providing power supply and fire fighting water to the essential service water pumping station from the safeguard building.

Each unit has 3 essential service water supply galleries: BGA, BGB and BGC. BGA and BGB correspond to the train A and train B of the essential service water system. Each train includes 2 mutually separate water supply galleries. BGC corresponds to train C of the essential service water system, which has only one water supply gallery. The gallery is mainly deployed with the essential service water pipe, fire fighting water pipe and cable tray.

h) Essential service water drain gallery

The essential service water drain gallery is used to drain the hot water from the RRI/SEC heat exchanger to the overflow well and finally to the sea through the drain open channel.

i) Liquid waste transfer gallery

The liquid waste transfer gallery is shared by the two units. It is an outdoor concrete gallery connecting the BWX/BNX building and equipped with low radioactivity liquid waste transfer pipes.

j) Extra cooling system and firefighting system building

The process subsystems of the BEJ building include the extra cooling system and nuclear island firefighting water production system. The BEJ building is located near the nuclear island fuel building.

16.4.4.2 Design and Analysis

16.4.4.2.1 Design

The design and analysis are in compliance with the regulations, codes and standards specified in sub-chapter 16.3.2.5. The design flow chart is similar to the flowchart shown in F-16.4-4. The design of the external envelopes of the buildings have considered environmental effects and external hazards including wind, snow, rain, lightning and extreme ambient temperatures.

16.4.4.2.2 Analysis

Finite element analysis is used for the SSE1 structures.

16.4.5 Foundations

16.4.5.1 Description

16.4.5.1.1 Common Raft Foundation

The reactor building, fuel building and safeguard buildings are located on the common raft foundation which is constructed from reinforced concrete. The approximate plan dimensions are 110m×82m.
The thickness of the common raft foundation varies in different zones. The thickness under the reactor building is approximately 4.00m, which is thicker than under the fuel building and safeguard buildings. In some area, there are pits in the common raft foundation.

The circular prestressing gallery is located under and connected to the common raft foundation as shown in F-16.4-1. It is used to anchor the vertical prestressing tendons of the internal containment structure. The support slab for the reactor building internal structures is located on the common raft foundation. The bottom section of the internal containment steel liner is located between the support slab and the raft foundation as shown in F-16.4-3.

16.4.5.1.2 Nuclear Auxiliary Building Foundation

The foundation of the nuclear auxiliary building is a raft foundation which is separate from the common raft foundation.

16.4.5.1.3 Diesel Generator Building Foundations

The foundations of the diesel generator buildings are raft foundations which are separate from the other building foundations.

16.4.5.2 Design and Analysis

Vertical loads are transferred to the foundation through the shear walls. Lateral loads are transferred through the roof slabs and floor slabs to the shear walls, and then into the foundation. The shear walls are used to stiffen the foundation rafts, and the loads on the foundations will be distributed according to their stiffness.

The design and analysis are in compliance with the codes and standards specified in sub-chapter 16.3.2.5.

Finite element analysis is used for the design and analysis of the foundations, with spring and shell elements used to model the ground soil/rock and foundation structure respectively. Loads have been applied according to the combinations defined in sub-chapter 16.3.3.3.

16.5 Construction

16.5.1 Construction Specifications

Construction specifications have been developed during the design to specify the requirements for construction of the civil works and structures. For UK HPR1000, the construction specifications will be compatible with the design codes and standards, UK regulations, construction practices and materials. To enable this they will contain any specific or additional measures required for workmanship, materials, detailing, tolerances, inspection and testing.

16.5.2 Construction Materials

The construction materials for the civil works and structures (e.g. concrete, steel reinforcement, prestressing tendons and steel liners) meet the requirements of the construction specifications which are compatible with the design codes and standards.

For massive concrete structures, the construction specifications have specified appropriate material requirements to limit early age thermal cracking.

16.5.3 Construction Quality Control

The construction quality control procedures have been defined during the design and implemented during the construction and inspection period. The quality control procedures have complemented the construction specifications and included the controls for the construction or manufacture, delivery and installation of each structural part. They define the necessary inspection and testing records to ensure compliance with the construction specifications. They also contain procedures for design change and non-conformance.

16.5.4 Construction Technologies

The steel liner of the internal containment cylinder and dome are used as the internal formwork for the concrete. Therefore, the steel liner is installed before the concrete is poured. Temporary formworks are used for the external surfaces of the containment and upper part of the dome. The steel liner for the internal containment dome have been fabricated at ground level on the construction site and then lifted in one piece from the ground to the final position.

The steel liner welds have been fully inspected before concreting. The internal containment leakage rate has been tested to demonstrate the pressure tightness of steel liner after concreting as described in sub-chapter 16.6.2.

The internal containment structure will be instrumented to allow monitoring of its structural behaviour as described in sub-chapter 16.6.2. The monitoring system has been developed during the design.

The construction tolerances of the concrete structure, steel liner and penetrations have been determined during the design according to the design requirements, geometric shape of the structure, steel liner stability, concrete strength and the construction methods to be used.

16.6 Testing, Inspection and Monitoring Requirements

16.6.1 General Requirements

Testing, inspection and monitoring of the civil engineering structures have been undertaken to:

a) Demonstrate that appropriate standards of workmanship are achieved during construction.

b) Demonstrate that the structures are sufficiently free of defects after their construction and that any identified defects can be tolerated.

c) Confirm that the structures that retain or prevent leakage are leak tight prior to operation.

d) Demonstrate that the structures continue to meet their safety functional requirements during normal operation.

e) Identify any significant defects from ageing and degradation that could compromise the safety functional requirements of structures during commissioning, operation and decommissioning.

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

All structures have been 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 categorization of each structure. Where significant structural defects are identified, their effects on the safety functional requirements are assessed and remedial measures are applied where necessary.

All safety related structures will be visually inspected at regular intervals during commissioning, operation and decommissioning. The inspection interval will be selected according to the anticipated ageing and degradation mechanisms and the safety categorization of each structure.

The following sections identify the additional inspection, testing and monitoring that have been undertaken for specific structures.

16.6.2 Reactor Building Containment Structures

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

a) 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 and no visible damage.

b) Periodic tests will be conducted:

- Comprehensive test on the whole containment system;
- Frequent local test on the key components with great leakage risks (in order to avoid excessive increase of the unit shut-down time).

c) 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 an acceptable grout material.

d) 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 unbounded tendons will be provided in the inner 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.

16.6.3 Reactor Building Internal Structures

The reactor building internal structures will be regularly inspected during commissioning, operation and decommissioning so far as is reasonably practicable given the access constraints.

The internal structure is not directly related to the sealing function of the containment, but the stainless steel pool shall be subject to leakage test before commissioning.

16.6.4 Other SSE1 Structures

For the SSE1 structures other than the reactor building, construction testing, in-service inspection and monitoring will be undertaken as described in sub-chapter 16.6.1.

16.6.5 Foundation

Construction testing, in-service inspection and monitoring of the foundation structures will be undertaken as described in sub-chapter 16.6.1. The settlement of the foundations will be measured at regular intervals (nominally 6 months) and will be compared to design predictions and acceptance limits.

16.7 References

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