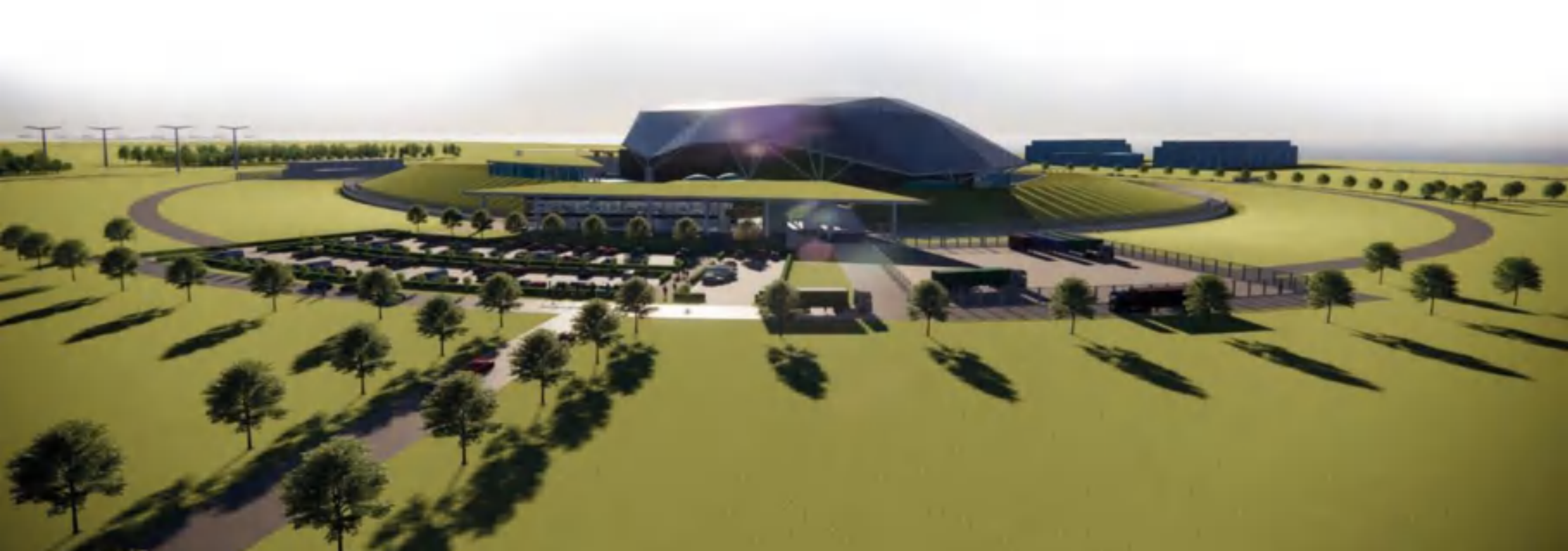
Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 9B: Civil Engineering Works and Structures



Record of Change

Date	Revision Number	Status	Reason for Change
March 2023	1	Issued	Initial Issue
February 2024	2	Issue	Incorporates revised approaches defined at Reference Design 7, aligned to Design Reference Point 1, including: • Structural and design analysis methods • Design bases for each structure, including safety functions and requirements, safety categorisation and classification, and seismic performance classification • Updated structural descriptions
May 2024	3	Issue	Updated to correct revision history status at Issue 2. Chapter changes include: • Additional description to clarify the extent of the Hazard Shield (section 9B.0.5), and minor clarifications of structural descriptions throughout • Additional details within the conclusions for how arguments and evidence presented meet the generic E3S objective Also minor template/editorial updates for overall E3S Case consistency.

Executive Summary

Chapter 9B of the Environment, Safety, Security, and Safeguards (E3S) Case presents the civil engineering works and structures of the Rolls-Royce Small Modular Reactor (RR SMR).

The chapter outlines the arguments and preliminary evidence to underpin the high-level Claim that the Civil structures are conservatively designed and verified to deliver E3S functions through-life, in accordance with the E3S design principles, to reduce risks to as low as reasonably practicable (ALARP), apply best available techniques (BAT) and in line with secure by design and safeguards by design.

The civil structures covered include the foundations and retaining wall to support Reactor Island, the Seismic Isolation System to protect against seismic activity, the Basemat and Containment Support Structures for mounting the Containment Vessel, the Containment Internal Structures to house Reactor Island systems, the Fuelling Block, the Hazard Shield over Reactor Island to protect structures, systems and components (SSCs) against external hazards, the structures necessary to support the safety classified backup power systems, as well as the structures necessary to support the Essential Service Water System (ESWS).

The chapter presents the civil and structural codes and standards and the structural design and analysis methods. For each civil structure, the safety functions, safety categorisation, safety classification and seismic performance classification are defined, and the structural design description is summarised. No functional requirements for environment, security and safeguards are identified for the civil structures in this version.

Version 2 of the generic E3S Case is developed in support of the reference design 7 (RD7) design, corresponding to design reference point 1 (DRP1) for the generic design assessment (GDA). Further arguments and evidence are to be developed to underpin the top-level claim, including safety requirements from iterative internal hazards, external hazards, and deterministic analysis, detailed design development, and structural and design substantiation work.

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9B.0 Introduction to Chapter

9B.0.1 Introduction

Chapter 9B of the Rolls-Royce Small Modular Reactor (RR SMR) generic Environment, Safety, Security and Safeguards (E3S) Case presents the overarching summary and entry point to the design and E3S information for the civil structures of the RR SMR.

9B.0.2 Scope and Maturity

The scope of the civil, structural and architecture (CS&A) [S01] generic E3S Case covers the civil structures associated with Reactor Island, Essential Service Water Systems (ESWS) and backup generation. It also covers the structures that may impede the function of safety class 1 and 2 structures, systems, and components (SSCs) if subject to failure.

Excluded from the scope of the generic E3S Case are Turbine Island structures, Cooling Water Island structures (other than ESWS structures) and Balance of Plant structures (except backup generation structures).

The generic site parameters that are used to inform the design of the civil structures above are described and justified in E3S Case Version 2, Tier 1, Chapter 2: Generic Site Characteristics.

Version 2 of the generic E3S Case is based on the design at reference design 7 (RD7), corresponding to design reference point 1 (DRP1) for the generic design assessment (GDA). The codes and standards and structural design and analysis methods are described. The safety functions to be delivered by civil structures are presented, and the appropriate safety categorisation, safety classification and seismic performance classification is designated for the civil structures within scope. No functional requirements for environment, security and safeguards are placed onto civil structures at RD7/DRP1. The design definition presented is based on the design maturity of each respective civil structure at RD7/DRP1. Verification and validation (substantiation) of civil structures is still to be undertaken (see section 9B.4.3).

9B.0.3 Claims, Arguments and Evidence Route Map

The overall approach to claims, arguments, evidence (CAE) and the set of fundamental E3S claims to achieve the E3S fundamental objective are described in E3S Case Version 2, Tier 1, Chapter 1: Introduction [1]. The associated top-level chapter claim for E3S Case Version 2, Tier 1, Chapter 9B: Civil Engineering Works and Structures is:

Claim 9B: Civil structures are conservatively designed and verified to deliver E3S functions through-life, in accordance with the E3S design principles, to reduce risks to ALARP, apply BAT and in line with secure by design and safeguards by design.

A decomposition of this claim into sub-claims, and mapping to the relevant Tier 2 and Tier 3 information containing the detailed arguments and evidence, is presented in the E3S Case Route Map [2].

Given the evolving nature of the E3S Case alongside the maturing design, the underpinning arguments and evidence may still be developed in future design stages; the trajectory of this information, where possible, is also illustrated in the route map (and forward action plans within lower tier documents), which aligns the anticipated arguments and evidence to future issues of the generic E3S Case (subject to ongoing planning).

A proportionate summary of the arguments and evidence from lower tier information, available at the current design stage, is presented within this chapter. A mapping of the claims to the corresponding sections that summarise the arguments and/or evidence is provided in Appendix A (section 9B.6). An overview of the documentation that underpins this chapter of this generic E3S Case is summarised in the document map provided in Appendix B (section 9B.7).

9B.0.4 Applicable Regulations, Codes and Standards

Codes and standards for the design of RR SMR buildings and structures are selected based on relevant good practice (RGP), an assessment of codes and standards adopted by previous requesting parties, and the latest codes, standards, and publications applicable to the design and construction of safety and non-safety related civil structures.

Based on this approach, the following policy has been adopted for the selecting codes and standards for the design of civil and structural elements:

1. The strength design of nuclear safety related structures will adopt American standards
2. The strength design of non-nuclear safety related structures will adopt European standards
3. Serviceability design will consider a combination of American and European standards
4. Material specification will be in accordance with European and British standards.

Further underpinning of the approach to codes and standards is documented within the Civil and Structural Codes and Standards Policy [3], and within the Material Code Compliance Report [4] for further information on material specification.

Table 9B.0-1 to Table 9B.0-4 summarise the structural design (strength) codes and standards adopted for the RR SMR, Table 9B.0-5 summarises the serviceability standards, Table 9B.0-6 and Table 9B.0-7 summarise the civil codes and standards, and Table 9B.0-8 summarises the materials standards.

Table 9B.0-1: Analysis Standards for RR SMR

Design Area	Codes and Standards
Analysis	American Society of Civil Engineers (ASCE) 4-16 Seismic Analysis of Safety Related Nuclear Structures, American Society of Civil Engineers, 2017.
	ASCE 43-19 Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, American Society of Civil Engineers, 2019.
	British Standard (BS) EN 1337-1 Structural Bearings, 2000.
	BS EN 15129 Anti-seismic Devices, 2018.

Table 9B.0-2: Aircraft Impact Standards for RR SMR

Design Area	Codes and Standards
Aircraft Impact	International Atomic Energy Agency (IAEA), Safety Aspects of Nuclear Power Plants in Human Induced External Events: General Considerations, IAEA Safety Report Series No. 86, 2017.
	IAEA, Safety Aspects of Nuclear Power Plants in Human Induced External Events: Assessment of Structures, IAEA Safety Report Series No. 87, 2018.
	IAEA, Safety Aspects of Nuclear Power Plants in Human Induced External Events: Margin Assessment, IAEA Safety Report Series No. 88, 2017.
	Nuclear Energy Institute (NEI), Methodology for Performing Aircraft Impact Assessments for New Plant Designs, NEI 07-13, 2011.

Table 9B.0-3: Nuclear Safety Related Structural Standards for RR SMR

Design Area	Codes and Standards
Loading Code	BS EN 1991 Eurocode 1: Actions on Structures, 2002.
Disproportionate Collapse	Ministry of Housing, Communities & Local Government: The Building Regulations – Approved Document A: Structure, 2010.
Structural Concrete Design	American Concrete Institute (ACI) 349M-13 Code Requirements for Nuclear Safety-Related Concrete Structures, American Concrete Institute, 2014.
	ACI 318M-08 Building Code Requirements for Structural Concrete, American Concrete Institute, 2008.
	ACI 350.3-06 Seismic Design of Liquid-Containing Concrete Structures, American Concrete Institute, 2006.
	ACI 349.1R-07 Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures, American Concrete Institute, 2007.
Structural Steel Design	American National Standards Institute / American Institute of Steel Construction (ANSI/AISC) N690-18 Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities, American Institute of Steel Construction, 2018.
	ANSI/AISC 360-16 Specification for Structural Steel Buildings, American Institute of Steel Construction, 2016.
	ANSI/AISC 341-16 Seismic Provisions for Structural Steel Buildings, American Institute of Steel Construction, 2016.

Table 9B.0-4: Non-nuclear Safety Related Structural Standards for RR SMR

Design Area	Codes and Standards
Loading Code	BS EN 1990 Eurocode – Basis of Structural Design, 2002.
	BS EN 1991-1-1: Eurocode 1: Actions on Structures – Part 1-1: General actions - Densities, self-weight, imposed loads for buildings, 2002.

Design Area	Codes and Standards
Disproportionate Collapse	Ministry of Housing, Communities & Local Government: The Building Regulations – Approved Document A: Structure, 2010.
Structural Concrete Design	BS EN 1992-1-1: Eurocode 2: Design of Concrete Structures – Part 1-1: General rules and rules for buildings, 2004.
Structural Steel Design	BS EN 1993-1-1: Eurocode 3: Design of Steel Structures – Part 1-1: General rules and rules for buildings, 2005.

Table 9B.0-5: Serviceability Design Standards for RR SMR

Design Area	Codes and Standards
Serviceability	ACI 349M-13 Code Requirements for Nuclear Safety-Related Concrete Structures, American Concrete Institute, 2014.
	ANSI/AISC N690-18 Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities, American Institute of Steel Construction, 2018.
	BS EN 1992-1-1: Eurocode 2: Design of Concrete Structures – Part 1-1: General rules and rules for buildings, 2004.
	BS EN 1992-3: Eurocode 2: Design of Concrete Structures – Part 3: Liquid retaining and containment structures, 2006.
	BS EN 1993-1-1: Eurocode 3: Design of Steel Structures – Part 1-1: General rules and rules for buildings, 2005.
	Construction Industry Research and Information Association (CIRIA) C766 – Control of cracking caused by restrained deformation in concrete, 2018.
	BS 8500-1:2015+A2:2019, Concrete – Complementary British Standard to BS EN 206 Part 1: Method of specifying and guidance for the specifier.

Table 9B.0-6: Geotechnical Standards for RR SMR

Design Area	Codes and Standards
Geotechnical Analysis	BS EN 1991-1-1: Eurocode 1: Actions on Structures – Part 1-1: General actions - Densities, self-weight, imposed loads for buildings, 2002.
	BS EN 1997: Eurocode 7 – Geotechnical Design (Parts 1 to 3) and the UK National Annex.
	BS 8004: 2015 – Code of practice for foundations.
	IAEA, Geotechnical Aspects for Site Evaluation and Foundation for Nuclear Power Plants, NS-G-3.6, 2004.
	ASCE 43-19 – Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities, 2019.
	ASCE 4-16 – Seismic Analysis of Safety-Related Nuclear Structures, 2017.

Table 9B.0-7: Roads and Networks Standards and Publications for RR SMR

Design Area	Codes and Standards
Roads and Networks	Design Manual for Roads and Bridges (DMRB).
	Manual for Streets 1 and 2.
	BS EN 12056-1: Gravity Drainage Systems Inside Buildings: Part 1, 2 and 3.
	CIRIA C753 – The SuDS Manual, 2015.
	Sewers for Adoption, 2018.
	National Joint Utilities Group (NJUG) Guidelines, 2008.

Table 9B.0-8: Material Standards for RR SMR

Design Area	Codes and Standards
Concrete	BS EN 206:2013+A2:2021, Concrete – Specification, performance, production and conformity.
	BS 8500-1:2015+A2:2019, Concrete – Complementary British Standard to BS EN 206 Part 1: Method of specifying and guidance for the specifier.
	BS 8500-2:2015+A2:2019, Concrete – Complementary British Standard to BS EN 206 Part 2: Specification for constituent materials and concrete.
Reinforcement	BS 4449:2005+A3:2016, Steel for the reinforcement of concrete – Weldable reinforcing steel – Bar, coil and decoiled product – Specification.
	BS EN 10080:2005, Steel for the reinforcement of concrete - Weldable reinforcing steel - General.
Steel	BS EN 10025-1:2004, Hot rolled products of structural steels, Part 1: General technical delivery conditions.
	BS EN 10025-2:2019 Hot rolled products of structural steels, Part 2: Technical delivery conditions for non-alloy structural steels.
	BS EN 10210-1:2006 Hot finished structural hollow sections of non-alloy and fine grain steels, Part 1: Technical delivery conditions.
	BS EN 10210-2:2019 Hot finished steel structural hollow sections, Part 2: Tolerances, dimensions and sectional properties.
	BS EN 10056-1:2017 Structural steel equal and unequal leg angles, Part 1: Dimensions.
	BS EN 10056-2:1993 Structural steel equal and unequal leg angles – Part 2: Tolerances on shape and dimensions.
	BS EN 10029:2010 Hot-rolled steel plates 3mm thick or above – Tolerances on dimensions and shape.

9B.0.5 Overview of Civil Structures

The RR SMR encompasses a Reactor Island, Turbine Island, Cooling Water Island, and Balance of Plant. A summary of the structures for each area that are within the scope of the generic E3S Case is shown in Figure 9B.0-1 and described in the subsequent sections, with further detail provided in the Overview of RR SMR Civil Engineering Structures [5]. The overall layout of the site is described in E3S Case Version 2, Tier 1, Chapter 1: Introduction [1]. To orientate/locate elements of the design within this report, the cardinal compass points have been utilised, with 'north' being toward the top of the page on plan views of the site layout and the 'east-west' axis running through Reactor Island and Turbine Island (with the Reactor Island to the 'west' of the Turbine Island).

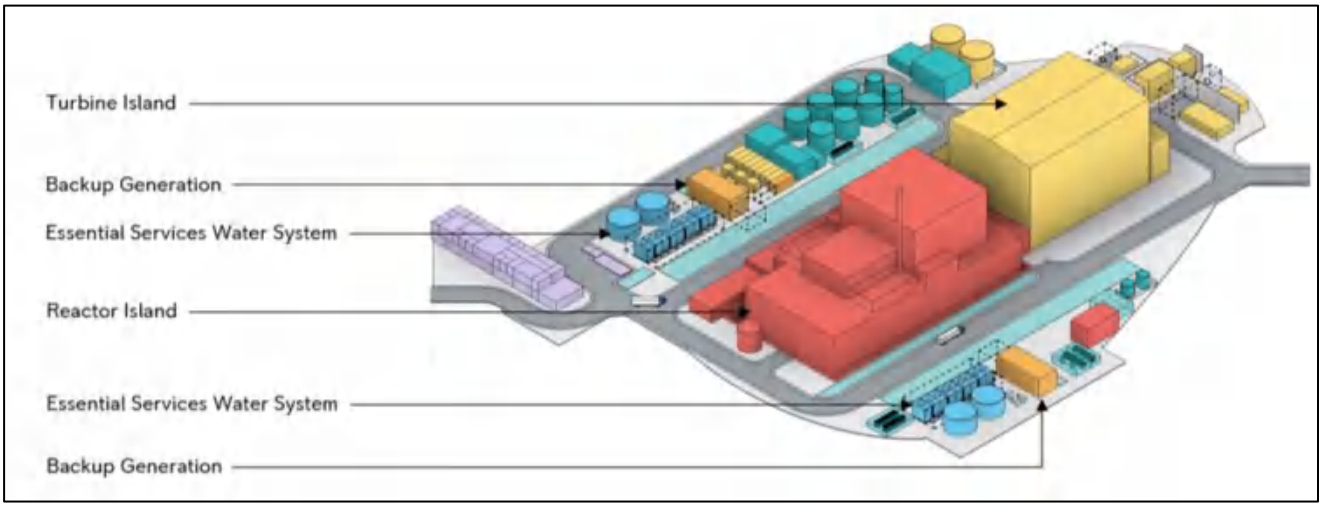

Figure 9B.0-1: RR SMR Structures within scope of Generic E3S Case

9B.0.5.1 Reactor Island

The Reactor Island includes the SSCs that house the reactor, SSCs for the transfer, handling, and storage of new and used fuel, and associated nuclear auxiliary systems. It is approximately 137 m long ('east-west') and 84 m wide ('north-south'). Most of the Reactor Island structures are supported on a raft foundation 123.2 m long ('east-west') and 70 m wide ('north-south'), the top of which is 11.2 m below ground level. An overview of the key Reactor Island structures in the overall site layout is presented in Figure 9B.0-2 and Figure 9B.0-3.

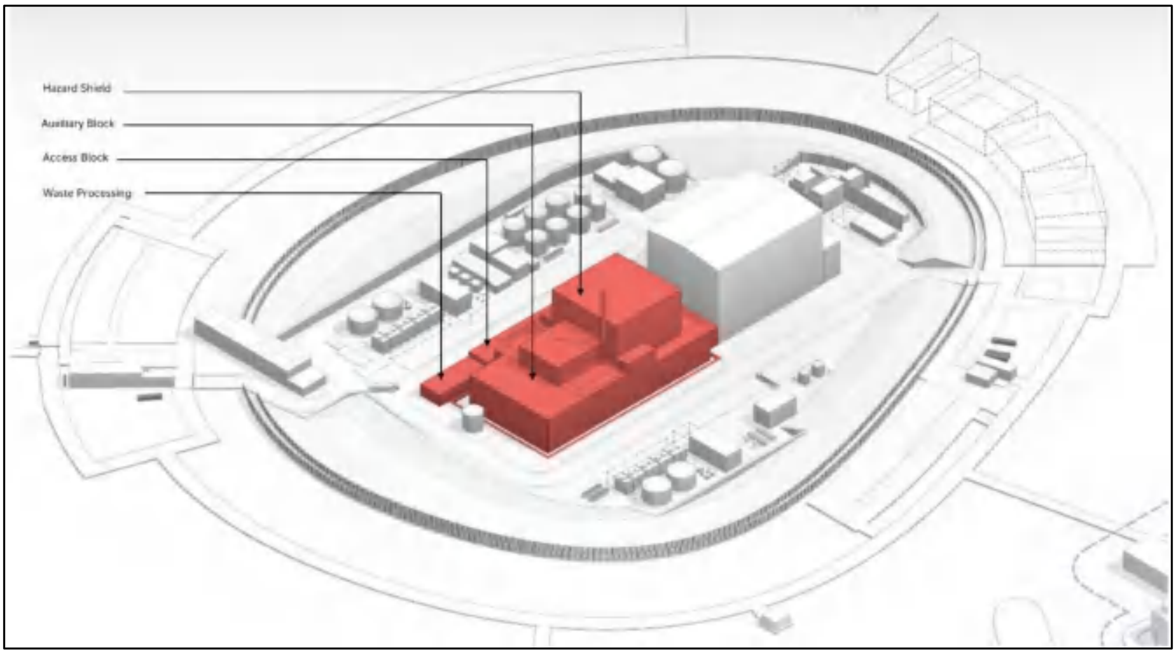

Figure 9B.0-2: Reactor Island Structures

The blocks/zones within Reactor Island are illustrated in Figure 9B.0-3 and Figure 9B.0-4. A brief overview of each block/zone is summarised in subsequent sub-section.

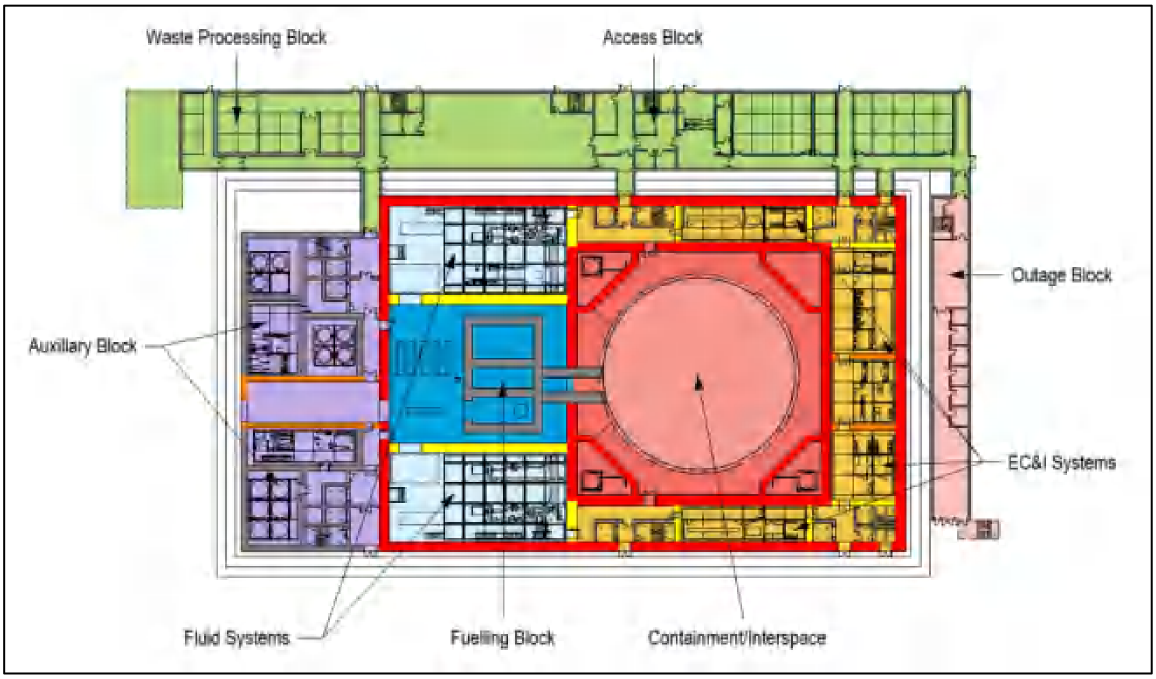

Figure 9B.0-3: Plan of Reactor Island Structures and Areas

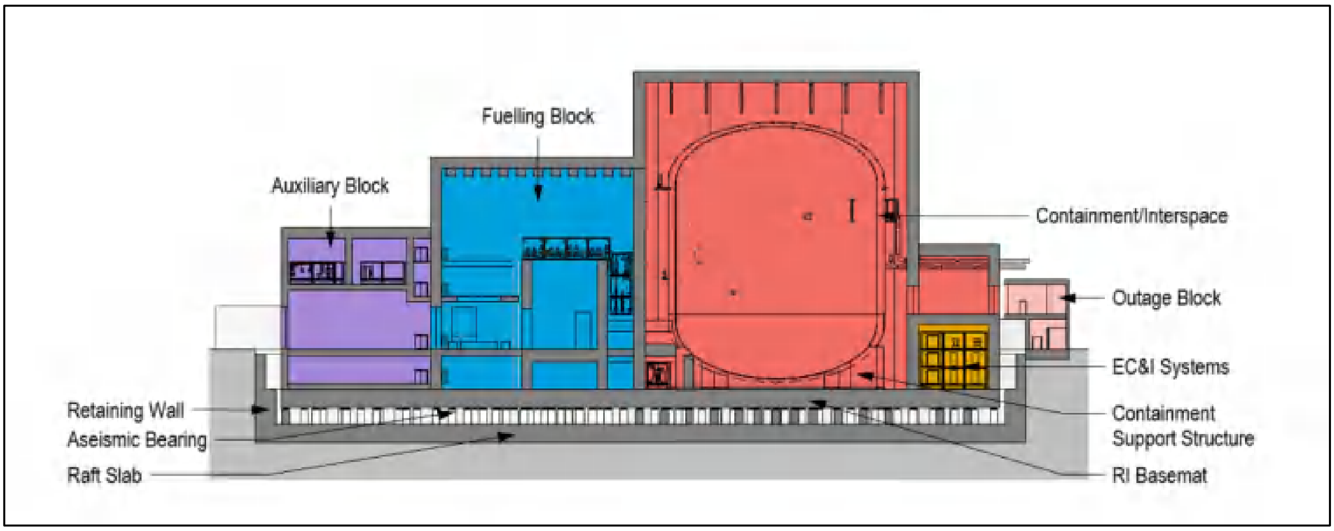

Figure 9B.0-4: Indicative Section through Reactor Island Structures

9B.0.5.1.1 Hazard Shield [UWD]

The Hazard Shield is a large, reinforced concrete (RC) structure that protects safety critical SSCs from external hazards, including accidental and malicious aircraft impacts. It is approximately 91 m long, 61 m wide and extends 45 m above ground level.

The Hazard Shield houses the Containment Internal Structures, Interspace, Fuelling Block, Electrical, Control and Instrumentation (EC&I) Systems and Fluid Systems blocks. The extent of the Hazard Shield encompasses the safety measures that are required to ensure fulfilment of fundamental safety functions (FSFs) during an accidental and malicious aircraft impact. The functionality of the safety measures is ensured by the Hazard Shield structural elements shaded in red in Figure 9B.0-3.

Inside the external envelope of the Hazard Shield, segregating walls which also form part of the Hazard Shield [UWD] are shaded yellow, and structures that function as impact protection structures to protect large openings are shaded orange. The impact protection structure to the west of the Hazard Shield protects the cask handling and transport entrance to the Fuelling Block. These structural elements are assigned to the Auxiliary Block but are required for overall fulfilment of the aircraft impact safety case. Further details of the aircraft impact design philosophy and methodology can be found in the Aircraft Impact Design Philosophy and Methodology Statement [6].

Further details of the Hazard Shield are provided in section 9B.2.5 of this chapter.

9B.0.5.1.2 Raft Foundation and Retaining Wall [UWC]

The RC Raft Foundation provides support to the Reactor Island structures which are supported on the Basemat, as indicated in Figure 9B.0-4. The Retaining Wall is integral to the raft foundation at its base and retains the external ground and groundwater surrounding the Reactor Island. The retaining wall is physically separated from the Hazard Shield and Basemat.

Further details of the Raft Foundation and Retaining Wall are provided in section 9B.1.1 of this chapter.

9B.0.5.1.3 Seismic Isolation System [UWC]

The Seismic Isolation System is supported from the RC Raft Foundation and comprises a series of RC pedestals and aseismic bearings, which in turn support an RC Basemat. The seismic isolation is provided between the Basemat and pedestals by the aseismic bearings, which decouple the horizontal accelerations.

Further details of the Seismic Isolation System are provided in section 9B.1.2 of this chapter.

9B.0.5.1.4 Basemat and Containment Support Structure [UWD]

The RC Basemat supports SSCs housed inside the Hazard Shield and Auxiliary Blocks, as indicated in Figure 9B.0-3. The Containment Support Structure supports the Containment Vessel (described in E3S Case Chapter 6: Engineered Safety Features [7]), whilst also ensuring the provision of access to the base of the Containment Vessel for construction and examination, maintenance, inspection, and testing (EMIT) activities.

Further details of the Basemat and Containment Support Structure are provided in section 9B.2.1 of this chapter.

9B.0.5.1.5 Containment Internal Structures [UJA]

The Containment Internal Structures provide support to the safety-related systems located inside the steel Containment Vessel. The Containment Internal Structures support and protect the primary circuit vessels and associated pipework, the refuelling pool and refuelling cavity, and the fuel handling machine and main overhead crane.

Access into/out of containment is provided by a main equipment access hatch in the ‘east’ face of the vessel, and two personnel airlocks, one in the ‘southeast’ and one in the ‘northwest’. The main equipment access hatch and the ‘southeast’ personnel airlock are at containment floor level, with the ‘northwest’ personnel airlock on the upper containment first floor level.

Further details of the Containment Internal Structures are provided in section 9B.2.1 of this chapter.

9B.0.5.1.6 Interspace [UJB]

The Interspace is the area which surrounds the Containment Vessel and includes the Personnel Airlocks, Equipment Access Hatch into/out of the Containment Vessel, the Accumulators, the Buttresses, and the Local Ultimate Heat Sink (LUHS) tanks.

The purpose of the structures within the Interspace is to provide segregation and separation between trains of the systems, as well as to support the pipework, vessels, and systems within the Interspace, and support to pipework for the main steam lines and feedwater lines routing into/out of Containment.

9B.0.5.1.7 Fuelling Block [UFA]

The Fuelling Block provides the route for the receipt, handling, storage and dispatch of new and spent fuel. The entry route for casks and new fuel is located to the ‘west’ of the Fuelling Block. Vehicle access is provided to the new fuel receipt and inspection area, which provides space for receipt and inspection of new fuel. Intermediate floors within the Fuelling Block provide additional space and support for SSCs and EMIT activities.

The Fuelling Block houses the Spent Fuel Storage and Cask Loading System, which comprises the Spent Fuel Pool, Upender Pit and Cask Loading Pit. The pool and pit structures are supported on the Basemat [UWD]. The Fuelling Block houses a Fuel Transfer Channel which provides a passage between Containment Internal Structures and the Upender Pit for the transfer of fuel assemblies.

To enable fuel transfer and fuel handling activities, the civil structures also provide support to a number of mechanical and fuel handling systems. This includes the:

1. Spent fuel pool handling machine
2. Fuel transfer handling machine
3. New fuel elevator
4. Spent fuel pool overhead crane
5. Multi-purpose canister lid handler.

Further details of the Fuelling Block are provided in section 9B.2.3 of this chapter.

9B.0.5.1.8 Reactor Island Process Clusters

A series of 'process clusters' are housed within several of the blocks/zones within Reactor Island. Process clusters are defined as the conglomeration of 'system modules' into discrete structural framing systems, and house mechanical, electrical and plumbing (MEP) equipment that can be assembled in an offsite factory. System modules are formed from module units and can vary in length depending on the systems within them. These are illustrated in Figure 9B.0-5.

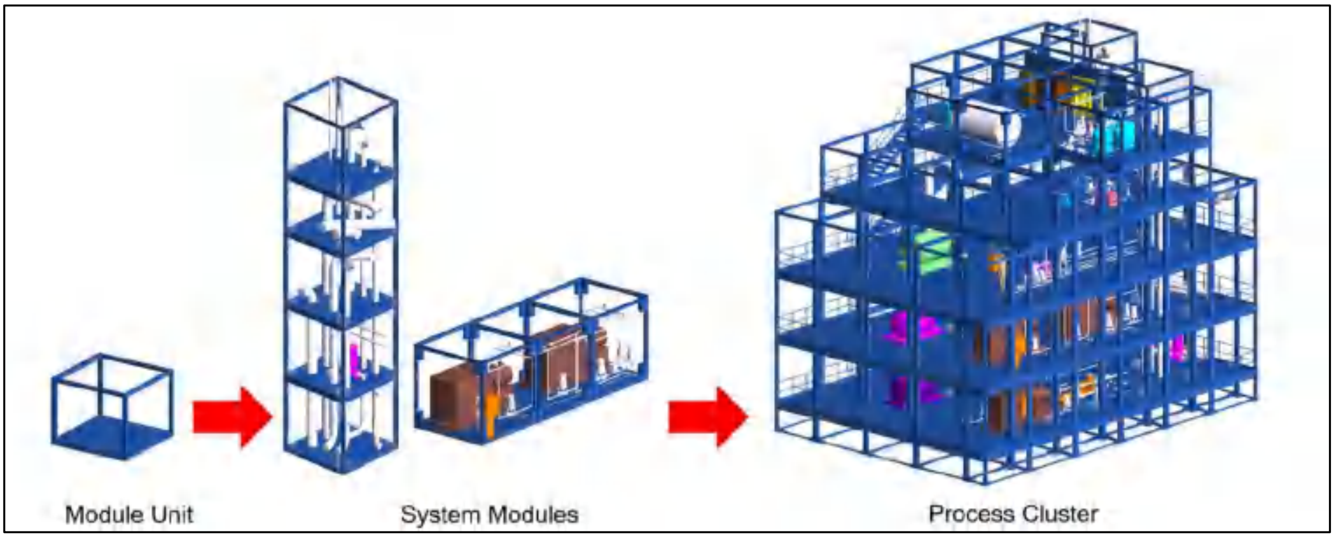

Figure 9B.0-5: Assembly of Modules, System Modules and Process Clusters

The process clusters for the various blocks/zones within Reactor Island are summarised below, with further details of the EC&I Block, Fluids Block and Auxiliary Block provided in section 9B.2.4 of this chapter.

EC&I Block [UJS]

The EC&I Block houses the main control room (MCR) and safety-critical EC&I systems and the associated heating, ventilation and air conditioning (HVAC) system and back-up cooling system, within four separate trains.

The EC&I Block trains are primarily comprised of mechanical kit of parts (MKoP) process clusters which are supported by the Basemat. These MKoP process clusters are housed within the Hazard Shield.

Fluids Block [UJT]

The Fluids Block is comprised of two trains, and houses systems associated with the reactor plant and the cooling of the fuel temperature within the Reactor Island. One train is located to the 'north' of the Fuelling Block and the other is located to the 'south'. The Fluids Block trains are primarily comprised of MKoP process clusters that are supported by the Basemat. These MKoP process clusters are housed within the Hazard Shield.

Auxiliary Block [UKA10]

The Auxiliary Block houses the systems and functions required for the collection, storage, treatment, processing, and disposal of solid, liquid, and gaseous radioactive waste. Within the Auxiliary Block, there are numerous configurations of MKoP process clusters which are required to support SSCs. Internal barriers are provided to segregate process clusters and provide protection against internal hazards, with external barriers providing external hazard protection.

9B.0.5.1.9 Waste Processing Block [UKA20]

The Waste Processing Block houses functions for decontamination and processing and packing of low-level waste (LLW). It is anticipated to be of a modular construction, with suitable barriers to meet internal and external hazard requirements.

9B.0.5.1.10 Outage Block [UKB]

The Outage Block houses the containment preparation and laydown area, which provides a space directly adjacent to the Containment Vessel and interspace to facilitate EMIT and replacement activities. At ground level, an area is provided to house temporary personnel facilities during outages.

The Outage Block is anticipated to be a civil structure, with suitable barriers to meet applicable internal and external hazard requirements. It will also house a bridging structure to allow access into the Hazard Shield.

9B.0.5.1.11 Access Block [UKB]

The Access Block houses the primary personnel access point into the Reactor Island area, radiologically controlled areas (RCA) and health physics. It also houses the site security control centre, the outage control centre (which accommodates the co-ordination of outages), the emergency response centre (the location for the co-ordination of emergency responses), and the technical support centre (which houses key technical staff who support site operation). It is anticipated to be a modular construction, with suitable barriers to meet applicable internal and external hazard requirements.

9B.0.5.2 Structures for ESWS [UPJ]

The ESWS primarily comprise Mechanical Draft Cooling Towers (MDCTs) and Make-Up Water Tanks. Two trains of MDCTs operate with a two-loop system of heat exchangers, with trains located to the 'north' and 'south' of Reactor Island to ensure separation. Each train of the ESWS has dedicated make-up water tanks, adjacent to the MDCTs, to ensure continuity of cooling function in the event of loss of external water supply. The tanks are supported on an RC raft foundation.

Further details of the structures for ESWS are provided in section 9B.3.1 of this chapter.

9B.0.5.3 Backup Generation Structures [UBM]

Backup generators provide backup power to the safety classified systems if normal power sources are interrupted. The backup generators are located to the 'north' and 'south' of Reactor Island to provide separation between the two trains.

Further details of the Back-Up Generation Structures (BUGS) are provided in section 9B.3.2 of this chapter.

9B.0.6 Overall Design Basis

The RR SMR is designed to ensure that the FSFs can be delivered following internal and external hazard design basis events, at all lifecycle stages. Four FSFs are defined for RR SMR [8], including control of reactivity (CoR), control of fuel temperature (CoFT), confinement of radioactive material (CoRM), and control of radiation exposure (CoRE).

The FSFs are decomposed into high-level safety functions (HLSFs) to protect against postulated initiating events (PIEs), including internal and external hazards, with safety measures assigned to deliver the HLSFs; this is documented within the fault schedule. These functional requirements are then decomposed and allocated to SSCs that comprise the safety measure, and assigned a safety category that is used to classify the SSC that delivers the function in accordance with the E3S categorisation and classification method. Further details on this process is provided in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [8], with the outputs of internal and external hazards analysis presented in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [9].

Safety categorised functional requirements are allocated from safety measures onto civil structures. The civil structures are required to deliver functions centred around the five high-level civil safety functions defined in Table 9B.0-9, described in further detail in the Design Basis for Reactor Island Structures [10].

Table 9B.0-9: Civil Safety Function Descriptions

Civil Safety Function	Function Description	Function Example
Protect	To prevent something from being harmed or damaged by an external or internal hazard.	The Seismic Isolation System (aseismic bearings) shall protect SSCs via the reduction of horizontal accelerations on top of the Basemat and the subsequent secondary response that SSCs are subject to.

Civil Safety Function	Function Description	Function Example
Support	To provide restraint to something to prevent or limit its movement under an applied force either translationally in three perpendicular axes or rotationally about three perpendicular axes.	The Basemat shall support the Hazard Shield.
Confine	Prevention or control of releases of radioactive material to the environment in operation or in accidents.	The fuel pool structure shall confine radioactive material.
Shield	To provide physical protection from radiation or electromagnetic waves.	The fuel pool structure shall shield operational personnel from the contents of the fuel pool.
Withstand	The ability of a structure to retain its structural integrity and stability under operational and design basis load conditions.	The Hazard Shield shall withstand internal forces and displacements during a seismic event.

For civil structures that are allocated functional requirements from safety measures, the safety classification assigned to the structure is generally based on the highest classified SSC that the structure must interface with.

The FSFs and associated civil safety functions defined for each civil structure at RD7/DRP1 are summarised within the 'design basis' sections of 9B.1, 9B.2, and 9B.3 in this chapter.

Structures are also assigned a seismic performance classification (SPC), which defines the performance level of each structure in response to a seismic event, this process is described further in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [8].

Depending on the safety classification of SSCs, SSCs are also designated a seismic design basis (SDB), which is a combination of a seismic design category (SDC) and limit state. A limit state is defined in ASCE 43-19 [11] as a limiting acceptable condition of the SSC and may be defined in terms of a maximum acceptable displacement, strain, ductility, or stress.

For safety class 1 and safety class 2 nuclear safety-related structures, the SDB shall be a minimum of 5C (SDC-5 and limit state C) to allow for some limited permanent distortion during and following a design basis event in accordance with ANS 2.26-2004 [12] and ASCE 43-19 [11]. Where structures are required to remain elastic during and following a design basis event, they are classified with an SDB of 5D.

The SDB for each civil engineering system is summarised within the 'design basis' sections of 9B.1, 9B.2, and 9B.3 in this chapter.

9B.0.7 Methodologies for Analysis and Design

The analyses and design methodologies to be adopted for safety classified structures (as defined in Design Basis for Reactor Island Structures [10]) are presented in the Structural Design Method

Statement (SDMS) [13]. The methodology for assessing the effects of collapse of structures on safety class 1 or 2 structures will be considered in a future revision of the SDMS [13].

Methodologies have been developed for global and local structural assessments for RC and steel structures, geotechnical analysis and design, and methods for assessing static and dynamic soil-structure interaction (SSI) effects. The chosen seismic performance criteria for safety classified structures in accordance with ASCE 43-19 [11] are also presented.

The software to be used for civil engineering analysis is identified, along with plans for validation and verification of analysis results.

The following sub-sections relate to methodologies for design basis conditions. Section 9B.0.7.6 covers methodologies specific to beyond design basis conditions.

9B.0.7.1 Actions

The loads used in the design of the civil structures are derived from normal operations, and design basis internal and external hazards. The scope of design basis internal hazards and external hazards which civil structures are to be designed for are presented in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [9]. For the derivation of load combinations, load cases are categorised in accordance with the terminology used in Section 9.1 of ACI 349M-13 [14] and Section NB2 of AISC N690-18 [15]:

1. Normal loads
2. Severe environmental loads
3. Extreme environmental loads
4. Abnormal loads.

9B.0.7.1.1 Normal Loads

Normal loads include dead loads (D), live loads (L), roof live loads (L_r), crane loads (C_r), reactions from operating pipework and equipment (R_o), operating temperature loads (T_o), fluid loads (F), earth pressure and groundwater pressure loads (H), operating wind loads (W), operating snow loads (S) and operating operational rain loads (R).

Dead loads (D) include the self-weight of structural and non-structural members, and the self-weight of fixed permanent equipment.

Live loads (L) will be defined based on the occupancy level of the area being assessed and the associated load drawings that will be produced for the different areas of the plant.

Roof live loads (L_r) will be defined based on the use and occupancy of roof structures.

Crane loads (C_r) will be defined as the weight of the crane and its rated lifting capacity. In the case of moving bridge cranes and monorail cranes, the trolley and bridge will be positioned at the locations where the resulting loading effect is maximised.

Reaction from operational pipework and equipment (R_o) will be defined as the related internal moments and forces that occur under normal operating conditions. This will exclude associated dead load and earthquake induced forces.

Operating temperature loads (T_o) will be the loads induced on structure due to thermal effects of operating temperatures and thermal gradients and are defined as external maximum and minimum dry bulb temperatures for a $2x10^{-2}$ year event.

Fluids load (F) will be defined as the equivalent hydrostatic pressures on the walls and floors of water retaining structures i.e. pools. This excludes earthquake-induced hydrodynamic pressures.

Earth pressure and groundwater pressure loads (H) are defined as the lateral static soil pressures, static surcharge pressures and hydrostatic pressures induced on buried structures and foundations.

Operating wind loads (W) are defined as design wind pressures based for a 10-minute fundamental wind velocity for a $2x10^{-2}$ year event.

Operating snow loads (S) are defined as ground snow loads based on a $2x10^{-2}$ year event.

Operating rain loads (R) are defined as the live loads resulting from the ponding of rainwater on roof structures.

9B.0.7.1.2 Severe Environmental Loads

Severe environmental loads include an operating basis earthquake (E_o), design basis temperature loads, design basis wind loads, design basis snow loads and design basis ice loads.

Operating basis earthquake loads (E_o) are defined from a scaling factor applied to the corresponding design basis earthquake spectra. Operating basis earthquake loads will consider the self-weight of structural and non-structural elements, self-weight of fixed equipment, an appropriate proportion of live load occupancy, an appropriate proportion of crane loading, hydrodynamic fluid loads, and dynamics earth pressures and hydrodynamic water pressures.

Design basis temperature loads will be the loads induced on structure due to thermal effects of design basis temperatures and thermal gradients and are defined as external maximum and minimum dry bulb temperatures for a $1x10^{-4}$ year event.

Design basis wind loads are defined as design wind pressures based on a $1x10^{-4}$ year event.

Design basis snow loads are defined as ground snow loads based on a $1x10^{-4}$ year event.

Design basis ice loads are defined as the loads associated with a clear ice density and thickness for a $1x10^{-4}$ year event.

9B.0.7.1.3 Extreme Environmental Loads

Extreme environmental loads include a design basis earthquake (E_{ss}), tornado loads (W_t) and external flooding loads.

Design basis earthquake (E_{ss}) loads are defined from the corresponding design basis earthquake spectra. Design basis earthquake loads will consider the self-weight of structural and non-structural elements, self-weight of fixed equipment, an appropriate proportion of live load occupancy, an appropriate proportion of crane loading, hydrodynamic fluid loads, and dynamics earth pressures and hydrodynamic water pressures.

Tornado loads (W_t) are defined as the pressures associated with the tornado wind speed, and the change in pressure differential due to the rapid change in atmospheric temperature. Tornado loads will also take account of tornadic generated missiles.

External flooding loads will be defined as the hydrostatic pressure loads induced on structures due to the maximum external flooding level.

9B.0.7.2 Abnormal Loads

Abnormal loads include accidental temperature (T_a), accidental piping and equipment reactions (R_a), differential pressure loads (P_a), pipe break reactions (Y_r), jet impingement loads (Y_j), missile impact loads (Y_m) and fire.

Accidental temperature (T_a) loads induced on structure due to thermal effects and thermal gradients due to accidental temperature conditions.

Accidental piping and equipment reactions (R_a) will be defined as the related internal moments and forces that occur under accidental conditions.

Differential pressure loads (P_a) will be defined as the change in pressure gradient across civil structures during accidental conditions.

Pipe break reactions (Y_r) will be defined as the related internal moments and forces that result from pipe break.

Jet impingement loads (Y_j) will be defined as loads resulting from pipe break, concentrated on a small area.

Missile impact loads (Y_m) will be defined as loads resulting from the kinetic energy transferred into a target surface from a projectile.

9B.0.7.2.1 Load Combinations

Load combinations defined in the SDMS [13] include the codified combinations as per ACI 349M-13 [14] and AISC N690-18 [15]. The full list of load combinations to be utilised for the analysis and design of civil structure is in development and will be reflected in Version 3 of the generic E3S Case.

9B.0.7.3 Analysis Methodology

9B.0.7.3.1 General

For the analysis of Reactor Island structures, a three-model approach is adopted (and documented in the SDMS [13]) to account for the interface between the structural and geotechnical analyses. The following models will be considered:

1. Geotechnical models: these will be used to develop a representation of the soil stiffness for inclusion in the Reactor Island global structural model to capture the effects of SSI

2. Reactor Island global structural model: this model will include a detailed representation of the RI raft foundation, the Seismic Isolation System components, and interconnected primary structural elements within the Hazard Shield that contribute to the primary vertical and lateral force-resisting system adopted. Effects induced from the soil will be modelled via elastic SSI

springs. The Reactor Island global model shall also include a simplified representation of local structural models, with representative mass and stiffness accounted for

3. Local structural models: individual models will include a detailed description of structures that are isolated from the primary vertical and lateral load-resisting systems of the Hazard Shield and associated interconnected systems (e.g. steel module clusters and Containment Support Structure).

A combination of static and dynamic assessments will be performed to complete the geotechnical and structural analysis of the RR SMR structures.

The Reactor Island global structural model will be used to generate secondary response spectra (SRS) at the Basemat and suspended floor slab levels to feed into the design of structures in local structural models, and the seismic qualification of safety critical SSCs. The Reactor Island global structural model will also be used to progress the design of the Seismic Isolation System components to determine the minimum seismic separations to be maintained between structures on and off the Seismic Isolation System.

For the design of safety class 1 and 2 structures, the outputs from these analysis models will be used to:

1. Determine appropriate forces and moments to carry out the design of all civil structures

2. Demonstrate satisfactory global stability (e.g. sliding, overturning) of the civil structures.

Further details on the analysis methodologies for safety class 1 and 2 structures can be found in the SDMS [13].

9B.0.7.3.2Static

Static Soil-Structure Interaction

In line with the methodology presented in section 6.4 of the SDMS [13], in the global structural model, the ground will be represented by modulus of subgrade reaction (MSR) springs. The MSR spring stiffnesses will be derived from the results of the analysis using a geotechnical model incorporating a simplified representation of structural stiffness and a representation of the ground. The applied loads and the derived settlements will be used to determine the MSR at points on the base of the Raft Foundation.

Key aspects affecting ground deformation and settlement that are considered at this design stage are given in section 6.17 of the SDMS [13].

9B.0.7.3.3 Seismic

Dynamic Soil-Structure Interaction

In line with section 6.4 of the SDMS [13], soil and foundation stiffness will be represented in the seismic analysis for the global structural model by distributed frequency-dependent vertical and horizontal springs and dampers to capture dynamic SSI effects. This is consistent with a direct modelling approach to ASCE 4-16 [16]. For implementation in the structural analysis, frequency-independent spring and damper values will be used, calculated from the frequency-dependent functions, and evaluated at the structure-foundation fundamental frequency for the relevant degree of freedom.

Response Spectrum Analysis

In line with section 6.15 of the SDMS [13], three-dimensional, dynamic modal-response-spectrum analyses will be used for the seismic design of the structural elements. Structural mode shapes and associated periods of vibration will be computed using an Eigenvector modal analysis. The analyses will be performed in separate steps for the Reactor Island global model and the local models.

Limited to the Reactor Island global model, dynamic equivalent SSI springs, derived as described above, will be used as boundary conditions. For the local models, fixed boundary conditions will be generally assumed for the base nodes. Releases will be considered for those nodes (i.e. steel module clusters' base nodes) where rotational capacity may not be required.

Time History Analysis

In line with section 6.16 of the SDMS [13], three-dimensional, linear time history analysis will be performed for the RI global model to generate secondary response spectra at the raft foundation level, Basemat level, and elevated floor and roof levels. The analyses will utilize ground motion histories that comprise one vertical and two horizontal orthogonal components. Ground motion histories will be applied as boundary conditions to dynamic equivalent SSI springs, derived as described above.

9B.0.7.4 Design Methodologies

9B.0.7.4.1 Reinforced Concrete

The design of RC structures is defined within section 9 of the SDMS [13]. The codes and standards which shall be utilised for the strength design of RC structures is defined in Table 9B.0-3 and Table 9B.0-4. The codes and standards which are utilised for the serviceability design of RC structures is defined in Table 9B.0-5.

The strength design of RC structures shall be carried out in accordance with ACI 349M-13 [14] and ACI 318M-08 [17]. Details associated with the design of walls, slabs, beams and columns are presented within Section 9 of the SDMS [13]. Details associated with the design of anchorages are presented within Section 10 of the SDMS [13].

The serviceability design of RC structures shall be carried out in accordance with ACI 349M-13 [14] and ACI 318M-08 [17]. For the control of horizontal drift, maximum limits are adopted from ASCE 43-19 [11] for both Limit C and Limit D structures. For crack control, in the absence of specific provisions from ACI 349M-13 and ACI 318-08M, RGP shall be followed to control flexural, thermal and shrinkage cracking (e.g. CIRIA C766).

9B.0.7.4.2 Steel

The design of structural steelwork is defined within section 10 of the SDMS [13]. The codes and standards which shall be utilised for the strength design of structural steelwork structures is defined in Table 9B.0-3 and Table 9B.0-4. The codes and standards which are utilised for the serviceability design of structural steelwork structures is defined in Table 9B.0-5.

The strength design of structural steelwork shall be carried out in accordance with AISC 360-16 [18], AISC 341-16 [19] and AISC N690-18 [15]. Details associated with the design of members subjected to flexure, compression, tension, shear and torsion are presented within Section 10 of the SDMS [13]. Details associated with the design of steel connections are presented within Section 10 of the SDMS [13].

The serviceability design of structural steelwork shall be carried out in accordance with AISC 360-16 [18], AISC 341-16 [19] and AISC N690-18 [15]. For vertical deflection limits, in the absence of specific provisions from AISC 360-16 [18], AISC 341-16 [19] and AISC N690-18 [15], RGP shall be followed to provide limits for vertical deflections with reference being made to BS EN 1993-1-1 [20] and BS EN 1993-6 (although it is acknowledged that as the design develops there will be a requirement to consider more onerous vertical deflection limits from supported SSCs). For the control of horizontal drift, maximum limits are adopted from ASCE 43-19 [11] for both Limit C and Limit D structures. Horizontal deflection limits are also considered in accordance with BS EN 1933-1-1 [20] and BS N 1993-6.

9B.0.7.4.3 Aseismic Bearings

The design of aseismic bearings is defined within section 11 of the SDMS [13]. The codes and standards which shall be utilised for the analysis and design of aseismic bearings are defined in Table 9B.0-1. A hybrid approach will be adopted for the RR SMR isolated structures, where:

1. The analysis is carried out based on the methodology outlined in section 6, therefore following the American code provisions of ASCE 4-16 [16] and ASCE 43-19 [11].

2. The elastomeric bearings are locally verified against shear strain, buckling and overturning stability and tension/compression checks, based on the methodology outlined in sub-section 11.3 of the SDMS, therefore following the code provisions of National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) [21], BS EN 1337 [22] and BS EN 15129 [23].

Section 12 of ASCE 4-16 [16] and section 9 of ASCE 43-19 [11] will be used to specify the general performance requirements, as well as the preferred methods of analysis, for the seismically isolated structures. Refer to sub-section 11.2 of the SDMS for further details.

Local verification of the elastomeric bearings will follow the design procedure given in section 8.2 of BS EN 15129 [23] (under seismic loading conditions) and section 5.4 of BS EN 1337 [22] (under non-seismic loading conditions). Testing protocols for the bearings will also follow the provisions given in BS EN 15129 [23] and BS EN 1337 [22]. Refer to sub-sections 11.3 and 11.4 of the SDMS for further details. The choice of the guidance in terms of the limiting shear strain and potential inclusion of the ENEA standard [21], will be a focus of the next issue of the SDMS (refer to FAP-SDMS-ALL-010).

Special Design Provisions for Seismically Isolated Structures

In line with ASCE 4-16 [16] and section 11.2 of the SDMS [13], a stop/displacement restraint will be provided along both orthogonal horizontal axes of the superstructure in order to prevent excessive displacement of the isolation system in the event of a beyond design basis event (BDBE). The maximum horizontal distance between the superstructure and the restraint will be defined as the clearance to the stop (CS). A CS not less than the 90th percentile BDBE displacement will be provided to the superstructure, in line with the provisions given in section 12.5.3 of ASCE 4-16 [16]. The stop will be designed to resist impact loadings associated with the BDBE event.

Design Requirements for Aseismic Bearings

Low-damping laminated rubber bearings have been selected as part of the Seismic Isolation System, to protect the Reactor Island structures supported by the Basemat.

In line with Table 12-1 of ASCE 4-16 [16], the design of the elastomeric bearings will be progressed such that:

1. No permanent damage to the isolation system is observed for the DBE shaking.

2. Isolator damage is acceptable for the BDBE shaking, whilst preserving the gravity load-carrying capacity.

Further details associated with the local verifications of aseismic bearings are presented within section 11 of the SDMS [13].

9B.0.7.5 Software

Section 14 of the SDMS [13] gives an overview of the main software packages that are planned to be used for the geotechnical and structural analysis and design of the RR SMR classified structures. These are summarised within this section:

1. Abaqus: A proprietary finite element (FE) package suited to carrying out time history, modal analysis, response spectra analysis, gravity and static loading assessments of reinforced concrete and steel structures exhibiting both linear and non-linear behaviour.

2. PTC MathCad Prime®: A computer software primarily intended for the verification, validation, documentation and re-use of engineering calculations.

3. Robot Structural Analysis Professional: A structural analysis software by Autodesk that uses building information modelling (BIM)-integrated workflows to exchange data with Autodesk Revit.

4. Tekla Tedds: A structural software primarily intended for the analysis and design of steelwork and RC elements according to ACI 318M-08 [17] and AISC 360-16 [18].

5. Plaxis 3D: The Bentley software program PLAXIS 3D will be used to generate modulus of subgrade reaction values to represent soil stiffness in structural models.

6. DynamAssist: A tool used to generate synthetic ground motion accelerograms compatible with a user-specified response spectrum.

7. Microsoft Excel will be used for post-processing the output data from the FE software and for supporting calculations based on first engineering principles. Any calculation carried out using Excel and Visual Basic for Applications (VBA) will be checked and verified for the successful running of individual calculations.

8. IDEA Statica®: A structural software intended for the design of steelwork connections.

Software Validation

The validation phase shall require comparison of the results of the software with well documented experiments for simple cases, and/or feedback from operating experience, and/or results from previously validated software, and/or from analytical solutions, and/or the judgement of experts. Hence, the validation and checking of analysis output will be undertaken using suitable hand calculations. Where spreadsheets or automated scripting are used for repetitive calculations in the design process, quality assurance checks shall be undertaken to control their use and where necessary, independent hand calculations shall also be undertaken.

9B.0.7.6 Beyond Design Basis Methodologies

For the development of the civil engineering E3S case, the assessment of structural performance beyond design basis conditions is applicable for hazards that have lower frequencies of occurrence than design basis conditions. The methodology for assessing the structure for beyond design basis conditions shall be presented in Step 3, as noted in FAP-SDMS-ALL-005 of the SDMS [13]. Methodologies related to aircraft impact assessment have been developed and are presented within this section.

Aircraft Impact Assessment

For the development of the aircraft hazard, both accidental and malicious aircraft impact hazards are considered as beyond design basis conditions. For accidental aircraft impact, this is based on analysis of crash frequency data which has determined the mean accidental aircraft crash rate onto the critical area of the RR SMR site to be less than the threshold to be considered as a design basis events. For malicious aircraft impact, this is based on expectations set out by ONR in their expectations letter for malicious aircraft impact and is in accordance with RGP such as NEI 07-13 [24]. Further information on the accidental aircraft crash frequency can be found in Analysis of Background Accidental Aircraft Crash Frequency [25].

To ensure the fulfilment of FSFs following an aircraft impact, safety measures have been identified and are in place to prevent and protect against such design extension events. These are summarised within the Aircraft Impact Design Philosophy and Methodology Statement [6], including the philosophy for whether functionality of these safety measures will be ensured through duplication and separation of relevant SSCs, or through the relevant SSCs being housed inside an impact protection structure. For the RR SMR design, the main impact protection structure is the Hazard Shield (see 9B.2.5).

For the design of the Hazard Shield, the methodology for assessing the performance of structures is reflective of this being a beyond design basis condition. This is documented within the Aircraft Impact Design Philosophy and Methodology Statement [6], and comprises the following key aspects:

1. The material properties to be used for structural assessment shall be based on best-estimate properties for structural materials

2. The methodology for assessing impacted structures includes:

    a. Local analysis of impacted structures, considering the potential for penetration, scabbing, spalling, perforation and punching shear.

    b. Global panel assessment of impacted structures.

    c. Global stability assessments (shear, uplift) for impact protection structures.

3. Nonlinear finite element analysis (FEA) will be adopted to justify the performance of civil engineering structures subjected to aircraft impact.

4. The acceptance criteria (for example, allowable structural deformation) for aircraft impact is in accordance with RGP, but is less onerous than acceptance criteria for design basis conditions.

For the assessment of plant performance, the aircraft impact assessment shall also include consideration of the consequential hazards of impact-induced shock and fire.

9B.1 Foundations and Buried Structures

9B.1.1 Raft Foundation and Retaining Wall

9B.1.1.1 Structural Role

The RC Raft Foundation provides the main load transfer from the Reactor Island Hazard Shield, Basemat and Containment Support Structure to the ground and external environment. A series of RC pedestals are embedded on top of the raft foundation that support (and provide access to) the aseismic bearings.

The structural role of the Retaining Wall is to withstand earth pressures, hydrostatic pressures, hydrodynamic pressures, and surcharges. it also supports bridging structures that provide access to the Hazard Shield and limits the horizontal displacement of the Basemat during a beyond design basis earthquake.

9B.1.1.2 Design Basis

The Raft Foundation and Retaining Wall deliver the 'protect' and 'support' civil safety functions aligned to FSFs of CoR, CoFT, and CoRM. They also deliver the 'support' civil safety function aligned to CoRE.

The safety function category for the Raft Foundation and Retaining Wall is category A. The associated classification is safety class 1.

The SPC for the Raft Foundation and Retaining Wall is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the Raft Foundation and Retaining Wall are provided in [10]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [26].

9B.1.1.3 Structural Description

At RD7/DRP1, the plan area for the Raft Foundation is 70 m ('north-south') x 123.2 m ('east-west'), with a raft thickness of 3 m. A section through the Raft Foundation and Retaining Wall is shown in Figure 9B.1-1.

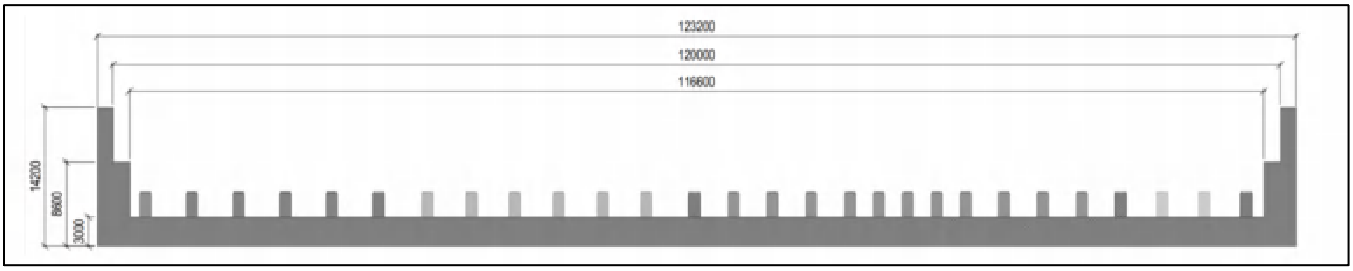

Figure 9B.1-1: East-West section through Raft Foundation and Retaining Wall

At RD7/DRP1, the RC Retaining Wall is 11.2 m high, with 1 m wide in-situ cantilever elements supported by the Raft Foundation (1.4 m wide including precast concrete shells).

Further structural details of the Raft Foundation and Retaining Wall, including vertical and horizontal load paths, are described in [26].

9B.1.1.4 Materials

The Raft Foundation is comprised of RC. The Retaining Wall is comprised of in-situ RC cantilever elements which are cast within a series of precast RC shells that act as permanent formwork to the in-situ concrete.

9B.1.1.5 Interfaces

As described in section 9B.1.1.1.

9B.1.1.6 System and Equipment Operation

Not applicable.

9B.1.1.7 Instrumentation and Control

Not applicable.

9B.1.1.8 Monitoring, Testing, Inspection and Maintenance

The Raft Foundation and Retaining Wall will be examinable and inspectable. At RD7/DRP1 detailed EMIT arrangements are still to be developed, however will likely include:

1. Visual inspections/crack surveys
2. Deformation monitoring
3. Reinforcement cover surveys
4. Delamination inspections
5. Chloride/carbonation monitoring.

9B.1.1.9 Radiological Aspects

Not applicable.

9B.1.1.10 Performance and Safety Evaluation

The verification activities that are required for the Raft Foundation and Retaining Wall to achieve its E3S requirements are largely associated with structural analysis, as described in section 9B.0.7. Other tests will include demonstration tests verifying the constructability of the Retaining Wall and RC pedestals, as well as waterproofing tests on the Retaining Wall. The outputs of verification activities will be reported in Version 3 of the generic E3S Case.

9B.1.2 Seismic Isolation System

9B.1.2.1 Structural Role

Aseismic bearings directly support the Basemat component of the Reactor Island Hazard Shield, Basemat and Containment Support Structure, to provide a direct load path through the RC pedestals to the Raft Foundation.

In addition to providing a vertical load path, the aseismic bearings also offer a base isolation system for the Hazard Shield and SSCs housed within it against horizontal seismic loading. The addition of seismic isolators changes the dynamic behaviour of the Reactor Island structure, increasing its fundamental period and thus reducing the horizontal secondary accelerations at the Basemat level.

9B.1.2.2 Design Basis

The Seismic Isolation System delivers the ‘protect’ and ‘support’ civil safety functions aligned to FSFs of CoR, CoFT, and CoRM. It also delivers the ‘support’ civil safety function aligned to CoRE.

The safety function category for the Seismic Isolation System is category A. The associated classification is safety class 1.

The SPC for the Seismic Isolation System is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the Seismic Isolation System are provided in [10]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [26].

9B.1.2.3 Structural Description

The size, number and layout of the aseismic bearings are site dependent. Preliminary assessments indicate that approximately 480 bearings shall be required for more favourable soil conditions to achieve the fundamental mode of vibration for the Hazard Shield of 0.5 Hz.

The aseismic bearing system is designed in accordance with ASCE 4-16 [16] to prevent cliff-edge failure, therefore the retaining wall acts as a stop for base-isolated structures to prevent excessive displacement during a seismic event.

9B.1.2.4 Materials

The aseismic bearings are anticipated to be low damping rubber elastomeric bearings, based on RGP from other nuclear applications.

9B.1.2.5 Interfaces

As described in section 9B.1.2.1

9B.1.2.6 System and Equipment Operation

Not applicable.

9B.1.2.7 Instrumentation and Control

Not applicable.

9B.1.2.8 Monitoring, Testing, Inspection and Maintenance

The aseismic bearings will require both regular and principal inspections in accordance with codes and standards. At RD7/DRP1 detailed EMIT arrangements are still to be developed.

9B.1.2.9 Radiological Aspects

Not applicable.

9B.1.2.10 Performance and Safety Evaluation

The verification activities that are required for the Seismic Isolation System to achieve its E3S requirements are largely associated with structural analysis, as described in section 9B.0.7. Other tests for the aseismic bearing include material testing.

The verification activities that are required for the Seismic Isolation System to achieve its E3S requirements include qualification in accordance with ASCE 4-16 [16], BS EN 1337 [22] and BS EN 15129 [23] (see section 9B.0.7.4.3). The outputs of verification activities will be reported in Version 3 of the generic E3S Case.

9B.2 Reactor Island Structures

9B.2.1 Containment Internal Structures [UJA]

9B.2.1.1 Structural Role

The Containment Internal Structures support and protect the primary circuit vessels and associated pipework, the refuelling pool and refuelling cavity, and the fuel handling machine and main overhead crane.

9B.2.1.2 Design Basis

The Containment Internal Structures deliver the 'protect', 'support' and 'confine' civil safety functions aligned to FSF of CoRM, and 'support' to CoR and CoFT. They also deliver the 'shield' civil safety function aligned to CoRE.

The safety function category for the Containment Internal Structures is category A. The associated classification is safety class 1.

The SPC for the Containment Internal Structures is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the Containment Internal Structures are provided in [10]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [27].

9B.2.1.3 Structural Description

The Containment Internal Structures are supported by the Hazard Shield, Basemat and Containment Support Structure by load transfer through the Containment Vessel. It can be split into two broad sub-structures:

1. Lower dome concrete, which consists of structures below the main floor level. It forms the Reactor Pressure Vessel (RPV) cavity, the base and lower walls of the Refuelling Pool, the base of the Refuelling Cavity, and the Main Containment Sumps.

2. Upper structures, which consists of all other structures above the main floor level, including the upper part of the Refuelling Pool walls, the Refuelling Cavity Walls, Steam Generator (SG) and Pressuriser enclosure walls, Main Overhead Crane (MOC) support structure, Fuel Handling Machine (FHM) support structure, and steelwork for module stacks.

The overall structural form is illustrated in Figure 9B.2-1.

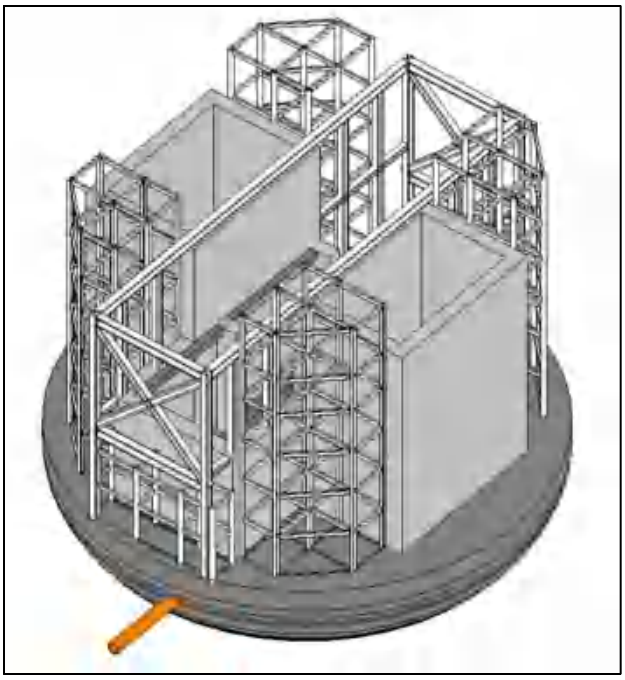

Figure 9B.2-1: Overview of Containment Internal Structures from South-West (module stack bracing not shown)

9B.2.1.4 Materials

The lower dome comprises an RC structure. The baseline structural form for the upper structures enclosing the SGs and pressuriser is an RC structure.

9B.2.1.5 Interfaces

As described in section 9B.2.1.1.

9B.2.1.6 System and Equipment Operation

Not applicable.

9B.2.1.7 Instrumentation and Control

Not applicable.

9B.2.1.8 Monitoring, Testing, Inspection and Maintenance

The Containment Internal Structures will be examinable and inspectable. At RD7/DRP1 detailed EMIT arrangements are still to be developed, however will likely include:

1. Visual inspections/crack surveys
2. Deformation monitoring
3. Reinforcement cover surveys
4. Delamination inspections

5. Chloride/carbonation monitoring
6. Leak detection for pools
7. Specific inspection requirements for key structures and interfaces.

9B.2.1.9 Radiological Aspects

The design and assessment of the shielding to be provided by the Containment Internal Structures is described in E3S Case Version 2, Tier 1, Chapter 12: Radiation Protection [28].

9B.2.1.10 Performance and Safety Evaluation

The verification activities that are required for the Containment Internal Structures to achieve its E3S requirements are largely associated with structural analysis to codes and standards, as described in section 9B.0.7. At RD7/DRP1, no novel testing activities are envisaged, as the Containment Internal Structures will be constructed from common structural materials.

9B.2.2 Basemat and Containment Support Structures [UWD]

9B.2.2.1 Structural Role

The Basemat is a suspended RC slab that provides the main load transfer between the buildings/blocks within the main footprint of Reactor Island and the supporting aseismic bearings. The Containment Support Structure transfers the load of the Containment Vessel and Containment Internal Structures into the Basemat.

9B.2.2.2 Design Basis

The Basemat and Containment Support Structures deliver the ‘support’ civil safety functions aligned to FSFs of CoR, CoFT, and CoRM.

The safety function category for the Basemat and Containment Support Structures is category A. The associated classification is safety class 1.

The SPC for the Basemat and Containment Support Structures is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the Basemat and Containment Support Structures are provided in [10]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [29].

9B.2.2.3 Structural Description

The Basemat, illustrated in Figure 9B.2-2, includes the following main components:

1. Basemat slab
2. Anchorage to aseismic bearings.

The Containment Support Structures, illustrated in Figure 9B.2-3, include the following main components:

1. Central plinth support, under the centre of the Containment Vessel

2. Perimeter supports, which are situated around the circumference of the Containment Vessel, near to the top of the lower dome section.

The Containment Support Structures resist vertical compressive loads from the Containment Vessel through both the central plinth and perimeter supports, and lateral loads are resisted primarily through the central plinth.

The baseline option for the perimeter supports is 3No. RC outer plinths with small gaps between to facilitate access. The alternative option is 12 No. steel-concrete (SC) composite columns, equally spaced around the perimeter. Both options are shown on Figure 9B.2-3.

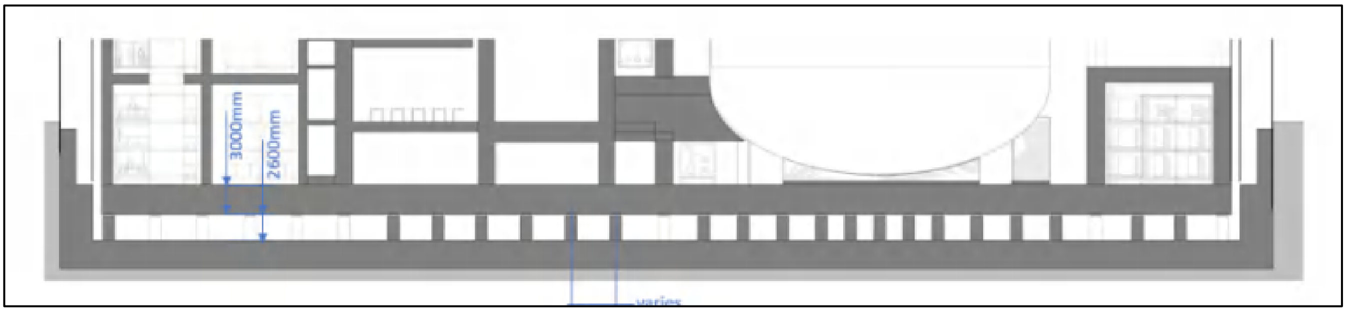

Figure 9B.2-2: Basemat Section

{REDACTED}

Figure 9B.2-3: Containment Support Structure - Outer Plinths (top), Columns (bottom)

9B.2.2.4 Materials

The Basemat and Containment Support Structures are generally comprised of RC.

9B.2.2.5 Interfaces

The Basemat supports the structures in the Hazard Shield and the Auxiliary Block, see Figure 9B.0-4. The Containment Support Structure is integral to the Basemat and is connected to the Containment Vessel.

9B.2.2.6 System and Equipment Operation

Not applicable.

9B.2.2.7 Instrumentation and Control

Not applicable.

9B.2.2.8 Monitoring, Testing, Inspection and Maintenance

The Basemat and Containment Support Structures will be examinable and inspectable. At RD7/DRP1 detailed EMIT arrangements are still to be developed, however will likely include:

1. Visual inspections/crack surveys
2. Deformation monitoring
3. Reinforcement cover surveys
4. Delamination inspections
5. Chloride/carbonation monitoring.

At RD7/DRP1, space is provided within the layout to permit access around the Containment Support Structures for EMIT activities, with a gap of several meters to the surrounding walls which form the interspace.

9B.2.2.9 Radiological Aspects

Not applicable.

9B.2.2.10 Performance and Safety Evaluation

The verification activities that are required for the Basemat and Containment Support Structures to achieve its E3S requirements are largely associated with structural analysis to codes and standards, as described in section 9B.0.7. At RD7/DRP1, no novel testing activities are envisaged, as the Basemat and Containment Support Structures will be constructed from common structural materials.

9B.2.3 Fuelling Block [UFA]

9B.2.3.1 Structural Role

The Fuelling Block houses, supports, and protects the SSCs that provide functions for handling of Nuclear Fuel Equipment [F], Reactor Plant [J] and Nuclear Auxiliary Systems [K].

9B.2.3.2 Design Basis

The Fuelling Block delivers the 'support' civil safety function aligned to the FSFs of CoR and CoFT, and support and confine to CoRM. It also delivers the 'shield' civil safety function aligned to CoRE.

The safety function category for the Fuelling Block is category A. The associated classification is safety class 1.

The SPC for the Fuelling Block is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the Fuelling Block are provided in [10]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [30].

9B.2.3.3 Structural Description

The Fuelling Block [UFA] includes the following components:

1. Spent fuel storage and cask loading system structures, including:
    a. Spent Fuel Pool Structure
    b. Cask Loading Pit Structure
    c. Upender Pit Structure
2. Intermediate floors at level 0, level 3, and level 5
3. Perimeter walls, which provide compartmentation and segregation from the Fluids Block, interspace, and the Auxiliary Block. They provide protection from internal hazards and also provide support to the Fuelling Block intermediate floors, and transfer loads from these components into the Basemat. Above level 7, these walls form part of the external envelope of the Hazard Shield.
4. Fuel transfer channel structure, which provides a shielded enclosure for the fuel transfer channel, and space for its inspection.
5. Mechanical and fuel handling support structures, including structures for the safety class 1 spent fuel pool crane and safety class 2 fuel transfer handling machine.

9B.2.3.4 Materials

The baseline solution for the spent fuel storage and cask loading system structures comprise RC structural elements. An SC option is also being considered for these pool and pit structures. The intermediate floors comprise of RC. The perimeter walls comprised of RC.

9B.2.3.5 Interfaces

As described in section 9B.2.3.1.

9B.2.3.6 System and Equipment Operation

Not applicable.

9B.2.3.7 Instrumentation and Control

Not applicable.

9B.2.3.8 Monitoring, Testing, Inspection and Maintenance

The Fuelling Block will be examinable and inspectable. At RD7/DRP1 detailed EMIT arrangements are still to be developed, however will likely include:

1. Visual inspections/crack surveys
2. Deformation monitoring
3. Reinforcement cover surveys
4. Delamination inspections
5. Chloride/carbonation monitoring.

At RD7/DRP1, space is provided within the layout to permit access around the Fuelling Block for EMIT activities.

9B.2.3.9 Radiological Aspects

The design and assessment of the shielding to be provided by the Fuelling Block is described in E3S Case Version 2, Tier 1, Chapter 12: Radiation Protection [28].

9B.2.3.10 Performance and Safety Evaluation

The verification activities that are required for the Fuelling Block to achieve its E3S requirements are largely associated with structural analysis to codes and standards, as described in section 9B.0.7. At RD7/DRP1, no novel testing activities are envisaged, as the Fuelling Block will be constructed from common structural materials.

9B.2.4 Process Clusters

9B.2.4.1 Structural Role

Process clusters are discrete structural framing systems formed from system modules that support the various MEP equipment assembled within them.

9B.2.4.2 Design Basis

The process clusters deliver the ‘protect’ and ‘support’ civil safety functions aligned to FSFs of CoR, CoFT, and CoRM. They also deliver the ‘shield’ civil safety function aligned to CoRE.

The safety function category for the process clusters is category A. The associated classification is safety class 1.

The SPC for the process clusters is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the process clusters are provided in [10]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [31].

9B.2.4.3 Structural Description

The process clusters described in this section:

1. Process clusters within the Fluids Block
2. Process clusters within the EC&I Block
3. Process clusters within the Auxiliary Block.

The segregating civil structural elements include the following main components:

1. Auxiliary Block external envelope and moat cap
2. Auxiliary Block internal walls and floors
3. EC&I Block and Fluids Block internal walls and floors.

The process clusters are an ordinary concentrically braced frame (OCBF) in accordance with AISC 341-16 [19]. The size of the modules within the process clusters varies depending on the SSCs within them.

The vertical loads from SSCs within modules are supported by the internal and perimeter floor beams. Where SSCs are supported via equipment mounts which are hung from roof beams or columns, the vertical loads associated with the SSCs are transferred into the roof beams and columns. Vertical loads from roof and floor beams are then transferred into the process cluster columns which support these beams via beam-to-column connections and transferred down the process cluster columns and into the Basemat or suspended floor/slab which supports the process cluster. Where floors support process clusters, vertical loads are transferred from the process cluster base connection through tension and/or compression into the floor via embedded anchor rods or anchor plates, loads are then transferred down internal walls and into the Basemat.

Under lateral loads, diagonal bracing elements within an OCBF shall undergo axial tension and/or compression, with forces being resolved at nodes which are connections between braces and beam/column elements. The bracing elements transfer lateral loads to the base of the process cluster and into the Basemat or supporting floor. At the base of the process clusters, the base connection shall transfer forces into the anchor rods or anchor plates into the civil structure via compression, tension and shear.

9B.2.4.4 Materials

At RD7/DRP1, process clusters are to be fabricated from grade S355 carbon steel. The segregating civil structural elements are RC.

9B.2.4.5 Interfaces

As described in 9B.0.5.1.8.

9B.2.4.6 System and Equipment Operation

Not applicable.

9B.2.4.7 Instrumentation and Control

Not applicable.

9B.2.4.8 Monitoring, Testing, Inspection and Maintenance

At RD7/DRP1, the layout of civil structural elements around the process clusters allows for EMIT activities of both the process clusters themselves, including elements that may be subjected to dynamic loading or cyclic loading, as well as the SSCs which are housed within them.

9B.2.4.9 Radiological Aspects

The design and assessment of the shielding to be provided by the process clusters is described in E3S Case Version 2, Tier 1, Chapter 12: Radiation Protection [28].

9B.2.4.10 Performance and Safety Evaluation

The verification activities that are required for the process clusters to achieve its E3S requirements are largely associated with structural analysis to codes and standards, as described in section 9.0.7.

At RD7/DRP1, opportunities are identified for rig testing to validate structural performance of the process clusters, including rig testing of module-to-module connections, and module performance for fire and flooding protection.

9B.2.5 Hazard Shield [UWD]

9B.2.5.1 Structural Role

The Hazard Shield protects safety critical SSCs from internal and external hazards. The external envelope of the Hazard Shield also protects safety critical SSCs from accidental and malicious aircraft impact.

9B.2.5.2 Design Basis

The Hazard Shield delivers the 'protect' and 'support' civil safety functions aligned to FSFs of CoR, CoFT, and CoRM. It also delivers the 'shield' civil safety function aligned to CoRE.

The safety function category for the Hazard Shield is category A. The associated classification is safety class 1.

The SPC for the Hazard Shield is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the Hazard Shield are provided in [10]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [32].

9B.2.5.3 Structural Description

The Hazard Shield includes the following main components:

1. Hazard Shield walls (including buttresses), which are RC structures integral with the Basemat

2. Hazard Shield roof supported by steel beams/trusses

3. Additional Hazard Shield structures

    a. Moat cap, helps protect the structural integrity of the aseismic bearing following an aircraft impact by preventing the ingress of fuel and other debris into the basement area (i.e. between the Basemat and raft foundation)

    b. Doors and impact protection structures, which protect openings from physical damage

    c. Bridging structures between the openings at the external boundary of the isolated Hazard Shield and non-isolated ground and adjacent buildings. These are required to provide access and egress to SSCs housed within the Hazard Shield.

Vertical loads acting on the Hazard Shield roof over containment is transferred to the supporting perimeter walls and buttresses by the roof trusses. These walls transfer vertical loads down to the Basemat. The roof slabs spanning above the Fuelling Block and Fluids Block act as two-way spanning slabs to transfer vertical loads into their perimeter walls down to the Basemat. The roof slabs above the EC&I Blocks principally act as one-way spanning slabs transferring loads to perimeter walls and then into the Basemat. The Basemat transfers loads down to the aseismic bearings, and in turn onto the RC pedestals into the raft foundations (see section 9B.1).

Lateral loads applied to the external envelope of the Hazard Shield are resisted through out-of-plane bending and shear in the walls. Lateral loads are transferred to diaphragm slabs, intermediate shear walls and buttressing walls via in-plane shear and in-plane bending. Horizontal seismic accelerations are transmitted to the primary vertical elements which distribute to the Basemat and aseismic bearings.

9B.2.5.4 Materials

The Hazard Shield walls and roofs are comprised of RC. Beams and trusses supporting roof slabs are formed from structural steel.

9B.2.5.5 Interfaces

The Hazard Shield structure is located on the Reactor Island Basemat.

9B.2.5.6 System and Equipment Operation

Not applicable.

9B.2.5.7 Instrumentation and Control

Not applicable.

9B.2.5.8 Monitoring, Testing, Inspection and Maintenance

The Hazard Shield will be examinable and inspectable. At RD7/DRP1 detailed EMIT arrangements are still to be developed, however will likely include:

1. Visual inspections/crack surveys
2. Deformation monitoring
3. Reinforcement cover surveys
4. Delamination inspections
5. Chloride/carbonation monitoring.

At RD7/DRP1, space is provided within the layout to permit access for EMIT activities of the roof and walls.

9B.2.5.9 Radiological Aspects

The design and assessment of the shielding to be provided by the Hazard Shield is described in E3S Case Version 2, Tier 1, Chapter 12: Radiation Protection [28].

9B.2.5.10 Performance and Safety Evaluation

The verification activities that are required for the Hazard Shield to achieve its E3S requirements are largely associated with structural analysis to codes and standards, as described in section 9B.0.7. At RD7/DRP1, no novel testing activities are envisaged, as the Hazard Shield will be constructed from common structural materials.

9B.3 Other Structures

9B.3.1 Structures for Essential Services Water System [UPJ]

9B.3.1.1 Structural Role

The structures for ESWS protect and support the ESWS, which include the SSCs that form the ultimate heat sink for the Reactor Island component cooling system.

9B.3.1.2 Design Basis

The ESWS delivers the 'protect' and 'support' civil safety functions aligned to the FSF of CoFT.

The safety function category for the ESWS is category B. The associated classification is safety class 2.

The SPC for the ESWS is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the ESWS are provided in [33]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [34].

9B.3.1.3 Structural Description

The structures for the ESWS include the following main components, which are illustrated in Figure 9B.3-1, Figure 9B.3-2 and Figure 9B.3-3:

1. ESWS Train 1 Make-Up Tank Foundation
2. ESWS Train 2 Make-Up Tank Foundation
3. ESWS Train 1 Cooling Tower Basin
4. ESWS Train 2 Cooling Tower Basin
5. ESWS Train 1 Pipe Culvert
6. ESWS Train 2 Pipe Culvert
7. ESWS Train 1 Above Ground Pipe Support Structure
8. ESWS Train 2 Above Ground Pipe Support Structure
9. ESWS Train 1 Above Ground Pipe Support Foundation
10. ESWS Train 2 Above Ground Pipe Support Foundation.

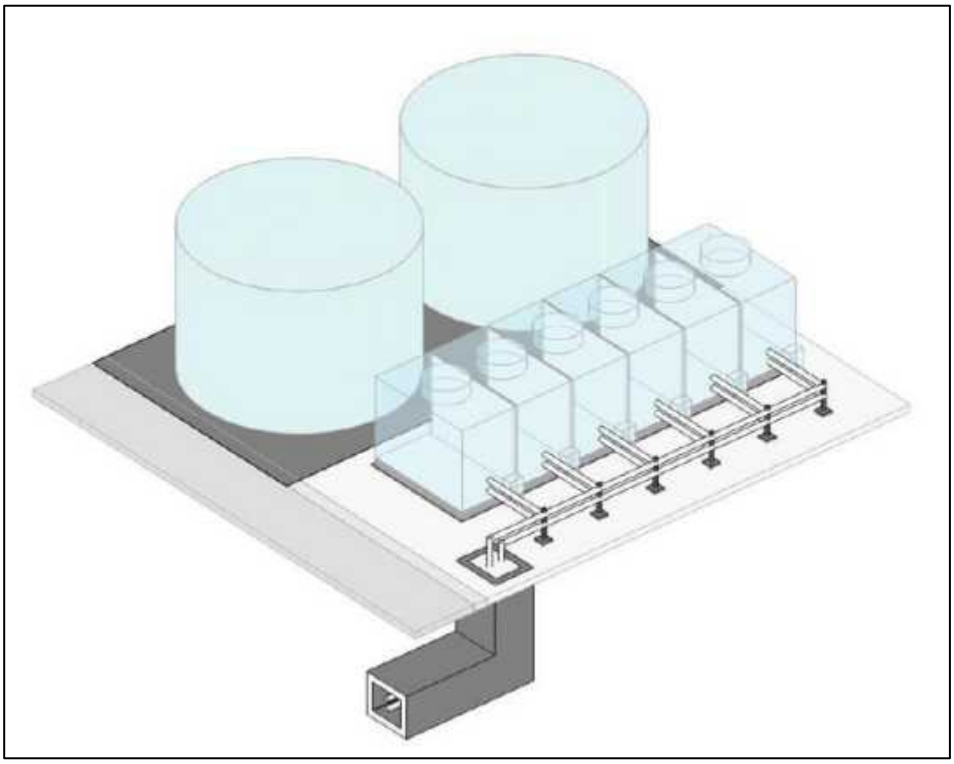

Figure 9B.3-1: Isometric View of Structures for ESWS Train 1

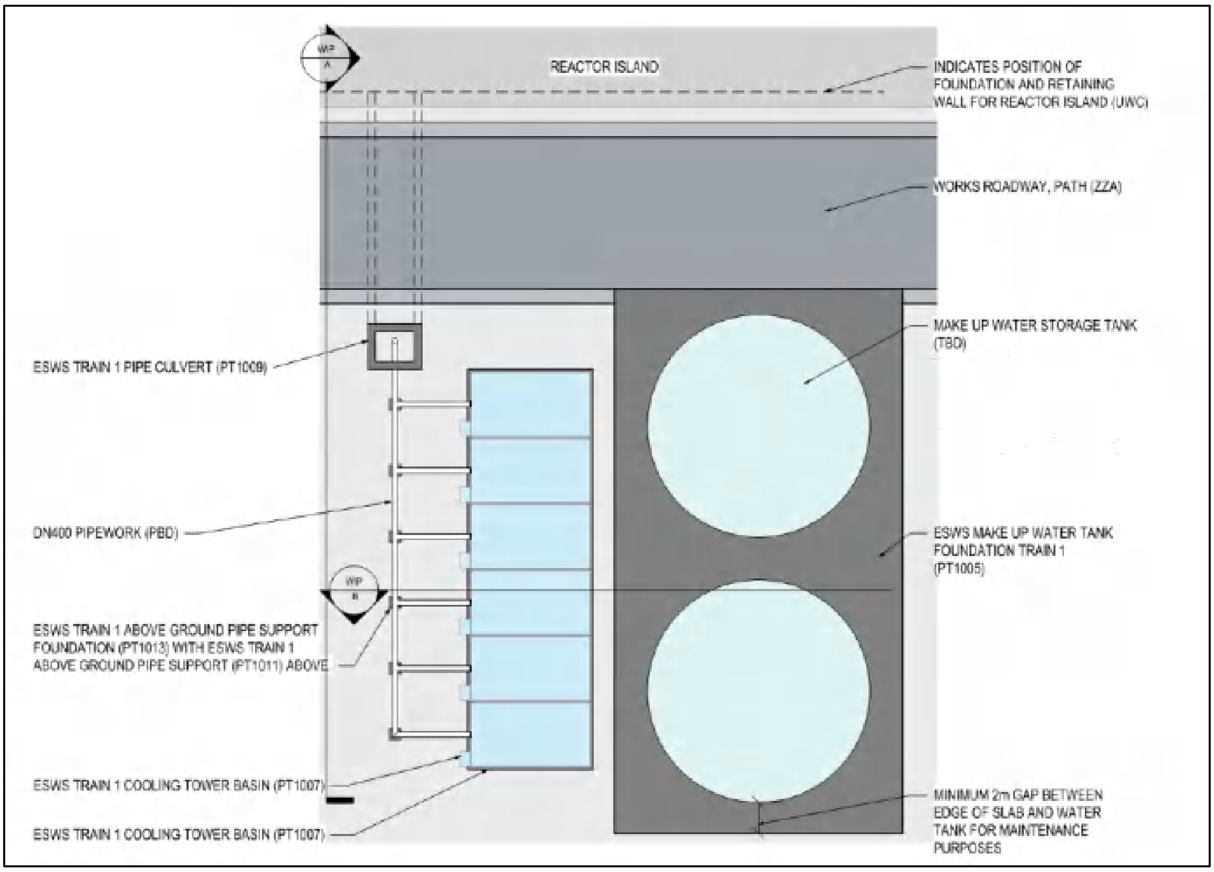

Figure 9B.3-2: Plan View of Structure for ESWS Train 1

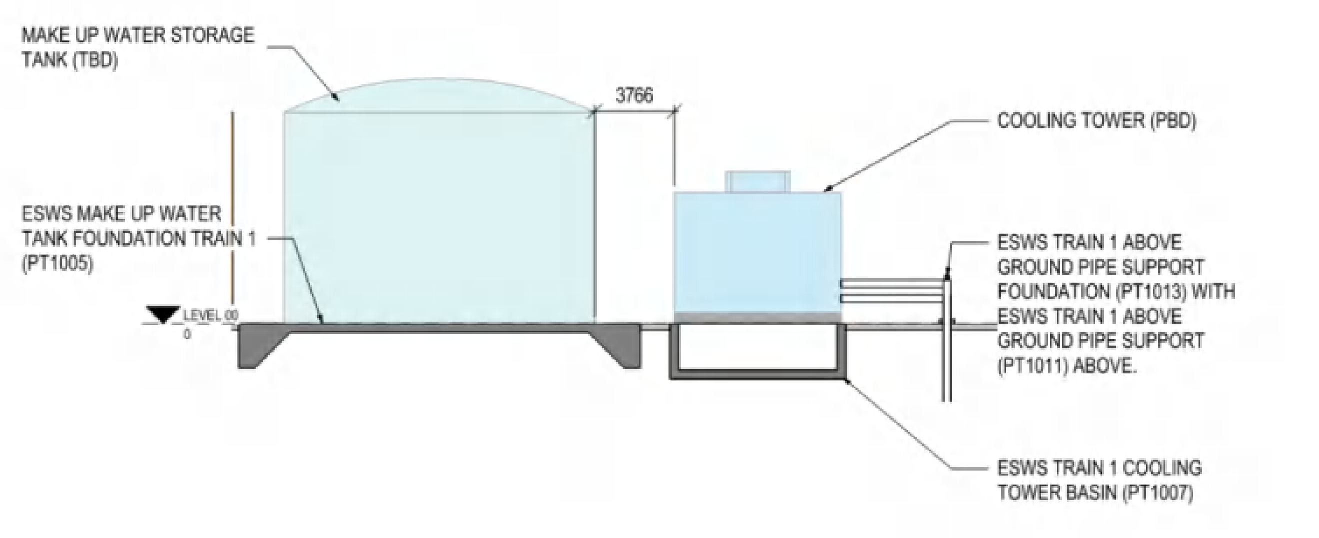

Figure 9B.3-3: Section Through Structures for ESWS Train 1

The ESWS make-up system foundations are rectangular ground bearing raft foundations. The ESWS make-up tanks are supported and anchored to the slab. The foundations support the weight of the tanks and distribute it to the supporting ground.

The ESWS cooling towers will be supported on the basin walls and restrained by anchor fixings. The basins support the weight of the towers and distribute it to the supporting ground. Earth pressures on the perimeter walls are resisted by the retaining wall in bending and shear. The retaining walls are restrained at their base and by internal dividing walls or return walls in the case of the end panels.

The ESWS pipe culverts will be rectangular below ground RC structures. Above ground pipework between the ESWS and Reactor Island will be supported by individual structures and foundations.

9B.3.1.4 Materials

ESWS structures comprise of RC.

9B.3.1.5 Interfaces

As described in section 9B.3.1.3.

9B.3.1.6 System and Equipment Operation

Not applicable.

9B.3.1.7 Instrumentation and Control

Not applicable.

9B.3.1.8 Monitoring, Testing, Inspection and Maintenance

The structures for ESWS will be examinable and inspectable. At RD7/DRP1 detailed EMIT arrangements are still to be developed, however will likely include:

1. Visual inspections/crack surveys
2. Reinforcement cover surveys
3. Delamination inspections
4. Chloride/carbonation monitoring

9B.3.1.9 Radiological Aspects

Not applicable.

9B.3.1.10 Performance and Safety Evaluation

The verification activities that are required for the ESWS structures to achieve its E3S requirements are largely associated with structural analysis to codes and standards, as described in section 9B.0.7. At RD7/DRP1, no novel testing activities are envisaged, as the ESWS structures will be constructed from common structural materials.

9B.3.2 Backup Generation Structure [UBM]

9B.3.2.1 Structural Role

The BUGS provide support to the back power systems modules for safety classified systems.

9B.3.2.2 Design Basis

The BUGS deliver the 'protect' and 'support' civil safety functions aligned to the FSFs of CoR and CoFT.

The safety function category for the BUGS is category B. The associated classification is safety class 2.

The SPC for the BUGS is SPC1. The SDB limit state is D with seismic design category 5.

The list of safety categorised functional requirements and basis for safety categorisation and classification of the BUGS are provided in [35]. Further details of the basis of design, including codes and standards applied and acceptance criteria, are provided in [36].

9B.3.2.3 Structural Description

The BUGS [UBM] include the following main components:

1. High voltage (HV) Essential Alternating Current (AC) Generator Module Train 1 Foundation
2. HV Essential AC Generator Module Train 2 Foundation
3. Essential AC Standby Supply Train 1 Service Tunnel
4. Essential AC Standby Supply Train 2 Service Tunnel.

Each of the HV Essential AC Generator Modules will be supported on individual foundations. Each foundation is a rectangular ground bearing raft foundation with modules anchored to the slab. The weight of the module is distributed to the supporting ground.

The service tunnels are rectangular in section below ground structures.

9B.3.2.4 Materials

The foundations and service tunnels comprise RC.

9B.3.2.5 Interfaces

As described in section 9B.3.2.3.

9B.3.2.6 System and Equipment Operation

Not applicable.

9B.3.2.7 Instrumentation and Control

Not applicable.

9B.3.2.8 Monitoring, Testing, Inspection and Maintenance

The BUGS will be examinable and inspectable. At RD7/DRP1 detailed EMIT arrangements are still to be developed, however will likely include:

1. Visual inspections/crack surveys
2. Reinforcement cover surveys
3. Delamination inspections
4. Chloride/carbonation monitoring.

9B.3.2.9 Radiological Aspects

Not applicable.

9B.3.2.10 Performance and Safety Evaluation

The verification activities that are required for BUGS to achieve its E3S requirements are largely associated with structural analysis to codes and standards, as described in section 9B.0.7. At RD7/DRP1, no novel testing activities are envisaged, as the BUGS will be constructed from common structural materials.

9B.4 Conclusions

9B.4.1 ALARP, BAT, Secure by Design, Safeguards by Design

The design of civil structures presented in this chapter are developed in accordance with the systems engineering design process. This includes alignment to RGP and operating experience (OPEX), design to codes and standards according to the safety classification, and a systematic optioneering process with down-selection of design options based on assessment against relevant criteria that ensure risks are reduced to ALARP, apply best available techniques (BAT), and are secure by design and safeguards by design, as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [8].

RGP and OPEX has been used to inform:

- The extent of the Seismic Isolation System
- The preliminary identification of a preferred isolator type (low damping rubber elastomeric bearings)
- The material specification of the bearing to avoid significant ageing effects
- The inclusion of a moat cap to protect the bearings
- The height of the supporting pedestals to facilitate future EMIT.

A key innovation for the RR SMR is the design of the seismic isolation, which is chosen as a preferred solution to support standardisation of the RR SMR concept to protect the supported structure above it from the damaging effects of horizontal earthquake motion. Learning and RGP from six existing nuclear power plants, and two ongoing nuclear construction projects, that utilise base isolation is being incorporated into the design of the RR SMR to support the overall demonstration that the RR SMR can reduce risks to ALARP [37].

This provides confidence that claims can be met when the full suite of arguments and evidence is developed. The overall demonstration of ALARP, BAT, secure by design and safeguards by design at RD7/DRP1 is presented in E3S Case Version 2, Tier 1, Chapters 24, 27, 32 and 33 respectively.

9B.4.2 Assumptions and Commitments on Future Dutyholder / Licensee / Permit Holder

None identified at this revision.

9B.4.3 Conclusions and Forward Look

The generic E3S Case objective at Version 2 is 'to provide confidence that the RR SMR design will be capable of delivering the E3S fundamental objective as it developed from a concept design into a detailed design' [1]. This confidence is built through development and underpinning of top-level claims across each chapter of the E3S Case, through supporting arguments and evidence. The top-level claim for chapter 9B is 'civil structures are conservatively designed and verified to deliver

E3S functions through-life, in accordance with the E3S design principles, to reduce risks to ALARP, apply BAT and in line with secure by design and safeguards by design'.

The arguments and evidence presented to meet the generic E3S Case objective at Version 2 include the selection of appropriate codes and standards that follow RGP, and the development and justification of design and analysis methodologies for safety classified structures. Safety functions are identified aligned to the FSFs, which are categorised in accordance with the E3S categorisation and classification methodology, with structures assigned both a safety and seismic classification.

The design and layout of the civil structures at RD7/DRP1 are also developed and evaluated in accordance with the E3S design principles through the integrated E3S and engineering processes [8], including design optioneering, to drive risk reduction to ALARP, and to demonstrate BAT, secure by design and safeguards by design. For example, the layout of structures is selected to enable segregation of redundant trains of safety systems and allows suitable space to facilitate future EMIT activities. Environment, security, and safeguards aspects are also considered, for example, design of the Hazard Shield in accordance with RGP to withstand malicious aircraft impact. This provides confidence that environment, security, and safeguards functions can be achieved by the design as functional requirements are derived through ongoing and iterative E3S analyses.

Further arguments and evidence to underpin claims will be developed in line with the E3S Case Route Map [2] and reported in future revisions of the generic E3S Case, which will further build confidence that the RR SMR can deliver its fundamental E3S objective. This broadly includes refinement of safety requirements from iterative internal and external hazards analysis, deterministic analysis, as well as identification of environment, security, and safeguards requirements. It will also include detailed design development, structural analysis and design substantiation work, and consideration of interaction hazards with adjacent buildings.

9B.5 References

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[3] Rolls-Royce SMR Limited, SMR0006030/001, "Civil and Structural Codes and Standards Policy," June 2023.

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[6] Rolls-Royce SMR Limited, SMR0005709/002, "Aircraft Impact Design Philosophy and Method," November 2023.

[7] Rolls-Royce SMR Limited, SMR0003771 Issue 3, "Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 6: Engineered Safety Features," May 2024.

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[9] Rolls-Royce SMR Limited, SMR0003977 Issue 3, "Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 15: Safety Analysis," May 2024.

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[27] Rolls-Royce SMR Limited, SMR0005695 Issue 1, “Design Description for Reactor Island - Containment Internal Structures,” January 2024.

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[29] Rolls-Royce SMR Limited, SMR0005700 Issue 1, “Design Description for Reactor Island - Basemat and Containment Support,” December 203.

[30] Rolls-Royce SMR Limited, SMR0005699/001, “Design Description for Reactor Island - Fuelling Block,” January 2024.

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9B.6 Appendix A: Claims, Arguments, Evidence

Table 9B.6-1 provides a mapping of the claims to the corresponding sections of the chapter that summarise the arguments and/or evidence. The full decomposition of claims and link to underpinning Tier 2 and Tier 3 information containing the detailed arguments and evidence is presented in the E3S Case Route Map [2]. The route map includes the trajectory of Tier 2 and Tier 3 information as the generic E3S Case develops, which will be incorporated into Tier 1 chapters as it becomes available and in line with generic E3S Case issues described in [1].

Table 9B.6-1: Mapping of Claims to Chapter Sections

Claim	**Section of Chapter 9B containing Arguments / Evidence summary**
Safety categorised functional requirements for the Civil Structures are complete and correctly categorised	9B.0.6 9B.1.1.2 9B.1.2.2 9B.2.1.2 9B.2.2.2 9B.2.3.2 9B.2.4.2 9B.2.5.2 9B.2.4.2 9B.3.1.2 9B.3.2.2
Environmental functional requirements for the Civil Structures are complete and correctly categorised	None at this revision
Security functional requirements for the Civil Structures are complete and correctly categorised	None at this revision
Safeguards functional requirements for the Civil Structures are complete and correctly categorised	None at this revision
Civil structures non-functional system requirements are complete	None at this revision
Civil structures non-functional system requirements are correctly assigned	None at this revision
Appropriate design codes and standards are identified	9B.0.4
The methodology for civil structures analysis and design is developed according to the codes and standards	9B.0.7
Analysis and design of the structures are conducted according to the methodology to ensure the E3S requirements are achieved	9B.1.1 9B.1.2 9B.2.1

Claim	Section of Chapter 9B containing Arguments / Evidence summary
Layout facilitates the civil structures achieving E3S functional requirements	9B.2.2 9B.2.3 9B.2.4 9B.2.5 9B.3.1 9B.3.2
The design principles and methods adopted for underpinning the design are validated and verified.	Not covered at this revision
The design of the structures accounts for RGP	9B.4.1
The design of the structures adopts ALARP, BAT and secure and safeguards by design principles	
E3S requirements are verified through manufacturing, assembly, installation, and commissioning	Not covered at this revision
Design can deliver its E3S requirements during its operational life	
Design can deliver its E3S requirements during decommissioning	

9B.7 Appendix B: Civil Engineering Document Map

Figure 9B.7-1 presents the document map containing underpinning arguments and evidence for the Chapter 9B of the generic E3S Case, noting analysis and design substantiation reports are still to be developed and will be reported in future revisions of the Chapter.

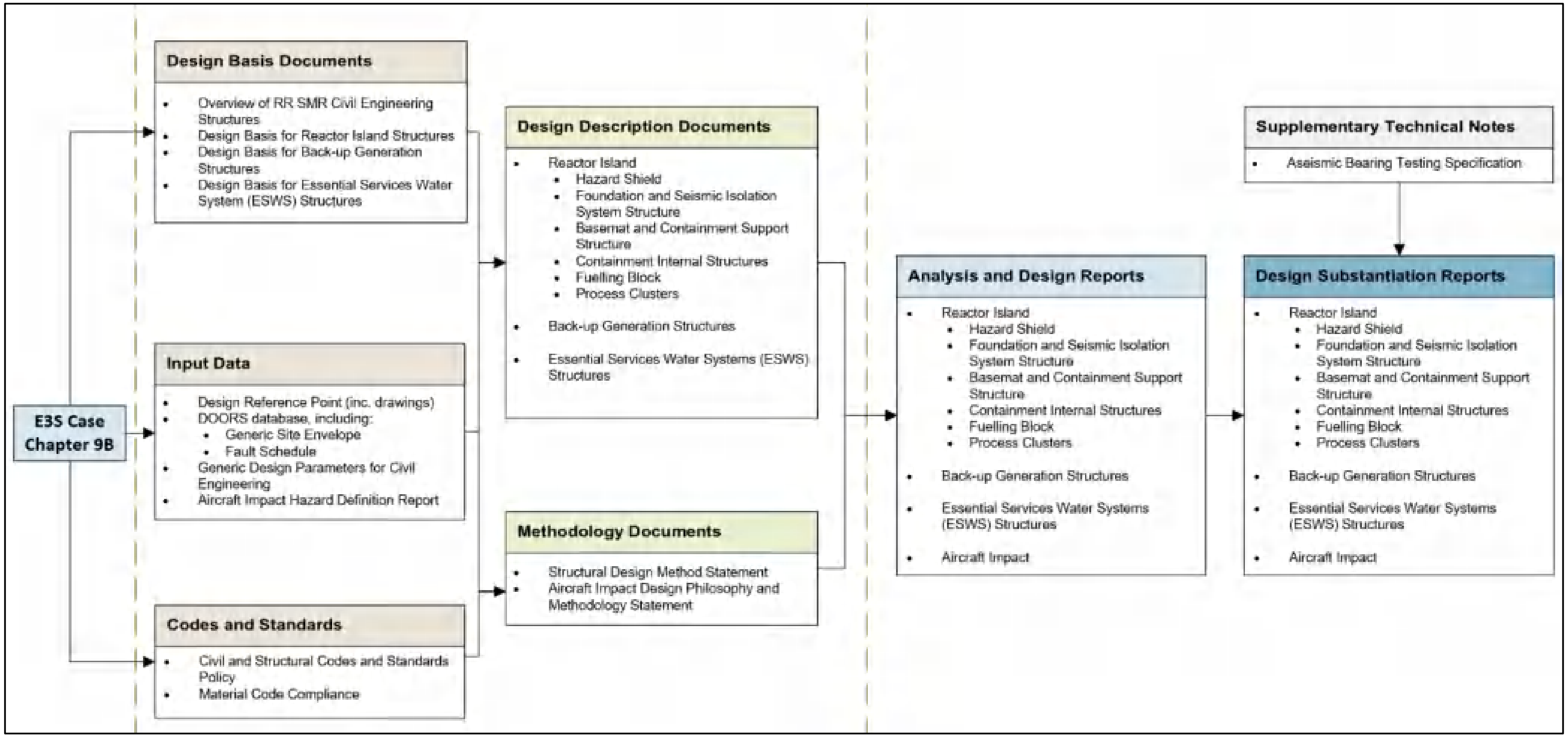

Figure 9B.7-1: Civil Engineering Document Map for Generic E3S Case

9B.8 Abbreviations

ACI	American Concrete Institute
ALARP	As Low As Reasonably Practicable
ANSI/AISC	American National Standards Institute / American Institute of Steel Construction
ASCE	American Society of Civil Engineers
BAT	Best Available Techniques
BDBE	Beyond Design Basis Event
BIM	Building Information Modelling
BS	British Standard
CAE	Claims, Arguments and Evidence
CIRIA	Construction Industry Research and Information Association
CoFT	Control of Fuel Temperature
CoR	Control of Reactivity
CoRE	Control of Radiation Exposure
CoRM	Confinement of Radioactive Material
C_r	Crane Loads
CS	Clearance to the Stop
CS&A	Civil, Structural and Architecture
D	Dead Loads
DOORs	Dynamic Object-Oriented Requirements System
DRP	Design Reference Point
E3S	Environment, Safety, Security and Safeguards
EC&I	Electrical, Control and Instrumentation
EMIT	Examination, Maintenance, Inspection and Testing
ENEA	National Agency for New Technologies, Energy and Sustainable Economic Development
E_o	Operating Basis Earthquake Load
ESWS	Essential Service Water Systems
E_{SS}	Extreme Environmental Loads

F	Fluid Loads
FAP	Forward Action Plan
FE	Finite Element
FEA	Finite Element Analysis
FSF	Fundamental Safety Functions
GDA	Generic Design Assessment
GR	Gated Review
H	Earth Pressure and Groundwater Pressure Loads
HLSF	High-Level Safety Functions
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
L	Live Loads
LLW	Low-Level Waste
L_r	Roof Live Loads
LUHS	Local Ultimate Heat Sink
MCR	Main Control Room
MDCT	Mechanical Draft Cooling Towers
MEP	Mechanical, Electrical and Plumbing
MKoP	Mechanical Kit of Parts
MSR	Modulus of Subgrade Reaction
NEI	Nuclear Energy Institute
OPEX	Operating Experience
P_a	Differential Pressure Loads
PIE	Postulated Initiating Events
R	Operating operational rain loads

R_a	Accidental Piping and Equipment Reactions
RC	Reinforced Concrete
RCA	Radiologically Controlled Areas
RD	Reference Design
R_o	Reactions from Operating Pipework and Equipment
RR SMR	Rolls-Royce Small Modular Reactor
S	Operating Snow Loads
SDB	Seismic Design Basis
SDC	Seismic Design Category
SDMS	Structural Design Method Statement
SPC	Seismic Performance Classification
SRS	Secondary Response Spectra
SSCs	Structures, Systems and Components
SSI	Soil-Structure Interaction
T_a	Accidental Temperature Loads
T_o	Operating Temperature Loads
VBA	Visual Basic for Applications
W	Operating Wind Loads
W_t	Tornado Loads
Y_r	Pipe Break Reactions
Y_j	Jet Impingement Loads
Y_m	Missile Impact Loads