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UK HPR1000 GDA Project

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Pre-Construction Safety Report
Chapter 24
Decommissioning

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24.1 List of Abbreviations and Acronyms

ALARP	As Low As Reasonably Practicable
BAT	Best Available Technique
BFX	Fuel Building
BMX	Turbine Generator Building
BNX	Nuclear Auxiliary Building
BQF	Spent Fuel Interim Storage Facility
BQZ	ILW Interim Storage Facility
BRX	Reactor Building
BSX	Safeguard Buildings
BWX	Radioactive Waste Treatment Building
CGN	China General Nuclear Power Corporation
DECC	Department of Energy and Climate Change (UK)
EA	Environment Agency (UK)
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
HAW	High Activity Waste
HPR1000 (FCG3)	Hua-long Pressurised Reactor under construction at Fangchenggang nuclear power plant unit 3
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
IWS	Integrated Waste Strategy
LAW	Lower Activity Waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository Ltd (UK)
MSQA	Management of Safety and Quality Assurance
NDA	Nuclear Decommissioning Authority (UK)

NPP	Nuclear Power Plant
ONR	Office for Nuclear Regulation (UK)
OPEX	Operating Experience
PCER	Pre-Construction Environmental Report
PCSR	Pre-Construction Safety Report
POCO	Post Operational Clean Out
PPE	Personal Protective Equipment
PWR	Pressurised Water Reactor
RCV	Chemical and Volume Control System [CVCS]
RGP	Relevant Good Practice
RPE	Nuclear Island Vent and Drain System [VDS]
RPV	Reactor Pressure Vessel
RWM	Radioactive Waste Management Ltd (UK)
SAP	Safety Assessment Principle (UK)
SFA	Spent Fuel Assembly
SFAIRP	So Far As Is Reasonably Practicable
SFIS	Spent Fuel Interim Storage
SFP	Spent Fuel Pool
SG	Steam Generator
SSC	Structures, Systems and Components
UK HPR1000	UK version of the Hua-long Pressurized Reactor
VLLW	Very Low Level Waste
WENRA	Western European Nuclear Regulators Association

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. Chemical and Volume Control System (RCV [CVCS]).

24.2 Introduction

Once a Nuclear Power Plant (NPP) has reached the end of its operational lifetime it is necessary to decommission the facility and restore the site back to an agreed end state. Decommissioning is considered throughout the processes of siting, design, construction, commissioning and operation, although it is the last stage in the lifecycle of nuclear facilities as described in Reference [1]. Decommissioning for the UK HPR1000 has been developed to meet UK regulatory requirements. This chapter presents the consideration of facilitating decommissioning, the decommissioning strategy and the preliminary decommissioning plan for the UK version of the Hua-long Pressurised Reactor (UK HPR1000). It also demonstrates that the plant can be decommissioned safely, effectively and with minimal impact on the environment and the public.

The following aspects are discussed in this chapter:

a) Design for facilitating decommissioning: the design of the UK HPR1000 ensures that decommissioning can be achieved with reduced risks to the workers and the public, minimised production of wastes and impacts on the environment and the public, simplified demolition procedures and lower costs. Additional measures will be considered and implemented as relevant during the full lifecycle of the plant to aid the decommissioning process, notably considering the requirements in References [2], [3] and [4]. Relevant information is provided in Pre-Construction Safety Report (PCSR) Sub-chapter 24.4;

b) Adequate preparation of a decommissioning strategy: the decommissioning strategy of the UK HPR1000 is considered, developed and integrated with other relevant strategies (e.g. radioactive waste management and spent fuel management). Relevant information is provided in PCSR Sub-chapter 24.5;

c) Adequate preparation of a decommissioning plan: there is valuable Operating Experience (OPEX) on decommissioning of Pressurised Water Reactor (PWR) and proven decommissioning techniques exist which are capable of minimising risks and impacts. In this chapter the timing of the decommissioning strategy is discussed, and a preliminary decommissioning plan is prepared to reflect the developments in techniques and experiences, in order to ensure that the methods and techniques adopted for decommissioning are safe and protect workers, the public and the environment. Relevant information is provided in PCSR Sub-chapter 24.6.

As Low As Reasonably Practicable (ALARP) and Best Available Technique (BAT) are discussed and demonstrated, commensurately to GDA stage and scope. Decommissioning is the last stage in the lifecycle of the UK HPR1000. Therefore, additional work is required by the future nuclear licensee to develop decommissioning during the nuclear site licensing phase and operating stage.

This chapter has been produced on the basis of the version 3 of the UK HPR1000 Design Reference (DR3), as described in *UK HPR1000 Design Reference Report*, Reference [5].

24.2.1 Chapter Route Map

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

To underpin this ***Fundamental Objective*****,** five high level claims (Level 1 claims) and a number of Level 2 claims are developed and presented in Chapter 1. Chapter 24 supports ***Claim 5.1*** and ***Claim 5.2*** derived from high level ***Claim 5***.

Claim 5: *The UK HPR1000 will be designed, and is intended to be operated, so that it can be decommissioned safely, using current available technologies, and with minimal impact on the environment and people.*

Claim 5.1: *The design and intended operation will facilitate safe decommissioning using current available technologies.*

Claim 5.2: *The decommissioning strategy and plan are prepared and maintained for the generic design, which reflect UK policy.*

To support Claim 5.1, this chapter has developed four Sub-claims:

a) ***Sub-claim 5.1.SC24.1:*** *The UK HPR1000 design features facilitate safe and effective decommissioning;*

b) ***Sub-claim 5.1.SC24.2:*** *Documents and records required for decommissioning are identified and under preliminary preparation;*

c) ***Sub-claim 5.1.SC24.3:*** *Faults and hazards of UK HPR1000 decommissioning are identified and assessed, and risks are shown to be capable of being ALARP*;

d) ***Sub-claim 5.1.SC24.4:*** *The UK HPR1000 can be decommissioned using current methods and technologies.*

To support the Claim 5.2, three Sub-claims are developed:

a) ***Sub-claim 5.2.SC24.5:*** *Proper preliminary decommissioning plans/strategies are prepared;*

b) ***Sub-claim 5.2.SC24.6:*** *Disposal routes are available (or will be available) for all waste arising during decommissioning;*

c) ***Sub-claim 5.2.SC24.7:*** *The decommissioning plan will be developed to reflect developments in technologies and experiences, to ensure that the timing and* *methods adopted for decommissioning are safe and protect the environment.*

A Route Map for Chapter 24 is developed in this sub-chapter and is presented in Appendix 24A. This Route Map sets out a 'framework' for Chapter 24.

In addition, the mapping of decommissioning against relevant Safety Assessment Principle (SAP) requirements is provided in *Mapping Document of Decommissioning against Relevant SAPs Requirement*, Reference [6]. An overview of ALARP demonstration in decommissioning in the GDA phase is provided in PCSR Sub-chapter 24.8 and in *ALARP Demonstration for Decommissioning of the UK HPR1000*, Reference [7]. The related BAT demonstration is presented in Pre-Construction Environmental Report (PCER) Chapter 3, Reference [8].

24.2.2 Chapter Structure

The structure of Chapter 24 is as follows:

a) Sub-chapter 24.1 List of Abbreviations and Acronyms

This section lists the abbreviations and acronyms that are used in this chapter.

b) Sub-chapter 24.2 Introduction

This section gives the route map, chapter structure, interfaces with other chapters and key assumptions of PCSR Chapter 24.

c) Sub-chapter 24.3 Applicable Codes and Standards

This section lists the codes and standards that are used for decommissioning.

d) Sub-chapter 24.4 Design Considerations of Facilitating Decommissioning

This section presents the design considerations for facilitating decommissioning.

e) Sub-chapter 24.5 Decommissioning Strategy

This section presents the decommissioning strategy and the end state of the UK HPR1000.

f) Sub-chapter 24.6 Preliminary Decommissioning Plan

This section presents the plan and main activities during decommissioning.

g) Sub-chapter 24.7 Records and Knowledge Management

This section presents documents, records and knowledge management required for decommissioning.

h) Sub-chapter 24.8 ALARP Assessment

This section provides an overview of ALARP demonstration for decommissioning.

i) Sub-chapter 24.9 Concluding Remarks

This section summarises the content of PCSR Chapter 24.

j) Sub-chapter 24.10 References

This section lists the supporting references of this chapter.

24.2.3 Interfaces with Other Chapters

The PCSR contains various chapters and a substantial level of design information. To help understanding of the relationship between Chapter 24 and other chapters in the PCSR, the relevant interfaces have been identified and are presented in T-24.2-1.

T-24.2-1 Interfaces between Chapter 24 and Other Chapters

PCSR Chapter	Interface
Chapter 1 Introduction	Chapter 1 provides the Fundamental Objective, Level 1 Claims and Level 2 Claims. Chapter 24 presents decommissioning relevant claims, along with sub-claims to support relevant claims that are addressed in Chapter 1.
Chapter 4 General Safety and Design Principles	Chapter 4 provides the selection principles of design codes and standards which are applied for decommissioning. Chapter 24 presents the applicable codes and standards for decommissioning.
Chapter 6 Reactor Coolant System	Chapter 6 provides the design substantiation relevant to facilitating decommissioning. Chapter 24 presents the principles and main design provisions that are relevant to facilitating decommissioning.
Chapter 7 Safety Systems	Chapter 7 provides the design substantiation relevant to facilitating decommissioning. Chapter 24 presents the principles and main design provisions that are relevant to facilitating decommissioning.
Chapter 10 Auxiliary Systems	Chapter 10 provides the design substantiation

PCSR Chapter	Interface
	relevant to facilitating decommissioning. Chapter 24 presents the principles and main design provisions relevant to facilitating decommissioning.
Chapter 11 Steam and Power Conversion System	Chapter 11 provides the design substantiation relevant to facilitating decommissioning. Chapter 24 presents the principles and main design provisions relevant to facilitating decommissioning.
Chapter 15 Human Factors	Chapter 15 provides the principles and methodology for human factors integration that shall be considered in decommissioning design. Chapter 24 presents decommissioning design considerations relevant to the HF of the UK HPR1000.
Chapter 16 Civil Works & Structures	Chapter 16 provides the requirements of civil works and structures including those to be applied for decommissioning. Chapter 24 presents the principles and main provisions relevant to building and structure design that facilitate decommissioning and structure dismantling.
Chapter 17 Structural Integrity	Chapter 17 provides material selection and structure design including those to minimising waste generation and facilitating to decontamination. Chapter 24 presents the design principles and main provisions relevant to material selection that facilitate decommissioning and structure dismantling.
Chapter 18 External Hazards	Chapter 18 presents the list of external hazards and hazard protection principles. Chapter 24 identifies the potential external hazards protection measures needed to be considered during decommissioning.

PCSR Chapter	Interface
Chapter 19 Internal Hazards	Chapter 19 provides the list of internal hazards and hazard protection principles. Chapter 24 identifies the internal hazards and control measures needed to be considered during decommissioning.
Chapter 21 Reactor Chemistry	Chapter 21 provides information on reactor chemistry relevant to minimisation of source term, which contributes to the reduction of decommissioning waste generation and facilitating decommissioning. Chapter 24 presents the design principles and main provisions relevant to reducing decommissioning waste generation.
Chapter 22 Radiological Protection	Chapter 22 provides the activated structure source term and deposit source term used for decommissioning source term assessment. Chapter 24 presents the design principles and main provisions relevant to radiological protection that facilitate radiological protection consideration during decommissioning and source terms.
Chapter 23 Radioactive Waste Management	Chapter 23 provides the radioactive waste management system to be used or considered for use for decommissioning. Chapter 24 presents the waste management strategy, principles and main design provisions relevant to facilitating decommissioning.
Chapter 25 Conventional Safety and Fire Safety	Chapter 25 provides the conventional health and safety risk management techniques and general prevention principles, including those relevant to the decommissioning stage. Chapter 24 presents application of the conventional health and safety risk management techniques and general prevention principles in the development of

PCSR Chapter	Interface
	the decommissioning safety case, and identifies main risks and associated mitigation measures as relevant.
Chapter 28 Fuel Route and Storage	Chapter 28 provides the fuel handling and storage system to be used during decommissioning. Chapter 24 provides the decommissioning strategy and preliminary decommissioning plan for the Structures, Systems and Components (SSC) related to the fuel handling and storage system.
Chapter 29 Interim Storage of Spent Fuel	Chapter 29 provides interim storage of spent fuel to be considered during decommissioning. Chapter 24 presents the general decommissioning consideration of spent fuel interim storage facility.
Chapter 33 ALARP Evaluation	Chapter 33 provides the ALARP approach and principles adopted for the UK HPR1000. Chapter 24 presents the ALARP assessment for decommissioning based on these principles and the approach.

24.2.4 Key Assumptions

In order to develop the safety case in relation to the decommissioning of UK HPR1000, the following assumptions are made:

a) The operational life of the UK HPR1000 is assumed to be 60 years in accordance with the design life of the UK HPR1000 presented in PCSR Chapter 2;

b) The beginning of decommissioning is when the station is in normal outage with no intention of further use for the purpose of electricity generation;

c) The preliminary decommissioning plan and strategy reflect current technologies and will be revised and maintained by the licensee;

d) Buildings and facilities will be utilised during the decommissioning process if risks are ALARP and measures are beneficial for waste minimisation and environmental and public protection;

e) Spent fuel will be stored in Spent Fuel Pool (SFP) for several years, followed by interim storage in the Spent Fuel Interim Storage Facility (BQF) until the

Geological Disposal Facility (GDF) is available;

f) Intermediate Level Waste (ILW) generated during decommissioning will be safely stored in the ILW Interim Storage Facility (BQZ) until the GDF is available;

g) Low Level Waste (LLW) or conventional waste generated during decommissioning will be disposed of promptly;

h) The end of decommissioning is considered to be when all station buildings and facilities have been removed and the site has been returned to an agreed end state (e.g. green field) with the regulators and the planning authority.

24.3 Applicable Codes and Standards

According to the selection principles of codes and standards specified in PCSR Chapter 4.4.7 and *General Principles for Application of Laws, Regulations, Codes and Standards*, Reference [9], the legislation, policy, codes and standards are analysed considering the design characteristics of the UK HPR1000, the UK regulatory requirements and the following three principles:

a) The legislation, policy, codes and standards should be internationally recognised in the nuclear industry;

b) The legislation, policy, codes and standards should be the latest or currently applicable approved standards;

c) The legislation, policy, codes and standards should be consistent with the plant reliability goals that are necessary for safety, security and environmental protection.

The main legislation and national policy related to decommissioning are identified as follows:

a) The Environmental Permitting (England and Wales) Regulations 2016, Reference [10];

b) The Environmental Permitting (England and Wales) (Amendment) Regulations 2018;

c) The Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations 2018;

d) Hazardous Waste Regulations 2018, Reference [11];

e) The Ionizing Radiations Regulations 2017, Reference [12];

f) Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999, Reference [13];

g) The Construction (Design and Management) Management Regulations 2015, Reference [14];

h) Review of radioactive waste management policy: Final Conclusions (CM 2919), 1995, Reference [15];

i) UK Strategy for Radioactive Discharges, 2009, Reference [16];

j) Regulatory Guidance Series, No RSR 1, Radioactive Substances Regulation – Environmental Principles, Reference [17];

k) Management radioactive waste from decommissioning of nuclear sites: Guidance on Requirements for Release from Radioactive Substance Regulation, Reference [18].

For codes and standards relevant to decommissioning, various sources coming from the UK, Western European Nuclear Regulators Association (WENRA) and International Atomic Energy Agency (IAEA) have been analysed and determined in *Analysis Report of Applicable Codes and Standards*, Reference [19].

The guidance, codes and standards relevant to decommissioning are:

a) Funded Decommissioning Programme Guidance for New Nuclear Power Stations 2011, Reference [20];

b) Safety Assessment Principles for Nuclear Facilities, Reference [2];

c) Nuclear Safety Technical Assessment Guide: Decommissioning, Reference [3];

d) Guidance on Managing Human and Organisational Factors in Decommissioning 2010, Reference [21];

e) Joint guidance, The Management of Higher Activity Radioactive Waste on Nuclear Licensed sites 2015, Reference [22];

f) Industry Guidance-Interim Storage of Higher Activity Waste Package – Integrated Approach 2017, Reference [23];

g) WENRA Decommissioning Safety Reference Levels 2015, Reference [24];

h) IAEA Decommissioning Facilities, No. GSR Part 6, 2014, Reference [1];

i) IAEA Safety Assessment for the Decommissioning of Facilities Using Radioactive Material No. WS-G-5.2, 2008, Reference [25];

j) IAEA Decommissioning of Nuclear Power Plants and Research Reactors and other Nuclear Fuel Cycle Facilities, No.SSG-47, 2018, Reference [26].

These guidance, codes and standards guide the development of the decommissioning safety case, including the design for facilitating decommissioning, the decommissioning strategy, the preliminary decommissioning plan and the waste management strategy. Detailed analysis of applicable codes and standards is presented in Reference [19] where Relevant Good Practice (RGP) is identified.

24.4 Design Considerations of Facilitating Decommissioning

The decommissioning of large NPPs is a complex and systematic engineering project, which includes various activities such as decontamination, dismantling of SSC, and radioactive waste treatment/transportation. These activities involve nuclear and conventional safety, radiological protection, radioactive waste management and environmental protection. Although decommissioning is the last stage of the lifecycle of the UK HPR1000, early consideration of decommissioning it during design stage plays an important role in achieving safe and effective decommissioning.

Therefore, based on the governmental policies/strategies, regulation, relevant codes, standards and guidance and decommissioning OPEX in Reference [27], the principles and requirements for facilitating decommissioning are collected and defined at the beginning of design stage. During the UK HPR1000 design stage, the requirements for facilitating decommissioning are considered in Reference [28]. Design & operating measures to fulfil these requirements have been and will continue to be considered and implemented as relevant, during the whole lifetime of the plant. Furthermore, for the ALARP/BAT demonstration during the GDA phase, decommissioning requirements are also taken into account, and integrated with all other design requirements.

The UK HPR1000 design has been developed taking into account requirements to facilitate decommissioning. The document *Consistency Evaluation for Design of Facilitating Decommissioning*, Reference [29], evaluates the design of UK HPR1000 to assess whether the design measures that have been implemented in UK HPR1000 fulfill these requirements, commensurately to GDA phase and scope.

This sub-chapter presents the main design requirements related to facilitating decommissioning and briefly describes the design measures that have been considered and implemented in UK HPR1000.

24.4.1 Site Selection

The siting of NPPs depends on many factors, such as areas covered by the grid and availability of cooling water, etc. It is also expected that siting of the UK HPR1000 will follow the UK policy set out in *EN6 Vol. I and II*, Reference [30]. Siting standards also involve considerations related to decommissioning. The main considerations for siting of NPPs will be taken into account during/after the nuclear site licensing phase. The following factors in particular should be considered.

a) During/after siting, a detailed initial investigation of physical , chemical and radiological contamination of the site will be performed and relevant records kept as one of the important references for site acceptance in the future;

b) The impact on the long-term integrity of buildings and other structures is considered, especially with regards to the effect of external hazards. For buildings that contain items important to safety, the civil structures of these buildings are designed to withstand the impact loads of design basis accidental aircraft crash, earthquakes, extreme wind, external missiles, external explosions, external flooding, sleet snow, etc. This contributes to the transition from operation to decommissioning of the plant, and supports operations during decommissioning;

c) Transport infrastructure, such as waterways, railways, etc., around the site will be evaluated, to make sure that the wastes generated during operation and decommissioning of NPPs can be disposed of off-site;

d) Space at or near the site is considered for locating decommissioning facilities and for storing the wastes generated during decommissioning. For example, the design lifetime of the BQZ building is 100 years, and the scale of the BQZ building can be extended to meet the storage needs of the ILW generated during decommissioning. The conditioned ILW will be stored in the plant for a long period until the GDF is available, during which time radiation levels will reduce through decay;

e) Utilities (such as power supply, fire water supply and potable water supply) are organised and set out so that they can provide continuous services during decommissioning. For instance, the UK HPR1000 is equipped with the outdoor piping network, including the piping network of the Potable Water System and Site Fire-fighting Water Distribution System. During decommissioning, both systems will be operational to facilitate the decontamination and dismantling process.

24.4.2 General Layout

The general layout considers the reservation of space and areas for transport of material, decontamination and dismantling. The space for decommissioning facilities as well as the efficient and effective logistics within the site is taken into account:

a) Construction space is reserved as far as reasonably possible for:

   1) The extension of the processing facilities for waste. There is space reserved for future developments, and the land use scale is determined according to the planning capacity;

   2) The guarantee of integrity and availability of public and auxiliary facilities, structures and equipment after permanent shutdown and partial dismantling. For example, the treatment of decommissioned waste will make the best use of the existing waste management facilities;

   3) New auxiliary facilities and special facilities after permanent shutdown if necessary;

4) Temporary facilities for waste turnover. It is necessary to evaluate whether large temporary facilities (such as waste temporary storage) will be built as required by the site conditions;

5) The entrance, exit and manoeuvering of large handling appliances, e.g. cranes and telehandlers used for dismantling. The optimisation and rational arrangement of the construction plant and machinery, office, road and site entrance are fully considered;

6) The premises for contractors at the site. Temporary facilities during construction can be practically planned and arranged by the contractor according to the technical requirements.

b) General layout of facilities is convenient for the different stages of dismantling without influencing the operation and maintenance of remaining facilities. The following aspects are considered:

1) The function and needs of ventilation facilities are considered during operation and decommissioning, as well as the order of demolition;

2) The effect of the dismantling order. Demolition of buildings and structures is usually ordered from simple to complex ones, i.e. from the peripheral auxiliary facilities (the conventional island buildings) to the nuclear island buildings;

3) Positions of facilities are convenient for equipment, personnel ingress and egress, air flow and material transfer during the different stages of decommissioning;

4) The general layout facilitates site area partitioning during decommissioning. For example, the system of zoning management can be established, and a sufficiently conservative design source term is used to complete the radiation partition;

5) The general layout facilitates staged dismantling and decommissioning works. Sufficient space is reserved for the staged dismantling and decommissioning works around the nuclear island building.

Below figure F-24.4-1 illustrates space and areas reservation on the generic layout of UK HPR1000. It will be refined at site licensing phase

BDA	Emergency Diesel Generator Building A
BDB	Emergency Diesel Generator Building B
BDC	Emergency Diesel Generator Building C
BDU	SBO Diesel Generator Building for Train A
BDV	SBO Diesel Generator Building for Train B
BEJ	Extra Cooling System and Fire-fighting System Building
BFX	Fuel Building
BNX	Nuclear Auxiliary Building
BPX	Personnel Access Building
BRX	Reactor Building
BSA	Safeguard Building A
BSB	Safeguard Building B
BSC	Safeguard Building C
BWX	Radioactive Waste Processing Building

F-24.4-1 Space and Area Reserved

24.4.3 Selection of Materials

Material selection has been optimised to minimise operational and decommissioning risks, considering the balance between operational performance and the requirements for decommissioning. The following aspects are considered and implemented relevant in UK HPR1000 design in the selection of materials to enable easier decontamination, dismantling and minimisation of waste generation:

a) To minimise the generation of radioactive waste, easily activated elements are avoided and controlled as far as is reasonably practicable, and the impurity content in materials is strictly limited. For example:

   1) The use of easily activated materials is minimised. Stellite (Cobalt based alloy) is avoided for equipment and valves which are in contact with primary coolant so far as is reasonably practicable, which reduces generation of Co-60 which is one of the main corrosion product generated in PWRs. Similarly, the use of antimony based alloys is prohibited in the UK HPR1000, in particular, thrust and line bearings for UK HPR1000 pumps are free of antimony and are therefore not anymore a source of Sb-122/Sb-124 which are also main corrosion products generated in PWRs coolant and waste and deposited on the circuit surface resulting in worker radiation exposure and solid radioactive waste during operation and decommissioning;

   2) The content of easily activated impurities in materials is strictly limited. For SSC in the UK HPR1000, the amount of sensitive elements (especially Co59) which could easily be activated and significantly contribute to dose rate and radioactive waste during operation and decommissioning are strictly controlled, Reference [29]. Furthermore, the cobalt content requirements of materials in contact with the UK HPR1000 primary coolant are more

stringent than Design and Construction Rules for the Mechanical Components of PWR Nuclear Islands;

3) Dense aggregate materials of concrete, such as barites, limonites, magnetites and ilmenites are not used in order to reduce the section thickness, meet attenuation requirements and reduce worker doses and minimise solid radioactive waste during operation and decommissioning So Far As Is Reasonably Practicable (SFAIRP). At the nuclear site licensing phase, easily activated elements will be avoided and controlled when aggregate is selected to meet the local requirements, ensuring worker doses and solid radioactive waste during operation and decommissioning are minimised SFAIRP.

b) Corrosion is minimised to notably ensure containment during operation. Measures implemented in UK HPR1000 to achieve this include (not limited to):

1) Corrosion resistant materials are selected according to operating conditions to guarantee that the selected materials are highly resistant to various forms of corrosion. For example, 690 alloy is used for Steam Generator (SG) tubes, because of its excellent corrosion resistant properties toward both primary and secondary coolants;

2) Surface treatment requirements on all surfaces of SSC which could be exposed to contamination are defined to prevent penetration of the contaminant and facilitate decontamination;

3) Noxious chemical elements of the consumables are avoided and when not possible, limited, to prevent/minimise corrosion on SSCs;

4) The chemistry regime is optimised to limit corrosion.

c) The material surfaces are designed to reduce the deposition of contaminants and/or to be easy to decontaminate any deposited contamination. In particular, the following measures (including, but not limited to) are implemented in UK HPR1000:

1) Materials with a dense surface, good corrosion resistance and that are easy-to-clean are selected, and porous materials are avoided for pollution-prone areas, which reduces deposition and facilitates decontamination during operational phase and decommissioning. For example, castings are mostly replaced by forgings, with the progress seen in manufacturing processes and design optimisation. Most of the materials for the Reactor Coolant System are forgings and plates;

2) Appropriate finishing treatment is applied where relevant. For example, a process of buffing is performed on SG tubes, which reduces the deposition of corrosion products on the surface of the tubes and facilitates decontamination;

3) The surface of carbon steels, low alloy steels and concrete is coated with easy to decontaminate paint to reduce corrosion and minimise deposition. In addition, a decontamination test is performed on the paint before it is selected for use inside the reactor containment, to prove the decontamination ability.

d) To reduce the spread of contamination which could notably lead to worker doses, and/or increase decommissioning waste arising, the following measures are considered:

1) In order to reduce the time spent by workers in the irradiated areas during decontamination, flammable materials and fibrous materials, which need particular protection measures to be removed before decontamination, are restricted for use. For example, the use of asbestos as a thermal insulation material is prohibited due to the serious health hazards that will cause during installation/dismantling and to the increased time workers would spend in irradiated areas, resulting in higher worker doses;

2) Hydrophobic glass wool is selected for heat insulation material. The glass wool is protected with stainless steel shells which prevent the material from getting into contact with the flammable fluid.

e) The choice of reusable or recyclable materials is considered at the design stage to reduce the amount of radioactive solid waste generated during operation and decommissioning, and to optimise the management of the unavoidable solid radioactive waste produced. For example, most metals and concrete could be reused or be recycled after decontamination processes. Metals could be melted to be reused, and conventional rubber could be reused as reinstatement material.

Additionally, reactor chemistry plays an important role in minimising contamination in the circuits. For example, zinc injection is intended to be implemented in UK HPR1000 through the Chemical and Volume Control System (RCV [CVCS]), which will result in a reduction in the dose rate in the primary circuit by minimising the release and deposition of corrosion products, which will reduce worker doses and radioactive waste arising during operation and decommissioning. Details are presented in PCSR Chapter 21: Reactor Chemistry.

24.4.4 Equipment Design

The following equipment design aspects are considered to facilitate decommissioning, consistent with Reference [27] and [31]:

a) The equipment is designed with a simple structural form to make drainage, decontamination and dismantling easier. For instance:

1) Equipment which needs to be drained is designed with a simple drain nozzle in the bottom area;

2) Equipment connected to the floor is designed with bolted connections for easy dismantling. For the equipment nozzles, welded connections are prioritised in order to reduce the risk of leakage during operation, hence ensuring safety of the plant and reducing spread of contamination. Screwed or flanged connections are only used where strongly required for operational maintenance.

b) Internal and external surfaces of equipment and pipes are smooth to reduce contaminant accumulation.

1) The inner and outer surfaces are smooth without hollows or blind holes to ease decontamination;

2) For primary loops equipment, such as the SG, Pressuriser, Main Coolant Line, Surge Line and Reactor Pressure Vessel (RPV), the roughness of internal and external surfaces is no more than Ra6.3;

3) For lifting equipment and equipment with carbon steel surfaces, painting is applied to smooth surfaces.

c) Components with simple structures and smooth shapes without hollows or blind holes are adopted for connectors, fasteners, fixing devices and supporting devices of plant and equipment, which will contribute to decontamination and reduce the accumulation of contamination. For example, the pressuriser supporting heater plates are smooth and bolted to the pressuriser. In addition, the plate has many holes without hollows or blind holes which make the liquid easier to drain, so that the accumulation of contamination is reduced.

d) Equipment and pipes collecting and conveying liquids are easy to drain, and proper slopes or emptying traps are designed into the system.

e) Aids used for installation and dismantling activities, such as connections and fixings to walls, ceiling and floors are considered. The design life and the replaceability of equipment with the specific characteristics related to equipment installation and dismantling activities have been taken into account during the design stage:

1) Overall dimensions of the equipment to be installed or dismantled;

2) For the lifting equipment (such as the Polar Crane) required during the installation/dismantling operation, the related requirements need to be specified, including decommissioning requirements;

3) Procedures for monitoring lifting equipment need to be defined, including:

- Lifting accessories, such as the lifting beam, slings, chains, overturn device, etc.;

   - Lifting path;

4) Working environment for dismantling operations that might pose problems for operating personnel are identified and minimised, including:

   - Risk of radiation exposure within the BRX;

   - Difficulties of approaching the equipment being dismantled;

   - Visibility, temperature and humidity not suitable for operating personnel.

24.4.5 Process Design

For the process design, how decommissioning can be facilitated during the dismantling works is considered, including:

a) Emptying of equipment and systems;

b) Water filling, drainage and filtration of pool;

c) Waste disposal;

d) Equipment lifting;

e) Ventilation of radioactive areas, fire monitoring and protection;

f) Environmental monitoring;

g) Sump and ground drainage;

h) Power supplies, compressed air supplies and production water supplies.

In addition, the following principles are considered:

a) Measures to reduce any residual radioactive sources inside the facilities after the final shutdown are adopted, including:

   1) Measures to reduce the generation of residual radioactive sources. In the process design, the systems are provided with adequate and reliable isolations to reduce potential leaks. For example, two isolation valves are provided for the Reactor Coolant Pressure Boundary and for containment penetrations of radioactive fluids. For components in contact with radioactive fluids, austenitic stainless steel is adopted in order to reduce potential corrosion in the components;

   2) Measures to reduce the retention of radioactive sources. The systems are required to fulfil their functions using simple configurations, and the quantity of components is optimised to reduce the retention of radioactive sources in the systems. Components in contact with radioactive fluids, such as those associated with tanks and sumps, are designed with simple structures and surfaces. Consequently, the accumulation and retention of radioactive sources

can be reduced;

3) Measures to facilitate decontamination. Connecting points for decontamination, draining and sampling are provided in the systems to facilitate decommissioning of the contaminated components and pipes. The design of tanks and sumps avoids potential radioactive sediment and provides measures for concrete tanks (pools) and sumps to facilitate cleaning. Tanks and sumps are equipped with steel liners (e.g. the In-containment Refuelling Water Storage Tank, Reactor Pit Flooding Tank, SFP, etc.) or coatings (e.g. Reactor Pools) to ensure simplified decontamination.

b) Emptying and decontamination methods are considered to facilitate decommissioning and maintenance. For example:

1) The bottom of the container are equipped with an outlet at their lowest point which can facilitate emptying;

2) In pipeline layout, a certain gradient is set to prevent liquid accumulation and encourage flow;

3) The decontamination system is used to remove or reduce contamination. In addition, decontamination equipment will also have an associated pipeline as required for the decontamination process.

c) Primary coolant chemistry is controlled to reduce the migration and deposition of activation and corrosion products. For example, a high concentration of $^{7}LiOH$ is used to optimise the pH in the primary circuit, which will minimise the corrosion of structural materials and transport of corrosion products to the reactor core. Control of the pH also maintains the integrity of the fuel cladding material to minimise the leakage and break, reducing the potential for fission product release, minimising the spread of contamination and hence minimising elevated waste volumes and risks to operators during decommissioning. Further supporting information surrounding management of water chemistry can be found in PCSR Chapter 21: Reactor Chemistry.

d) Measures which reduce the exposure dose of workers during decontamination are considered during the design. For example:

1) An appropriate decontamination process used to reduce the exposure dose of workers during decontamination is considered in the design;

2) The interfaces reserved by container-type decontamination objects are physically isolated from decontamination objects themselves, which reduces the dose received by the decontamination operator;

3) The opening and closing of equipment related to filtration, evaporation, desalination and associated valves will be remotely operated where

reasonably practicable;

4) Equipment will be located in the appropriate radiation zone according to the radioactivity level. When workers enter the different radiation zones, the appropriate protection measures will be taken to reduce the exposure dose.

24.4.6 Building and Structure Design

Concrete is the largest part of waste from decommissioning of NPPs, therefore, building and structure design facilitating decommissioning should be taken into account and implemented as relevant as it can significantly reduce radioactive concrete waste. The following principles are adopted for concrete buildings and steel structures (steel lining, steelwork, etc.) to facilitate its decommissioning:

a) There are coatings or metal liners for all the surfaces of buildings (structures) which may be in contact with radioactive fluids during operation. The coatings and metal liners are adopted to mitigate significant contamination of concrete surfaces and facilitate the decontamination during decommissioning. The lining material corrosion resistance, radiation resistance, shock resistance and flame resistance are considered. This contributes to minimise deposition of radioactive substances and facilitate decontamination of the surfaces to remove any deposited contamination, resulting in lower radiation doses and solid radioactive waste arising during operation and decommissioning. For instance:

   1) For the pools within the nuclear island, a stainless steel liner is applied to the concrete walls and slabs of the pools;

   2) For the internal containment, the sealing steel liner is anchored to the internal concrete including the internal surface of the dome, cylinder wall and bottom plate;

   3) The lining materials used in the UK HPR1000 are divided into non-alloy and alloy steels. The parameters of the metal liners, including corrosion resistance, radiation resistance, shock resistance and flame resistance are consistent with the applicable codes and standards; more detailed information about pool liner is provided in the report *Consistency Evaluation for Design of Facilitating Decommissioning*, Reference [29].

   4) Coatings are applied to structures which may be in contact with radioactive fluids. These structures include concrete walls, slabs, floors and ceilings, steel structures, embedded plates and doors, etc.

b) Floors, walls, coatings and metal liners are flat, smooth and easy to decontaminate, and the penetration positions are reduced and sealed. This also contributes to minimise deposition of radioactive substances and facilitate decontamination of the surfaces to remove any deposited contamination. For instance:

1) The architectural design of buildings follows the general flatness requirements of the floors and walls;

2) For surface coatings, decontamination tests are carried out. The decontamination percentage and contamination sensitivity rate are controlled to ensure that the coating is easy to decontaminate;

3) The penetrations are typically divided into four types: the Equipment Access Hatch, Personnel Access Airlocks, Mechanical (Fluid) Penetrations and Electrical Penetration. Moderate-energy penetrations contain two or more pipework sections in the same penetration. All penetrations are sealed and the leak rate of the containment penetrations is monitored and gathered by the containment leak rate testing and monitoring system.

c) Removable plates, barrier shields and access openings are adapted to improve the accessibility of personnel and equipment during decommissioning. The emergency personnel gates, stairs and elevators are set up for personnel entering and leaving, equipment gates, movable cover-plates and movable shielding walls are set up for equipment introduction and delivery. This contributes to minimising needs for cutting equipment/structures to be dismantled and therefore prevents/minimises worker doses incurred from these cutting operations as well as secondary radioactive waste generated from these cutting operations. It also minimises conventional health and safety risks, e.g. working from height, contaminated wound, and confined space. A typical example is the movable shielding wall of the SG room: the movable wall is connected to the floor and walls on both sides through bolts, and the movable wall can be easily removed to facilitate the dismantling of equipment as one piece during decommissioning.

d) Consideration is given to the position of cutting and packing of main components for dismantling and storage, and lifting equipment is provided for heavy or large components. This contributes to minimising conventional health and safety risks, e.g. working from height, confined space, lifting operations.

   When the demolition work of equipment is finished, the dismantling of main components of concrete structures begins and there are sufficient locations for cutting and packing of main components. For example, the +17.50m operational deck floor of reactor building internal structures can be used for dismantling and storage.

   For the dismantling of heavy or large components in reactor building, the polar crane can be used as lifting equipment. For structures outside containment, temporary lifting equipment is provided for dismantling of heavy or large components.

e) The bearing capacity of floors considers dismantling of large components and the floors that may need to be removed during dismantling of large components are identified. The use of easily removed plates or blocks is considered. This contributes to minimising needs for cutting equipment/structures to be dismantled and therefore prevents/minimises worker doses incurred from these cutting operations as well as secondary radioactive waste generated from these cutting operations. It also minimises conventional health and safety risks, e.g. working from height, contaminated wound.

1) The ingress and egress of equipment and dismantling of large components are considered as loads during bearing capacity design of floors. There are three floors designed to hold large components. These features will facilitate future dismantling operations;

2) To facilitate the dismantling and egress of large equipment or components, a hole in the floor area and corresponding cover plate are designed as a potential solution;

3) Temporary shielding measures may increase the load of the floor because of the uncertainty of the load value in the design stage. The evaluation of the bearing capacity of the floor can be undertaken during the decommissioning stage, and temporary support at the bottom of the floor will be set up when necessary;

4) Considering the fact that the critical load combination for the bearing capacity of floors is earthquake load plus loads generated by accident, the margin of bearing capacity of floors is sufficient for the dismantling period of NPPs.

f) The possibility of staged dismantling of buildings (structures) is considered to enable progressive dismantling of building without impairing structural integrity of the buildings that must be kept intact for decommissioning needs.

1) The design of the separate raft foundation of buildings (structures) facilitates the staged dismantling of buildings. The BRX, BFX, BNX, Safeguard Building (BSX) and Turbine Generator Building (BMX) are located in different rafts. Therefore, the dismantling of the BMX does not affect the stability of the BNX or BRX, for example;

2) Each of the above buildings is an independent structure, and there are no shared load-bearing walls or floors between buildings. Demolition of a building will not affect the structural integrity of another building.

g) Consider reducing or practically eliminating the use of prestressed concrete. This contributes to minimise conventional safety risks, e.g. stored energy.

One of the typical lessons learned from Reference [30] is that the objectives of including design features to facilitate decommissioning should not be in conflict with the primary objective of the facility, which is safe and reliable operation and maintenance. Under the premise of safe operation of the NPPs, the use of prestressed concrete is as limited as possible.

For the buildings in the UK HPR1000, the prestressed concrete structure is only used for internal containment to ensure that accidental pressure can be resisted during the service period and the leakage of the containing radioactive substances can be prevented. From the dismantling experiences of NPPs, prestressed concrete containment can be demolished successfully with the hydraulic rams and controlled explosives.

For other buildings, the ordinary reinforced concrete structures or steel structures (non-prestressed structures) are adopted practically.

h) Long term integrity of structures and structural design for decommissioning to ensure safety of the plant and of workers and protection of members of the public and the environment during decommissioning activities.

The safety classification and the seismic categorisation of the plant are identified to achieve relevant safety functions, such as support of SSC in the building, prevent damage of external hazards or limit internal hazards consequences, provide support and radioactive barrier function of SSC during the decommissioning stage.

For the structural design of civil engineering, the normal operation will be considered over a life span of 100 years when deriving loading from environmental hazards such as wind, rain, snow and ice as defined in the report *Generic Design Parameters for Civil Engineering*, Reference [32].

According to the above measures, the safety classification and the seismic categorisation of the plant are identified. Subsequently, the analysis and design of the structure are undertaken. The design method is mainly divided into two types: design method based on deterministic theory (also known as structural design analysis) and design method based on probabilistic theory.

Through the above analysis process, the safety function of the structures during decommissioning is ensured to be performed.

i) Construction methods take account of the fact that the plant will be decommissioned.

At present, the construction method of concrete structures mainly adopts an on-site supporting model and concrete pouring, and the construction of some areas adopts prefabricated components and on-site assembly. The construction methods of steel structures are mostly factory prefabrication of components, which are assembled on site by welding or bolting. Parts of the plant buildings are built using the steel structures to facilitate the decommissioning.

According to the present disassembly technology of concrete structure and steel structure, there is no difficulty in disassembling the concrete structure and steel structure constructed using the current construction method. These disassembly techniques are mature, and with the development of technology, disassembly of the plant will become easier.

24.4.7 Layout Design

Layout design is important for facilitating decommissioning activities, as provision of enough space and better accessibility will reduce:

a) Needs for cutting equipment/components to be dismantled and associated risks/impacts (e.g. worker doses, spread of contamination);

b) Duration of dismantling activities that could be induced by difficult or limited access to components to be dismantled, thence minimising workers doses;

The following principles in layout design are considered in UK HPR1000 for facilitating decommissioning:

a) Space for decommissioning is optimised whilst the volume of waste is minimised. Radioactive areas are isolated from non-radioactive areas and are also classified into different zones according to radiation levels. Whenever possible, the equipment or pipes without radiation are separated from those with radiation. Meanwhile, the corridors and maintenance spaces have been taken into account in the design stage to ensure accessibility of the equipment, which can also be used for decontamination and dismantling.

b) The accessibility and laydown areas of equipment and components during decommissioning are considered. To facilitate the dismantling of large equipment or components, construction techniques such as bolted precast concrete elements, structural blocks or bolted structural steelworks connections are adopted in the design. Separate personnel and equipment passages and entrances are provided for decommissioning.

c) The retention and deposition of radioactive substances in systems are avoided through the following:

    1) Rational structure design is considered:

        - Specific pipe design measures are implemented in order to align the inner surface of the systems and make it smooth, e.g. using butt welding for piping instead of socketing weld as far as practicable;

        - In the design of pipe routing, appropriate slope is considered to reduce the retention of radioactive substances;

        - Minimising the number of elbows and tees, using large radius elbows and avoiding of pipe dead legs;

- Drainage at the bottom of tanks and lower point of piping systems is provided.

d) Embedded pipes, fittings and equipment in walls and floors are avoided as far as practicable:

1) In the layout design, the number is minimised by optimising the pipe routing, such as by shortening the pipe length and minimising the use of pipe penetrations. If it cannot be avoided that the pipes pass through walls, sleeves are used to prevent pipes from embedding in the civil structure.

2) When embedded pipes are necessary, the following measures are implemented:

- Collection points are set to reduce the number of embedded pipes;
- Pipes run in a straight line to ensure the length is minimised;
- Embedded pipes are designed as double envelope pipe structures, where the external pipe is embedded in the concrete directly and is not in contact with the fluid. The inner pipe is used to carry the medium and is held by the external pipe without welding.

The layout facilitates the decommissioning work and provides effective shielding during dismantling. For example, removable slabs and walls are provided for maintenance and dismantling. Biological shielding, such as shielding walls and shielding doors, is considered during operation and can also be used to reduce the exposure of workers during decommissioning. In addition, movable biological shielding can be provided during dismantling if necessary, e.g. movable lead sheet.

24.4.8 Waste Management

Many of the design measures presented in the previous sections contribute to minimise waste arising or activity levels and therefore will facilitate waste management during decommissioning, e.g. material selection. This section focuses on provisions for facilitating waste management during decommissioning that have not already been captured in previous sections. These provisions are presented below:

a) Minimising the accumulation of decommissioning radioactive waste;

Minimisation of decommissioning radioactive waste accumulated on site is a significant element of the radioactive waste management strategy in the UK HPR1000, especially for solid radioactive waste management, and contributes to the reduction of on-site radiological risks.

The radioactive wastes arising from UK HPR1000 decommissioning include the radioactive gaseous and airborne waste, radioactive liquid waste and radioactive solid waste. To ensure the radioactive waste generated from the UK HPR1000 can be safely managed, the source term and management proposal for these wastes have been determined commensurately to GDA stage and scope, which is presented in *Decommissioning Waste Management Proposal*, Reference [33]. This notably ensures the solid radioactive waste envisaged to be generated during decommissioning can be treated and packaged in line with off-site disposal or treatment facilities at the design stage. In order to minimise the risk that the conditioning and packaging of the ILW decommissioning wastes is incompatible with the future GDF, a disposability assessment of ILW decommissioning wastes has been undertaken during GDA phase to get the advice from Radioactive Waste Management Ltd (RWM). The High Activity Waste (HAW) waste information generated during the operation and decommissioning has been prepared and provided in *UK HPR1000 HAW Disposability Assessment Submission*, Reference [34], and submitted to RWM for disposability assessment.

According to the RWM assessment summarised in *Generic Design Assessment: Summary of Disposability Assessment for Wastes and Spent Fuel arising from Operation and Decommissioning of the UK HPR1000 Pressurised Water Reactor*, Reference [35], sufficient information has been provided by the Requesting Party to produce valid and justifiable conclusions under the GDA disposability assessment. These conclusions are that the HAW from the UK HPR1000 operation and decommissioning is expected to be disposable but some site-specific issues are raised.

For these issues site-specific, responses have been provided to demonstrate that the GDA proposal and design do not prevent resolution of the issues at relevant time in the future and do not result in waste that is not disposable or in significant design changes or constraints on the operator/operation of the plant. Details are presented in *Response to RWM Assessment Report on UK HPR1000 HAW and Spent Fuel Disposability,* Reference [36].

b) Adopting appropriate decontamination techniques;

Decontamination during decommissioning is carried out to remove accumulated radioactive material to reduce the dose received by personnel and minimise the volume/radioactivity of solid radioactive wastes.

To identify appropriate techniques that could be used for decontamination of UK HPR1000 during decommissioning, mature and effective decontamination techniques that are widely used for decontamination of NPPs at decommissioning stage have been reviewed and pre-selected, notably focusing on system decontamination, components decontamination and structure decontamination. The details for decontamination techniques selection for decommissioning and techniques available for decommissioning of UK HPR1000 is presented in Sub-chapter 4 and 5 of *Decontamination Processes and Techniques during*

Decommissioning, Reference [37]. It is also noted that when using any of the decontamination techniques, some risks and impact will be introduced and have to be considered, prevented or minimised. The main risks or impacts relevant to each decontamination technique is also identified and the associated mitigation measures relevant to the design of UK HPR1000 have been or will be incorporated so as to facilitate decontamination based on OPEX and understanding of the current techniques. This is detailed in Sub-chapter 6 of *Decontamination Processes and Techniques during Decommissioning*, Reference [37] and in the *ALARP Demonstration for Decommissioning of the UK HPR1000*, Reference [7]. Other mitigation measures are relevant to operational or decommissioning stage and would have to be further considered by the future operator at the nuclear site licensing phase.

c) Providing safety interim storage for decommissioning ILW.

The ILW envisaged to be generated during decommissioning will be treated and packaged in appropriate containers in line with the requirements of GDF. These packages are then to be interim stored in the Interim Storage Facility (BQZ), which is designed to safely store the ILW anticipated to be generated during the lifecycle of two units, during operational and decommissioning phases. A two phased construction plan is proposed for this facility based on an optioneering process presented in Sub-chapter 7.1.2 of *Conceptual Proposal of ILW Interim Storage Facility*, Reference [38], considering safety, environmental impact, technical feasibility and cost factors. The storage capacity of phase 1 facility is to be designed to accommodate the ILW packages generated by two UK HPR1000 units during the initial operational period of 30 years. The storage capacity of phase 2 facility is to be designed to accommodate the ILW packages to be generated during the remaining operational period and the decommissioning, of two UK HPR1000 units. The design lifetime of BQZ building is 100 years, and the scale of BQZ building can meet the storage needs of the ILW generated during decommissioning, which is consistent with the lessons learned from OPEX, Reference [27].

24.4.9 Radiological Protection

The design requirements to facilitate decommissioning from the radiological protection point of view have also been taken into account when carrying out the UK HPR1000 design, including the following aspects:

a) Source term reduction

During decommissioning, the decontamination, disassembly, conditioning and packaging of SSC are the most exposed activities, for which the main contributor to worker doses is the activated structures and deposit source term. Hence, the most effective way to reduce the radiological risk during decommissioning activities is to reduce the activated structures and deposit source term.

To reduce the activated structure and deposit source term, during the design stage materials with good corrosion resistance and with low cobalt content are selected for SSC design to reduce activation and corrosion products, and the inner surface of the components are treated to reduce the deposition, as described in Sub-chapter 24.4.3.

b) Contamination management and access control

Radiation and contamination zoning are carried out for normal operation during the design stage. This will form important inputs to identify the contamination levels, predict the radiation levels and decide the access control scheme inside the radioactive buildings during decommissioning.

c) Shielding design

The walls, shield doors and labyrinths designed as radiation shielding for normal operation will remain as shielding for decommissioning to reduce the dose received by workers if necessary.

d) Exposed duration reduction

The layout design ensures that there will be enough space in rooms and passages to facilitate decommissioning activities as described in Sub-chapter 24.4.6, which can help reduce the worker's exposure duration for access and operation during decommissioning.

e) Sampling and monitoring

Sampling and monitoring are set for radioactive systems to help obtain corresponding information on radioactivity during normal operation. This is an important input for radiological characterisation during decommissioning and will be recorded as part of knowledge management for decommissioning.

24.5 Decommissioning Strategy

The UK HPR1000 decommissioning strategy provides information to demonstrate the following:

a) The UK HPR1000 can be safely, environmentally and effectively decommissioned at the end of its operational life using current available technologies;

b) The design, and intended construction, operation, and decommissioning of the UK HPR1000 will be developed to reduce the risks/impacts on the workers, the public, and the environment, in accordance with BAT and ALARP principles.

24.5.1 General Principles of Decommissioning Strategy and End State

In general, the decommissioning objective and the end state of a nuclear site are the key factors that influence the decommissioning strategy. The following principles will be applied to achieve the agreed end state:

a) Strategies should be compliant with UK Government policies and legislation, including the policies on sustainable development;

b) Appropriate and scientific methods should be adopted;

c) BAT should be adopted to reduce the volumes and activity levels of radioactive wastes and the impact on the environment and the public;

d) ALARP principles should be applied to protect the public and the workforce;

e) Strategies should take the views of stakeholders into account;

f) Strategies should be reviewed and updated periodically;

g) No options should be foreclosed;

h) Plans should be optimised;

i) Decommissioning activities should be carried out as soon as reasonably practicable, and all relevant factors should be taken into account at the same time;

j) All relevant factors in the decommissioning plan & strategy should be considered and transparently assessed, supported by robust objective information and arguments;

k) The creation of radioactive waste forms that may exclude options for safe and effective long-term waste disposal should be avoided;

l) Volumes of radioactive waste created should be minimised;

m) The benefits of delaying operations to take advantage of radioactive decay should be considered;

n) The requirements for the release from radioactive substances regulation should be considered.

The end state for the UK HPR1000 is not fixed at this time and will be agreed by the licensee with relevant stakeholders during the decommissioning stage. As a minimum it is assumed that any site with the UK HPR1000 will be decommissioned such that the site can be delicensed (e.g. green field). To achieve this, the buildings and structures above -1m need to be dismantled after decontamination. Buildings and structures which are not contaminated and are below -1m will be left in place. Demolition products will be used as backfill for underground voids, trenches, and basements.

24.5.2 Decommissioning Strategy for UK HPR1000

According to IAEA and UK and international experience, two viable strategies can be considered for completing decommissioning of NPPs: immediate dismantling and deferred dismantling. In principle, these two possible decommissioning strategies are applicable for all facilities in Reference [1].

a) Immediate dismantling: In this case, decommissioning actions begin shortly after the permanent shutdown. Equipment and SSC of a facility containing radioactive material are decontaminated and removed to a level that permits the facility to be released from regulatory control for unrestricted use, or released with restrictions for its future use;

b) Deferred dismantling: In this case, as soon as the nuclear fuel is removed from the BRX, all or part of a facility containing radioactive material will be processed or placed under safe storage, so that the facility can be maintained until it is subsequently decontaminated and/or dismantled. Deferred dismantling may involve early dismantling of some parts of the facility as well as early processing and removal of some radioactive materials, which can ensure the safe storage of the remaining parts.

Both immediate dismantling and deferred dismantling are possible for the UK HPR1000 based on the preliminary analysis carried out considering safety, technical, environmental, regulatory, social and economic factors. The decommissioning strategy option study set out in Appendix D of *Preliminary Decommissioning Plan*, Reference [39], is preliminarily prepared and will be continuously developed for the UK HPR1000 and integrated with other relevant strategies, e.g. waste management.

Based on the main considerations for selection of the decommissioning strategy, the preliminary decision recommends immediate decommissioning as the preferred option for the UK HPR1000. This is consistent with UK Government policy and guidance in The Base Case in Reference [20], and is line with the IAEA guidance, which recommends prompt decommissioning of the power station. However, this does not foreclose other options. The final decision will be made by the licensee in the future, taking relevant factors (views of stakeholders, legislation, policy & guidance, design & operational history, financial resources, latest OPEX etc.) as well as operational history and site specific conditions into full consideration.

Immediate decommissioning provides the clearance of the site at the earliest opportunity, reducing hazards and risks. These off-set the additional worker dose and HAW volumes that are created. It aligns largely with international PWR decommissioning OPEX, for example German PWRs are following this path, and generally US plants do as well where funds allow. US PWRs have been completely dismantled safely and without significant adverse environmental impact.

The decommissioning strategy for the UK HPR1000 is consistent with UK government policies and strategies, including policy on sustainable development, and identifies and explains any differences if any.

24.6 Preliminary Decommissioning Plan

A preliminary decommissioning plan including assumptions, strategy, project management, main activities, waste management, and relevant safety management has been developed to show that decommissioning of the UK HPR1000 is feasible using current technologies and within current policies, regulatory context and waste management framework. The preliminary decommissioning plan will be subsequently revised throughout the lifetime of the nuclear facility.

This sub-chapter gives brief information on the implementation of the decommissioning strategy based on an assumed plant status at the end of the operational stage and an assumed target end point for decommissioning.

The licensee will be responsible for updating decommissioning plans as required if UK legislation or best practice changes, or if there are any changes to the assumptions made. At appropriate periods in the future, detailed decommissioning plans will be developed by the licensee. During the preparation of these detailed decommissioning plans, the licensee will also develop or revise the relevant documents prior to decommissioning operations.

24.6.1 Decommissioning Schedule

Decommissioning should be carried out as soon as is reasonably practicable, taking all relevant factors into account. Based on the preliminary analysis in the previous section the immediate decommissioning for the UK HPR1000 is assumed, the decommissioning schedule is justified in the safety case. However, deferred decommissioning remains an option.

The process of decommissioning the UK HPR1000 can be divided into four continuous stages. There may be some overlaps between these stages, but for clarity they are presented below as four distinct stages.

24.6.1.1 Stage 1

Stage 1 is the preparatory work for decommissioning, which will be performed before final closure of the NPPs. The main work at this stage includes:

a) A feasibility study of nuclear power plant decommissioning;

b) Preparation of a safety case for decommissioning;

c) Identification and development of decommissioning design and technology;

d) Identification of decommissioning inventory;

e) Final decommissioning plan preparation after thorough investigation into the regulations and sufficient communication with other external stakeholders;

f) Review of organisational structure and programme for transitioning from an operating structure to a decommissioning structure;

g) Contract specification and contract management;

h) Evaluation of nuclear facilities and systems' availability, e.g. workshops, Heating, Ventilation and Air Conditioning (HVAC) systems, Nuclear Island Vent and Drain System (RPE [VDS]), in order to ensure the availability of facilities;

i) Preliminary characterisation;

j) Construction of temporary facilities or modification of existing facilities if necessary, e.g. decommissioning waste management facility.

The duration of this stage is estimated to be approximately five years.

24.6.1.2 Stage 2

Stage 2 refers to activities carried out shortly after final shutdown of the NPPs. The organisational management and procedures begin to change from operations to decommissioning. The main work at this stage includes:

a) Removal of Spent Fuel Assemblies (SFAs) from the reactor to the SFP;

b) Radiological characterisation;

c) Safety maintenance of plant and systems;

d) Post Operational Clean Out (POCO);

e) Preliminary decontamination of the main circuit, auxiliary facilities and process building.

The duration of this stage is estimated to be approximately two years.

24.6.1.3 Stage 3

The decommissioning activities of Stage 3 are based on those of Stage 2. The main work at this stage includes:

a) Safe storage of SFAs in the SFP (including failed fuels);

b) Removal and transport of SFAs from the SFP to Spent Fuel Interim Storage (SFIS) facility after appropriate cooling period. At this time, the failed fuels could be packaged into the containers (selected according to the latest packaging requirements and options) and then be transferred to BQF for storage. The final management strategy for failed fuels will be determined by the future licensee;

c) Dismantling of non-radioactive systems, non-decommissioning service systems and disposal and recycling of conventional waste;

d) Shielding and isolation of the remaining reactor body structure;

e) Additional decontamination before carrying out some dismantling work e.g. radioactive systems and radioactive equipment, etc.;

f) Dismantling of radioactive systems, radioactive equipment and buildings. This includes main circuit equipment, such as the SGs, coolant pumps, pressuriser and main circuit piping, auxiliary systems and buildings, etc.;

g) Treatment, storage and disposal of radioactive waste in accordance with the provisions of regulations;

h) Dismantling of the reactor body, biological shield and pre-stressed concrete.

The duration of this stage is estimated to be approximately eight years.

24.6.1.4 Stage 4

The main tasks of Stage 4 include:

a) Maintenance of the BQZ and BQF;

b) Clean-up of the site and restoration of green spaces;

c) Final surveys;

d) De-licensing;

e) Release from radioactive substances regulation.

The duration of stage 4 is estimated to be approximately three years (this duration assumed on the basis that the GDF is available during decommissioning of NPPs).

The HAW (e.g. RPV and RVI) generated will be stored on-site for a period of time to ensure the waste packages meet transport and GDF requirements.

It is noted that the decommissioning of BQF and BQZ is not considered during GDA. The timing for decommissioning of the two buildings will be determined by the future operator when the timing of the GDF will be consolidated and fixed.

Within the four-stage decommissioning process, there are a number of key activities, including radiological characterisation, spent fuel management, decontamination, dismantling, waste management and safety management, which are described in Sub-chapters 24.6.2 to 24.6.7.

Detailed information regarding the timescales of decommissioning is presented in the *Preliminary Decommissioning Plan*, Reference [39].

24.6.2 Radiological Characterisation

Radiological characterisation is an important activity throughout the plant lifetime, including during decommissioning. It aims to obtain and record information on the radiological status of the plant to support the plant activities and help reduce the exposure to workers so far as is reasonably practicable.

In the early stages of decommissioning, a more comprehensive radiological characterisation of the NPP is carried out. It aims to support the decommissioning evaluation and planning. It is also an important input for the estimation of waste quantities, selection of decommissioning technology, timing of decommissioning, and schemes for radiological protection.

The characterisation results provide details of the radiological status of the NPP, which help to identify the radiological risks for decommissioning, and to support the decommissioning works, such as development of a suitable decommissioning plan and waste management strategy, etc. The outcome of radiological characterisation will be documented as part of the record and knowledge management.

The radiological characterisation investigates the composition and distribution of radionuclides, the level and distribution of contamination and the nature and quantity of the pollutants and waste, etc. It is carried out by on-site surveys, document investigation, calculation and analysis. The history of the site and facilities is taken into account.

a) The on-site survey is carried out by sampling, analysis and radiation monitoring.

   The first step is to determine the numbers and locations of sampling points to ensure that the obtained samples are sufficient and appropriate to represent the status of the site. The samples are then taken and sent to the laboratory for chemical and radiological analysis to determine the radiological and chemical characteristics of the plant and facilities. The accuracy of the result obtained by this method depends on the adequacy of the sampling point number and their location. In addition, radiation monitoring is used to obtain the dose rate of components/areas;

b) All the records kept for decommissioning are reviewed to obtain radiological information from the relevant documents of the NPP, such as design documents, operational records, and event and accident records. The records of plant construction and modification should also be studied and verified;

c) Material conservation and radioactive balance calculations can be used to gain an insight into the sources. Documents for design schemes, construction, operation and maintenance documents, examination of materials, and accident handling records are all important and valuable inputs for theoretical calculation and analysis. The decommissioning source terms for activated components and structures are mainly predicted by this method due to their inaccessibility caused by the high radiation level. In addition, based on the dose rate data obtained by onsite surveys, the source term of the contaminated components can also be estimated.

The radiological characterisation results provide details of the radiological status of the NPP which helps to identify the risks and hazards for decommissioning and to support the decommissioning work, such as the development of the decommissioning plan and waste management strategy, etc.

According to the predicted decommissioning source term for the UK HPR1000, provided in *Decommissioning Technical User Source Term Report*, Reference [40], the radionuclides existing in the activated structures and components in the core or around the core mainly include Co-60, C-14, Fe-55, Ni-63 and Ni-59, among which Co-60 is a strong gamma emitter that can potentially have significant contribution to occupational exposure during decommissioning. In concrete, C-14, Cl-36, Ca-41, and Fe-55 should be considered. Besides, the deposition of the corrosion products in PWR components and systems during plant operation can induce significant radioactive contamination and needs to be carefully treated. The main radionuclides that can deposit in PWR components and systems are Co-60 and Co-58, which can potentially be contributors to occupational exposure during decommissioning.

More detailed information on the radiological characterisation is provided in *Preliminary Decommissioning Plan*, Reference [39]. Further information on predicted decommissioning source term for the UK HPR1000 is provided in *Decommissioning Technical User Source Term Report*, Reference [40].

24.6.3 Spent Fuel Management

The spent fuel management plan for the UK HPR 1000 during operation and decommissioning will be divided into the following three parts:

a) The SFAs are unloaded from the reactor core and need to be stored in the SFP for cooling due to their high radioactivity and decay heat. The cooling period will be set considering the decrease of activity and heat decay of SFAs during storage and the physical capacity of the SFP (the capacity accommodates the spent fuels generated from approximately 10 refuelling cycles). This process is considered as short term storage;

b) The on-site storage of spent fuel in an independent facility is considered as interim storage. After the technology optioneering, the dry storage in casks technology is considered as the preferred storage option for SFIS in the GDA phase. The SFAs will be loaded into fuel storage canisters and then transferred to the BQF within transfer casks. The management of SFAs produced during the last several fuel cycles prior to decommissioning will be similar to that during operation;

c) After the interim storage, the spent fuel will be retrieved and repackaged for off-site transport and final disposal. The spent fuel will be stored in the BQF until the final disposal facility is available. The design of the UK HPR1000 will also ensure the retrieval of SFAs from BQF. It is intended that the SFAs will ultimately be safely disposed of in the GDF.

Failed fuels are expected to be stored within the SFP until the decommissioning of the Fuel Building (BFX), which is presented in PCSR chapter 28. Considering international OPEX, two possible options for the containerisation/encapsulation of failed fuel after the removal from the SFP are available, as presented in *Spent Fuel Interim Storage Facility Design*, Reference [41]. None of these two options is foreclosed by the current strategy for UK HPR1000. Failed fuel management is a developing area all over the world and it is likely that worldwide OPEX in this field will have increased by the time when UK HPR1000 enters decommissioning (i.e. in more than 60 years). This may potentially include new options for the management of failed fuel. The final strategy for failed fuel management will therefore be decided at an appropriate stage (e.g. close to final shutdown or during decommissioning).

More information regarding fuel unloading and spent fuel storage in SFP can be found in PCSR Chapter 28 Fuel Route and Storage while for interim storage, the information can be found be in Chapter 29 Interim Storage of Spent Fuel.

24.6.4 Decontamination

Decontamination is of significance for each stage of the decommissioning program. It is applied to internal and external surfaces of systems/equipment, tools, floors, rooms and civil structures to remove surface contamination of the UK HPR1000 in order to:

a) Reduce the dose received by workers during decommissioning;

b) Minimise the activity levels/volume of solid radioactive waste;

c) Facilitate disassembly activities.

When defining if and how decontamination is to be applied, the operator will need to balance various factors, such as reduction of deposited activity and associated benefits, dose uptake, the secondary wastes generated in decontamination operations and the toxicity of chemicals and their effect on workers, the environment and the public.

Based on decommissioning OPEX, widely used decontamination processes and techniques, possible decontamination solutions for the UK HPR1000, main risks/impacts and mitigations relevant to decontamination are all considered in the supporting document *Decontamination Processes and Techniques during Decommissioning*, Reference [37]. The future licensee will update the decontamination plan, taking account the relevant operational data and up to date OPEX available at that time.

24.6.4.1 System Decontamination

The primary and auxiliary systems, including all components and pipework, need decontamination. As the components are connected by pipework they can be cleaned jointly in 'full system decontamination' by a chemical process during POCO.

Full system decontamination reduces the individual and total dose during decommissioning, and the number of decontamination cycles is determined by the results of sampling analysis. Once the radioactivity level is reduced to an acceptable level, decontamination is deemed sufficient.

24.6.4.2 Components Decontamination

After full system decontamination, depending on the dose levels and transport arrangements, large components (e.g. primary coolant pumps) will be transferred to a workshop for size reduction and/or further decontamination.

Smaller components (e.g. valves, pipe segments, instrument, tools etc.) will undergo further decontamination in the hot workshop. These components are dismantled into their subcomponents and prepared for decontamination according to their dose rate levels.

24.6.4.3 Decontamination of Buildings and Structures

Decontamination of concrete and steels surfaces in radioactive areas is carried out before the demolition of structures. The approach is to remove all the contamination and to demolish the structures as conventional industrial structures.

Concrete components (e.g. walls, floor, and room), are treated according to their contamination levels. Concrete structures are decontaminated using mechanical decontamination techniques (e.g. milling, shaving, wiping). The contaminated layer depth that needs to be removed is determined from calculations based on the radiological characterisation and the plant history. Once the calculated layer depth has been removed, new measurements are performed. If necessary more concrete will be removed until the measurement yields no more contamination.

Steel structures (e.g. equipment and pipe support, cable trays, beams, bars and other metallic material), are usually covered with decontaminable paints to facilitate decontamination. Slightly contaminated surfaces are decontaminated by wiping, and heavily contaminated surfaces are decontaminated by abrasive blasting. Most metallic materials can be recycled. Radioactivity levels of structures is lowered to an acceptable level before the cutting and dismantling activities are performed.

24.6.4.4 Decontamination Techniques

For all decontamination techniques, consideration should be given to the amount of secondary waste produced, the safety and exposure of operators and the effect on the environment and the public. The applications of the available decontamination techniques are presented in T-24.6-1.

T-24.6-1 Decontamination Techniques

Techniques	Applicable
Full System Decontamination	Closed System, Equipment, component
Foam Decontamination	Metal pieces and parts of complex components
Chemical Gel	Large component, carbon steel pipes with simple geometry
Strippable Coating	Large non-porous surfaces, easily accessible
High Pressure Water	Larger items
Ultrasonic Bath	Components
Abrasive Grit Blasting	Metallic structure
CO_2 Blasting	Concrete, paints
High Pressure Liquid Nitrogen Blasting	Metals, concrete
Grinding	Floors and walls, metals
Shaving	Floors and walls
Milling	Large number of similarly shaped items
Scabbling	Floors and walls
Vacuuming / Scrubbing	Large quantities of loose contaminants
Electropolishing (electrochemical decontamination)	Conductive surfaces

24.6.5 Dismantling

24.6.5.1 Dismantling of Systems and Components

The dismantling plans benefit from the feedback of relevant appropriate decommissioning experience, completed worldwide, especially that which is relevant to PWRs. The decommissioning conditions are often similar whilst not being exactly the same. Various dismantling techniques are available currently and they should be used, on a case-by-case basis.

In particular, various cutting techniques can be used to reduce the size of the equipment, as presented in *OPEX on Decommissioning*, Reference [27]. Cutting techniques include thermal (such as plasma), mechanical (such as circular saw) and water jet techniques. The most appropriate technique should be chosen after feasibility studies have been undertaken. Specific physical characteristics, such as size, thickness and material, radiological constraints and access should be taken into account.

Feedback on dismantling nuclear power plants shows that the techniques, knowledge and skills are already available to manage the challenges presented by decommissioning.

The dismantling process should be determined addressing the following points:

a) The risks to the workers, public and environment. The measures applied to detect, prevent, limit and progressively reduce relevant risks;

b) The final state of the facility;

c) The scheduling and nature of the dismantling works;

d) The relevant origin, characteristics, quantity, packaging, transportation, disposal, recycling and management of both nuclear and non-nuclear waste;

e) The maintenance requirements for the facility and the auxiliary buildings during the dismantling operation;

f) The emergency plan during the operation.

The predicted impact of decommissioning of UK HPR1000, and the logistical challenges presented by the reactor design, for example the transportation issues for the SGs, are understood from the design stage.

The dismantling of the UK HPR1000 is based on the following considerations:

a) Remote dismantling of highly or moderately activated components under water, such as reactor vessel internals;

b) Dismantling of contaminated components and slightly activated components in air, such as reactor coolant piping;

c) Making maximum use of the UK HPR1000 facilities for containment and shielding purposes during the dismantling. The access routes to the reactor containment building have been designed to facilities the introduction of dismantling equipment and removal of large components, such as the SGs;

d) Use of auxiliary buildings which will have a refurbished function especially during dismantling. While the reactor has been shut down, redundant auxiliary buildings can be refurbished in parallel to support decommissioning and waste management;

e) Removal of reactor coolant piping and reactor coolant pumps (primary cutting if necessary) from their location inside BRX to a workshop at the building floor service or in auxiliary buildings to be size-reduced for packaging;

f) Removal of the SGs as complete units from their respective shielded enclosures to a waste processing facility outside the BRX. Reverse handling and transportation design of large components, such as the SGs, reactor coolant pumps and the pressuriser during the installation stage, provide the possibility of removing the large components in one single piece, if appropriate;

g) The polar crane within BRX is designed for the handling of heavy equipment and reactor components during decommissioning. Lighter components can be handled by other means specific to the task and potentially added during the decommissioning stage;

h) The shielding needs will be taken into account during the dismantling and transportation process.

The basic dismantling process for the primary circuit is given below:

a) Preparation (drainage, decontamination etc.) of primary circuit dismantling, dismantling of auxiliary pipes;

b) Removal of the SGs from the BRX for dismantling in a dedicated workshop;

c) Removal and dismantling of the reactor coolant pumps;

d) Dismantling and removal of the reactor coolant piping;

e) Removal and dismantling of the pressuriser;

f) Preparation and dismantling of reactor vessel internals in the reactor pool under water;

g) Dismantling of the RPV;

h) Dismantling of reactor vessel head;

i) End of primary circuit dismantling.

Considering the primary coolant circuit equipment in the reactor building of the UK HPR1000 is of relatively large volume and is anticipated to have high radioactivity levels at the time of decommissioning, dismantling of the equipment has revealed to be challenging due their important size/volume and their high activity levels. Thus the proposed dismantling process for each piece of the UK HPR1000 primary circuit equipment is presented in *Preliminary Disassembly Program for the Main Equipment Decommissioning,* Reference [42]. This includes decommissioning strategy/plan, dismantling processes, main risks/impacts and associated mitigation measures relevant to dismantling. The preliminary program demonstrates that the primary equipment can be dismantled safely and in a way that will minimise environmental impacts, using existing techniques.

The treatment, management and disposal approach for the main equipment is presented in Sub-chapter 24.6.6 and detailed in the *Decommissioning Waste Management Proposal*, Reference [33].

24.6.5.2 Dismantling of Concrete and Steel Structures

a) Information of buildings

The generic site layout for the UK HPR1000 is based on a single unit reactor design, which is shown in F-24.6-1. The aerial view is shown in F-24.6-2.

The buildings are normal reinforced concrete structures except for the internal containment which is a pre-stressed concrete structure.

The principal construction materials for civil structures are concrete, reinforcing steel, structural steel and pre-stressed tendons, etc. Materials that are widely available in the UK have been adopted preferentially.

The structures are as follows:

1) Reactor Building (BRX), which consists of BRX internal structures, internal containment and external containments;

2) Safeguard buildings, which consist of Safeguard Building A (BSA), Safeguard Building B (BSB) and Safeguard Building C (BSC);

3) Fuel Building (BFX);

4) Nuclear Auxiliary Building (BNX);

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

6) Radioactive Waste Treatment Building (BWX);

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

8) Equipment Access Building (BEX);

9) Personnel Access Building (BPX);

10) Essential Service Water Pumping Station A (BPA) and Essential Service

Water Pumping Station B (BPB);

11) Circulating Water Pumping Station (BPW);

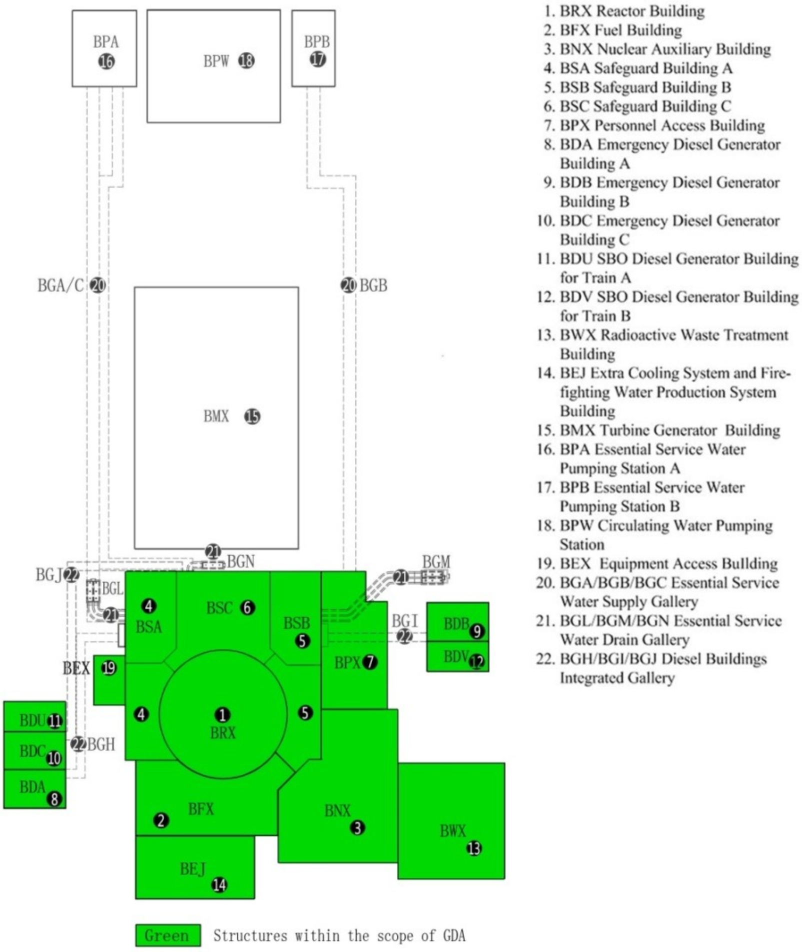
12) Essential Service Water Supply Gallery A (BGA), Essential Service Water Supply Gallery B (BGB) and Essential Service Water Supply Gallery C (BGC);

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

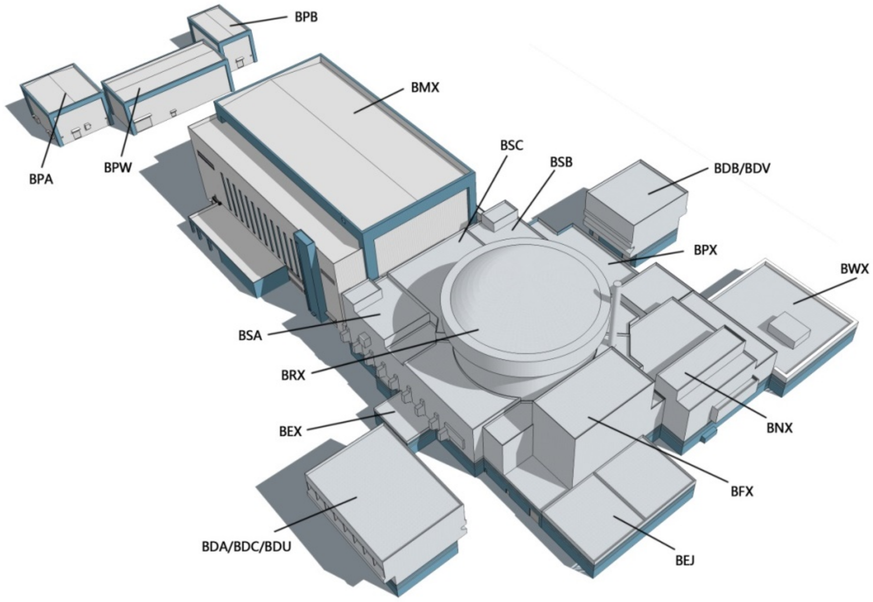
14) Essential Service Water Drain Gallery L (BGL), Essential Service Water Drain Gallery M (BGM) and Essential Service Water Drain Gallery N (BGN);

15) Turbine Generator Building (BMX);

16) Other buildings (including BQZ/BQF).



F-24.6-1 Generic Site Layout of the UK HPR1000



F-24.6-2 Overall View of the UK HPR1000

b) Dismantling sequence of buildings

The buildings on-site can be divided into two groups. The first group consists of the conventional island and non-nuclear parts of the plant. Some of the buildings are decommissioned immediately, and some existing buildings and systems are re-used for follow-up decommissioning activities where practicable and safe to do so. For example, the Turbine Hall could be converted into a waste management workshop.

The second group of buildings consists of the Reactor Building (BRX), Fuel Building (BFX), Nuclear Auxiliary Building (BNX) and Safeguard Buildings (BSA/BSB/BSC). Dismantling is performed as the following sequence:

1) Spent fuel removal from the BFX;

2) Systems and equipment are disassembled and removed after relevant decontamination;

3) Concrete surfaces in radioactive areas are decontaminated;

4) Completion of dismantling under water (e.g. reactor vessel), and dismantling of Safeguard Buildings;

5) Dismantling of the BFX;

6) Dismantling of the BNX after clean-up of all the buildings of the nuclear island;

7) Dismantling of the BRX from external containment to internal containment.

c) Methods of dismantling structures

According to the relevant physical principles of the particular process, the existing and proven techniques of concrete structures demolition are identified below:

1) Flame Cutting

The flame cutting process uses a torch that involves a heating gas (e.g. acetylene, propane or a liquid fuel) reacting with oxygen to form aflame. This flame heats up the material to a temperature where burning of the material can begin.

2) Plasma Arc Cutting

Plasma cutting makes use of a high-velocity high-temperature plasma (ionised gas) stream to melt the work piece and to transport the molten kerf material.

3) Laser Cutting

Laser cutting uses high-energy density light beams to heat and cut objects in a short time.

4) Mechanical cutting

Diamond wire sawing is a typical mechanical cutting tool for large components made out of concrete and steel.

5) Hydraulic cutting

A hydraulic ram mounted on an excavator is a very common piece of equipment in the construction and demolition industry. With the development of mechanical technology, excavators can extend to enough height and allow the ram to penetrate even the strongest reactor-grade concrete.

6) Explosive demolition

Explosive demolition is widely used in conventional building demolition.

All the above methods can be used to dismantle structures of the UK HPR1000. The choice depends on factors such as safety, dust emission, noise reduction requirements, storage requirements, secondary waste that would be generated and hazards associated with the technique.

d) Nuclear island plant dismantling considerations

The nuclear island includes all buildings which present a radiological hazard. The scope of decommissioning of the nuclear island includes:

1) Reactor Building (internal containment, external containment, internal structure);

2) Safeguard Buildings (safeguard building A/B/C);

3) Fuel Building;

4) Nuclear Auxiliary Building;

5) Personnel Access Building;

6) Equipment Access Building;

7) Radioactive Waste Treatment Building.

The nuclear island buildings will be demolished after the equipment and components have been removed.

The concrete surface in radioactive areas will be decontaminated before the structures are dismantled. Surface cleaning or scabbling to remove the surface of the concrete to a non-contaminated layer will be carried out.

The BRX consists of both internal and external containments. The walls are formed from pre-stressed concrete, with a stainless steel lining covering the internal surface sealing the structure to prevent the leakage of radioactivity. The external containment is a reinforced concrete dome that covers the top of the internal containment. The external containment will be dismantled followed by the demolition of the internal containment. All other nuclear island buildings are primarily concrete structures.

e) Dismantling consideration for conventional plant

The conventional plant includes all plant and buildings which are associated with power generation or operation of the site and do not present a radiological hazard. This therefore includes:

1) Turbine building;

2) Pumping station;

3) Substation and on-site transmission towers;

4) Other auxiliary buildings such as administration buildings, workshops, apartment buildings and other miscellaneous buildings on the site.

These will be decommissioned using current proven techniques for dismantling, in accordance with up to date regulations, international guidance and best practice.

More information of building dismantling is provided in *Decommissioning Building Dismantling Proposal*, Reference [43], including worldwide dismantling technologies, main risks/impacts and associated migration measures. This demonstrates that the UK HPR1000 buildings can be dismantled safely and in a way that will minimise environmental impacts, using existing techniques.

24.6.6 Waste Management

The waste management is an important part of decommissioning of nuclear facilities. The current decommissioning radioactive waste management proposal of the UK

HPR1000 during GDA has considered BAT and ALARP principles. It ensures options are not foreclosed and the licensee will improve this strategy and select the most appropriate option and demonstrate it is BAT and ALARP at the nuclear site licensing phase. The detailed information regarding the decommissioning radioactive waste management proposal during GDA is presented in *Decommissioning Waste Management Proposal*, Reference [33].

24.6.6.1 Decommissioning Radioactive Waste Management Principles of the UK HPR1000

The waste hierarchy, as illustrated in F-24.6-3, will be applied to the management of all wastes arising from the construction, operation and decommissioning of the UK HPR1000. The waste hierarchy is a stepwise approach to achieve waste minimisation. It encourages the options for waste management in the following order of priority:

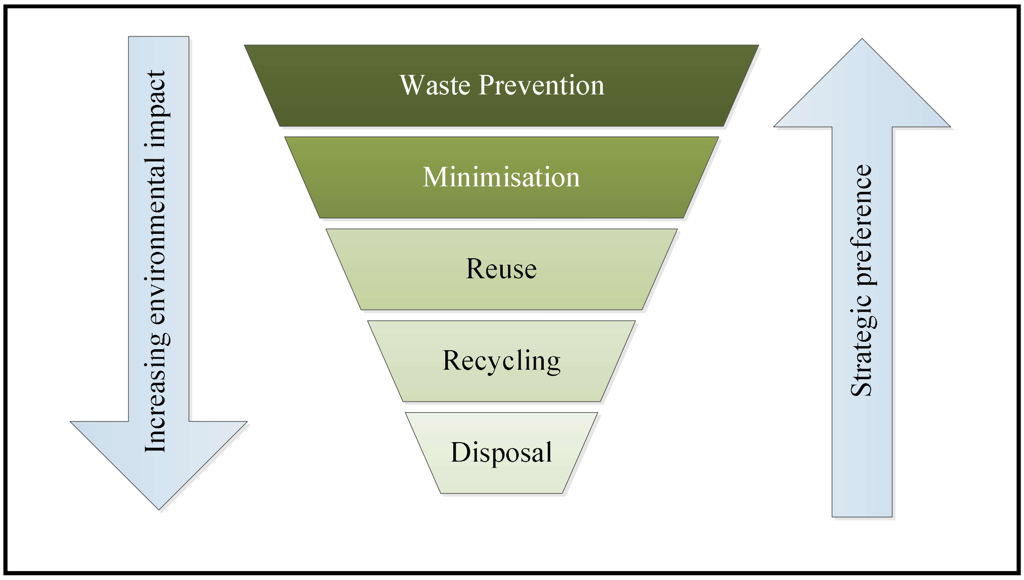
a) Prevention: Creation of waste should be prevented;

b) Minimisation: Waste should be reduced at source as far as possible;

c) Reuse: Where appropriate, waste materials should be reused directly or after refurbishment;

d) Recycling: Where appropriate, waste materials should be recycled;

e) Disposal: Waste should only be disposed of when the above options are not practicable.



F-24.6-3 Waste Hierarchy

24.6.6.2 Waste Inventory

24.6.6.2.1 Waste Streams

When the nuclear power plant reaches the end of its life and enters the decommissioning stage, the state of the NPP is changed from normal nuclear power generation to discharge of all fuel for decontamination, demolition and de-licensing. At this point, the origin of radioactive waste generation is quite different from that during operation, e.g. waste generated from decommissioning of main equipment.

During different decommissioning stages, different radioactive wastes will be generated. This is particularly the case during the decontamination and dismantling process. Radioactive decommissioning wastes can be divided into gaseous and airborne radioactive waste, liquid radioactive waste and solid radioactive waste.

a) Gaseous and airborne waste

The main production mechanisms are:

1) Gas produced by the chemical reaction during the decontamination process, etc.;

2) Airborne radioactive particulates generated during specific decommissioning operations, e.g. cutting processes.

b) Liquid waste

Liquid radioactive waste is mainly generated as a secondary waste resulting from decommissioning activities, including decontamination operations, physical (water based) cutting processes, etc.

c) Solid waste

Solid radioactive waste (including non-aqueous liquid radioactive waste) accounts for the largest proportion of all decommissioning radioactive waste, and includes neutron-activated materials, contaminated materials and other radioactive waste. Typically, decommissioning solid radioactive waste includes but is not limited to: system equipment and components, piping, concrete, metal, secondary waste (e.g. ion exchange resins, spent filter cartridges and activated charcoal from iodine traps (if used) and delay beds of Gaseous Waste Treatment System (TEG [GWTS])) and other miscellaneous waste generated during decommissioning activities.

Non-radioactive wastes include service systems from the turbine building and some systems from the auxiliary building, as well as material from steel/concrete structures.

24.6.6.2.2 Decommissioning Radioactive Waste Inventory

The preliminary decommissioning waste inventory and categorisation are determined based on the decommissioning waste inventory estimation methodology that is presented in the *Decommissioning Waste Management Proposal*, Reference [33].

These can be found in Appendix B. This preliminary inventory will be updated at a relevant time in the future by the future operator.

24.6.6.3 Waste Management

24.6.6.3.1 Gaseous or Airborne Radioactive Waste Management

There are generally low levels of radioactive gaseous or airborne effluents generated during decommissioning and these can be handled and discharged by existing (if safe and BAT to use) and temporary HVAC to ensure that discharges are minimised. The bulk of airborne activity will be particulate from material cutting and dry decontamination.

24.6.6.3.2 Liquid Radioactive Waste Management

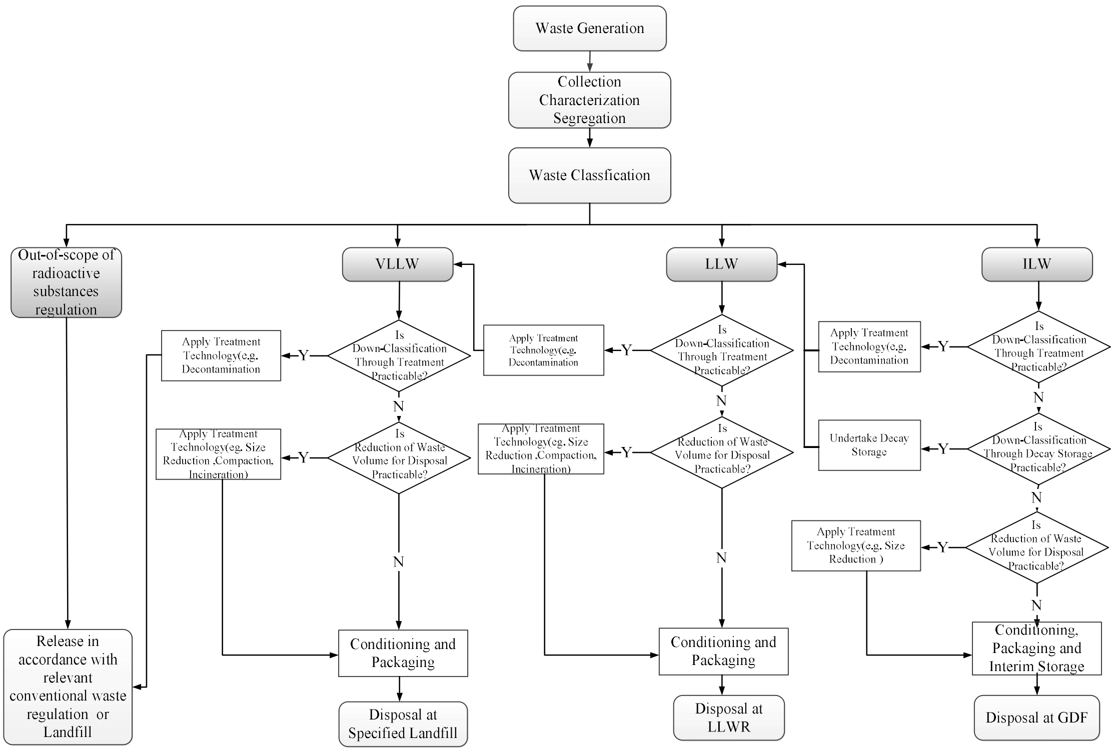
Liquid effluents will arise from decontamination and dismantling activities (water cooling for cutting for example), as well as from drains and washrooms.

In the early stages of decommissioning, radioactive liquid waste will be treated by the existing effluent management systems (if safe and BAT to use) or by temporary liquid effluent treatment facilities to ensure that liquid effluent discharges are minimised. The equipment that is available ranges from modular effluent clean up plants through to evaporators.

24.6.6.3.3 Solid Radioactive Wastes Management

a) Overview of solid radioactive waste management steps

Application of the waste hierarchy is a fundamental principle of the decommissioning radioactive waste management which is presented in Sub-chapter 24.6.6.1. Waste minimisation should be an essential element of radioactive waste management steps which consist of generation, characterisation and segregation, pre-treatment, treatment, conditioning, storage, transport and disposal. The various steps for the management of decommissioning solid radioactive waste are illustrated in F-24.6-4.



F-24.6-4 Hierarchy of Routes

b) Waste characterisation and segregation

For decommissioning solid waste management of the UK HPR1000, the future operator will adopt suitable facilities to apply waste characterisation and segregation. This will help effectively segregate the waste and helps the operator in selecting optimal management and disposal routes.

c) Waste treatment and conditioning

Based on existing facilities in the UK for the management and disposal of radioactive wastes, the proposal regarding the decommissioning waste treatment and conditioning is as follows:

1) Spent resins

Spent resins from decommissioning activities will be treated in the same way as the operational spent resins. They will be dewatered and packaged in 500 litre robust shielded drums (e.g. MOSAIK container) without encapsulate. The packaged resins will then be transferred to the BQZ until the GDF is available to receive waste from the UK HPR1000.

Some of the ILW spent resins could be identified as boundary waste, which can be decayed into LLW in a short time. These spent resins will be immobilised by mixing them with cement in the 210 litre drum. They will then be transferred to the BQZ for decay storage and then transferred to LLWR disposal facility when they are decayed into LLW.

2) Spent filter cartridges

The ILW spent filter cartridges from decommissioning are to be treated in the same way as proposed for operational spent filter cartridges as they are expected to have similar characteristics. They will be immobilised with cement grout in 3 cubic metre boxes and then be transferred to the BQZ until the GDF is available to receive waste from the UK HPR1000.

3) RPV and RVIs

The ILW RPV will be immobilised with cement grout within 4 metre boxes and the ILW RVIs will be immobilised with cement grout within 3 cubic metre boxes. The waste packages will then be transferred to the BQZ until the GDF becomes available to receive waste from the UK HPR1000.

4) Concrete

The ILW concrete from the activated primary bio-shield during decommissioning will be immobilised with cement grout in 4 meter boxes and then the waste packages will be transferred to the BQZ until the GDF becomes available to receive waste from the UK HPR1000.

5) Lower Activity Waste (LAW)

The LAW generated from decommissioning will be characterized, dismantled (where relevant) and segregated in relevant waste management buildings. To apply the waste hierarchy, decontamination and/or decay are to be implemented for all relevant wastes (to be determined by the future operator) and this can result in some wastes becoming out of scope of radioactive substances regulation. These wastes will be reused and recycled (where possible) or released in accordance with any relevant conventional waste regulation. The other LAW which cannot become out of scope of radioactive substances regulation are size reduced (where possible) and packaged into an appropriate container for the identified waste treatment or disposal route. These waste treatment or disposal routes include incineration, metal melting, super compaction and disposal.

Detailed information can be found in the *Decommissioning Waste Management Proposal*, Reference [33].

d) Interim storage

Based on UK requirements, LLW packages can be treated or disposed off-site soon after being produced and there is no dedicated LLW interim storage facility on-site.

ILW packages will need to be stored on-site in the BQZ and some ILW that are identified as boundary waste will also be stored in the BQZ. The BQZ will be designed to last for at least 100 years, as is required by UK industry guidance, Reference [44].

Therefore, for the UK HPR1000:

1) LLW generated during decommissioning will be stored in a temporary storage area on-site before being sent to the off-site treatment and/or disposal facility;

2) HAW generated during decommissioning will be stored in the on-site ILW interim storage facility before being sent to the GDF, assuming that the GDF is not available to receive UK HPR1000 HAW during the UK HPR1000 decommissioning;

3) ILW generated during decommissioning which are identified as boundary waste will be stored in the BQZ until they have decayed into LLW.

24.6.6.3.4 Non-Radioactive Wastes Management

There will also be very large volumes of non-radioactive waste from the facilities decommissioning. These will consist of metals, mostly steel and copper, and concrete. The strategy for these materials is the same as operational non-radioactive waste, which is presented in the report *Integrated Waste Strategy (IWS)*, Reference [45]. In order to minimise off-site transportation of waste, consideration will be given to seeking permits to infill on-site voids with demolition rubble.

24.6.6.4 Waste Disposability Assessment

According to the GDA scope in the report *Scope for UK HPR1000 GDA Project*, Reference [46], the disposability of LLW decommissioning waste is out of scope of GDA. Therefore, the analysis of acceptability of LLW decommissioning waste for off-site treatment and disposal is not undertaken during GDA. The future operator will undertake such analysis and obtain relevant agreements/acceptance from LLWR or relevant UK waste services providers during the UK HPR1000 decommissioning to ensure that LLW generated during decommissioning can be accepted by off-site facilities to minimise the accumulation of radioactive waste on site.

The GDF is under development and is not expected to be available for a number of decades. A part of the solid radioactive waste generated by the UK HPR1000 will be too radioactive to be disposed of via existing routes.

In order to minimise the risk that the conditioning and packaging of HAW generated throughout the reactor lifetime results in waste that is incompatible with a future GDF, a disposability assessment of the HAW from the UK HPR1000 has been undertaken during GDA to get the advice from RWM. For the disposability assessment of UK HPR1000 HAW generated during decommissioning, the *UK HPR1000 HAW*

Disposability Assessment Submission, Reference [34], was prepared and submitted to RWM.

According to the *Summary of Disposability Assessment for Wastes and Spent Fuel arising from Operation and Decommissioning of the UK HPR1000 Pressurised Water Reactor*, Reference [35], RWM has concluded that there is no issue that would challenge the disposability of the HAW expected to be generated from decommissioning of the UK HPR1000 and the HAW from the UK HPR1000 decommissioning is expected to be disposable. Some issues have been raised by RWM, but all have been analysed and shown to be resolvable by a future operator at the site licensing phase. According to the analysis results, a response to each issue has been proposed, which can guide the subsequent designers and assessors to focus on the important issues and possible solutions in the future site specific disposability assessment work. Details are presented in *Response to RWM Assessment Report on UK HPR1000 HAW and Spent Fuel Disposability*, Reference [47].

24.6.7 Safety Management

Identification, elimination or control of hazards and risks/impacts are key aspects in decommissioning, and this includes the hazards and risks/impacts to workers, environment and the public. Systems and devices designed for the operational phase may become useless or ineffective during the decommissioning stage. For example, some control systems will become redundant but others need to retain their function. Therefore the adequacy of safety measures needs to be re-evaluated as the work proceeds.

New potential hazards and risks/impacts will be identified and new safety measures and environmental protection measures should be adopted as necessary. Additional health and safety precautions will need to be implemented as decommissioning involves changing and evolving processes on the site and large numbers of temporary workers or augmented labour. A new organisation structure and administrative arrangements will need to be adopted. In addition, there are conventional safety risks associated with decommissioning and the use of dismantling techniques, e.g. use of lasers. Different decommissioning methods produce different hazards. In order to identify the potential hazards during decommissioning, the relevant process and activities are preliminarily analysed. Major hazards and risks/impacts from decommissioning and their mitigation measures are presented below.

24.6.7.1 Hazards and Risks/Impacts during Decommissioning

The overall UK HPR1000 hazards identification and assessment process is presented in PCSR Chapter 18 External Hazards and Chapter 19 Internal Hazards, and the conventional health and safety risk identification and assessment process during decommissioning can be found in PCSR Chapter 25 Conventional Safety and Fire Safety and the identified risk and design mitigation is recorded by conventional health and safety design risk registers.

On the basis of and considering the learning from *OPEX on Decommissioning*, Reference [27], *Safety Assessment for the Decommissioning of Facilities Using Radioactive Material*, Reference [25], *Decontamination Processes and Techniques during Decommissioning*, Reference [37], *Preliminary Disassembly Program for the Main Equipment Decommissioning*, Reference [42], and *Decommissioning Building Dismantling Proposal*, Reference [43], all the foreseeable hazards and risks/impacts of the UK HPR1000 decommissioning have been preliminarily identified together with suitable measures that are available and capable of preventing these hazards or reducing risks to ALARP levels. These hazards/risks and associated prevention/reduction measures have then been assessed commensurately to GDA phase and scope. All relevant measures have been adopted in the design of UK HPR1000 so that hazards are prevented where possible and risks are reduced to ALARP. Details are provided in the *ALARP Demonstration for Decommissioning of the UK HPR1000*, Reference [7], in PCSR Chapters 18 and 19 for external and internal hazards respectively, and in PCSR Chapter 25 for the conventional health and safety risks, and a typical example is provided in *Dismantling Example Analysis of Steam Generator*, Reference [48]. An overview of these, focusing on key aspects, is provided in this Sub-Chapter and in Sub-Chapter 24.8. As the decommissioning safety case develops and decommissioning techniques improve, knowledge and OPEX on PWR decommissioning increase and UK HPR1000 operational history becomes available, the identification and assessment of risks/hazards and associated mitigation measures will need to be refined and further developed.

Among all the hazards/risks assessed at GDA phase, the following ones have been identified as the main ones (commensurately to GDA phase and scope) based on a thorough analysis:

a) Radiological Risks

Worker dose from decontamination processes, cutting and removal of items, transfer of materials (reactor internals) and waste management, etc.

b) Internal Fire

There is a possibility of fire if there are combustible materials present in rooms. During decommissioning, flammable materials and the use of electrical equipment can lead to fire.

c) Explosion

Internal explosions could occur within the NPP site. For example, when explosive material leaks into the environment or high voltage electrical equipment fails, an explosion may occur. During decommissioning, explosions can also be triggered by cutting or demolition activities.

d) Dropped Load

Potential dropped loads include collapsed structures, falling objects and components. For seismically classified structures and heavy items of plant equipment located at significant heights, collapsing or falling can be prevented. Dropped loads are assumed to occur as a result of a lifting device failure.

e) Human Error

Human error may occur in decommissioning activities, such as in decontamination, disassembling and dismantling of SSC.

24.6.7.2 Control Measures

Suitable measures should be taken to control or mitigate the identified hazards according to the UK regulations, which include engineering measures, management measures, training and Personal Protective Equipment (PPE), etc.

Facilitating decommissioning activities at the design stage aims at reducing risks/impacts from UK HPR1000 decommissioning. Relevant information is provided in PCSR Sub-chapter 24.4 and in Reference [29]. Other available control measures and mitigation during decommissioning will be considered and implemented as relevant, with examples provided below.

a) Radiological protection

Protection and mitigation measures for radiological risks include:

1) Radiological characterisation before dismantling;
2) Adequately planning the activities and avoiding as far as possible concurrent activities in the same area;
3) Performing decontamination before dismantling;
4) Use of underwater cutting, especially for RVI;
5) Use of remote controlled equipment/tools;
6) Adequate provision of shielding/PPE.

b) Internal fire

Protection and mitigation measures for internal fire include:

1) Fire qualification of materials used in decommissioning;
2) Employing low flammability or high flash-point fuel and lubrication oils where reasonably practicable. Where this is not possible, the use of bunds will be employed to ensure any leakage of oil is locally contained;
3) Passive fire protection measures for high fire load equipment and systems;

4) Controlling electrical equipment ignition sources through application of appropriate standards;

5) When there is a fire in the plant, mitigation measures will be taken immediately. To make sure the fire can be detected and extinguished as soon as possible, three fire protection systems are incorporated in the design:

   - Fire detection systems;
   - Fire-fighting systems;
   - Smoke control systems.

c) Explosion

Protection and mitigation measures for internal explosion include:

1) Avoiding or managing the release of explosive gases from processes which generate these gases;
2) Limiting the use of explosive materials or pressurised tanks as far as is reasonably practicable in buildings important to safety. Where this is not possible, amounts are strictly limited to the necessary quantity;
3) An explosive gas detection system with a concentration safety margin;
4) An alarm system which will warn the operator of the concentration of explosive gas.

d) Dropped load

Protection and mitigation measures for dropped load include:

1) Periodic inspection and early detection of incipient failure;
2) Operational procedures and operator training to reduce the human error;
3) Preventing loads from being carried over or near equipment that may lead to radioactive release when struck;
4) Defining a safe lifting route;
5) A single straight-line movement of the crane for all major lifts is defined;
6) Limiting lifting heights.

e) Human error

Protection and mitigation measures for human errors include:

1) Consideration of human factors in the design stage, e.g. the corridor and entrance for personnel to approach the main components during decommissioning are provided in Reference [29];

2) Preliminary decommissioning plan is prepared in Reference [39], which reminds the licensee to periodically update to take into account technological development of decommissioning;

3) Development of decommissioning organisation to enhance work/health/training management and safety culture.

All the hazards/risks relevant to UK HPR1000 decommissioning will be re-assessed at the nuclear site licensing phase, and near to the decommissioning phase, based on accurate and up-to-date information, including UK HPR1000 plant history of operation, OPEX on PWRs decommissioning, applicable legislation and regulation, available techniques at that time, etc.

24.6.7.3 Organisation for Decommissioning

The licensee should make sure that an effective safety management organisation is established and maintained to ensure safe and effective decommissioning of facilities. There are major changes needed in the organisation when the plant changes from operation to decommissioning stage, which should be reflected in a revised organisational structure.

Included in this change is the change of emergency arrangements. Although the overall hazard will decrease, changes in hazards and new hazards generated by the decommissioning process (e.g. hot cutting processes), mean that the emergency arrangements will need revising at regular intervals. There will also be new workers on-site that will need to be adequately trained and briefed on all safety aspects.

The licensee should learn from the experience in radiological and conventional safety of other decommissioning projects and improve and adapt the safety measures and safety management to minimise the risks. A decommissioning safety case for decommissioning operations will be produced in accordance with the overall safety case before the decommissioning stage, and the safety case will be maintained until delicensing of the site.

24.6.8 Delicensing

The end state for the UK HPR1000 is not fixed at this time and will be agreed by the licensee with relevant stakeholders during the decommissioning stage. The Decommissioning Strategy and Plan presented in this report assumes that any site with a UK HPR1000 will be decommissioned such that the site can be delicensed.

The end-point of decommissioning includes decommissioning of all facilities and release of the site from radioactive substances regulation and the requirements of the Nuclear Site License.

The end state is where all licensable activities have ceased and the site licence is revoked and the period of responsibility under the Nuclear Installation Act (1965) has ended i.e. delicensing. The licensee will need to demonstrate there is no danger from ionising radiation. When there are no other interim or reuse states agreed, this end state should be assumed by the licensee and relevant stakeholders.

24.7 Records and Knowledge Management

Documents and records that may be required for decommissioning purposes are to be identified, prepared, updated, retained, and owned so that they will be available when needed. The process of producing and preserving these documents and records starts at the design stage and will continue throughout the whole lifecycle. The records need to be in an appropriate form, taking account of the long timescales over which they may need to be retained and accessed.

Knowledge management is an integrated, systematic approach to identifying, managing and sharing an organisation's knowledge and enabling groups of people to create new knowledge collectively to help in achieving the organisation's objectives. Knowledge management focuses on three aspects:

a) Organisational culture to stimulate and nurture sharing and use of knowledge;

b) Processes or methods to find, create, capture and share knowledge;

c) Technology to store and make knowledge accessible.

For decommissioning, knowledge and record management has three objectives:

a) Guarantee technical quality and safety standards;

b) Minimise risk during decommissioning;

c) Carry out effective training and enhance worker's competence.

24.7.1 Design, Construction and Commissioning Stage

The following records must be considered for potential use at the decommissioning stage during the design, construction and commissioning stages:

a) Design documents, design specifications, drawings and charts related to siting, design, construction and modification;

b) A site survey that provides characterisation of radiological conditions on the site. Baseline surveys should consider both surface and sub-surface conditions as well as groundwater. Any soil or geotechnical issues not conforming to the specification should be recorded;

c) Photos and videos for important construction and installation processes need to be recorded, supplied with captions, dates and annotations, such as earthwork & stonework, particularly for concealed structure construction;

d) Supporting samples of materials should be taken so that they can be used to identify original constituency, and then following operation understand the levels of corrosion, activation and contamination;

e) Any concessions or changes to the design and materials should be noted and recorded. As built drawings should be produced at the end of construction;

f) Any modification to the design, structures, systems and components during the commissioning stage should be noted and recorded.

24.7.2 Operational Stage

During the operational stage, the licensee of the plant will be responsible for collecting and maintaining records for future decommissioning. The records include:

a) Operational history (including incident records);

b) Radiological characterisation;

c) Radioactive substances and radioactive waste quantities, locations, condition, with specific focus at the end of normal operations;

d) Radioactive waste treatment and disposal records, e.g. the HAW records to meet the RWM requirements for wastes to be disposed of;

e) The physical condition of the facility, including examination, maintenance, inspection and testing records;

f) The detailed records of modification and overhauling during the operational stage.

24.7.3 Decommissioning Stage

The following is required during the decommissioning stage:

a) Decommissioning plan and other relevant reports;

b) The detailed records of decommissioning;

c) Waste treatment and disposal records.

24.7.4 Records and Knowledge Management Techniques

The decommissioning document information should be protectively stored and available for update, examination for the full lifecycle of the plant. Document records include drawings, diagrams and photographic records (particularly from construction of the plant) produced over the reactor lifetime.

Data gathering and information storage should be implemented and maintained with appropriate technology, from the beginning of the project design stage.

Knowledge management for decommissioning is necessary and important, and it should be well planned through all the life stages of nuclear facilities. A decommissioning project requires knowledge from previous stages, including modifications made to the facilities and any differences to the original design. Appropriate technical expertise and experience contribute significantly to this.

Three approaches are useful for decommissioning knowledge management:

a) Establishment of knowledge acquisition methods necessary for decommissioning

   1) Extraction and arrangement for data and information from international decommissioning research results;

   2) Organisation and systematisation of information by establishing rules and methods to extract necessary information from plant specific data;

   3) Establishment of knowledge extraction methods based on the decommissioning taxonomy.

b) Formulation of knowledge acquisition from experienced engineers

   1) Externalisation of implicit knowledge of employees along with their occupational history;

   2) Establishment of methods for extraction of knowledge and know-how from communication with experienced employees such as questionnaires, interviews or event simulations for socialisation and externalisation.

c) Construction of a management system

   1) Enhancement of information access system by knowledge engineering technologies;

   2) Enhancement of knowledge internalisation of present workers through discussion meetings;

   3) Establishment of knowledge transfer by special lectures or training by retiring workers;

   4) Knowledge transfer support from retirees by continuous communication even after retirement;

   5) Information exchange with other decommissioning facilities.

In PCSR Chapter 20 MSQA and Safety Case Management, management system and quality assurance are presented, including safety culture, personnel allocation and training, knowledge and experience feedback, document and record control.

24.8 ALARP Assessment

Decommissioning will occur at least 60 years post-GDA. Considering the complexity of decommissioning of large NPPs, an essential requirement for ensuring decommissioning is adequately considered at these early stages is to consider and adequately reflect all the relevant experience from previous and current decommissioning projects, and relevant design features to drive down risk. In line with the ALARP methodology, an iterative ALARP process for the decommissioning is developed and presented. Following this ALARP process, the risks associated with the decommissioning are demonstrated to be ALARP at GDA stage through the following aspects:

a) Holistic review of decommissioning, including:

   1) Evolution of the design; and

   2) Identification of the gaps/improvements through review of the design against RGP (and/or OPEX where relevant).

b) Undertaking optioneering to address the gaps identified and implementing the optimal options through design modification (if any);

c) Risk assessment; and

d) Conclusion.

The outcomes of the various iterations of the ALARP process are presented in the *ALARP Demonstration for Decommissioning of the UK HPR1000*, Reference [7], which is the basis of this sub-chapter, which aims to summarise the ALARP demonstration for the decommissioning.

24.8.1 Holistic ALARP Assessment

24.8.1.1 Evolution of the Design

The development process of the HPR1000 is presented in the *HPR1000 R&D History*, Reference [49]. It is developed from M310, through the Chinese Pressurised Reactor (CPR1000), the Chinese Improved Pressurised Reactor (CPR1000+), the Advanced Chinese Pressurised Reactor (ACPR1000) to form the Hua-long Pressurised Reactor under construction at Fangchenggang nuclear power plant unit 3 (HPR1000 (FCG3)), including design evolutions relevant to prevention/minimisation of the risks during decommissioning, and/or to facilitating decommissioning. Such design improvements are detailed in Reference [49]. Furthermore, modifications proposed for UK HPR1000 during GDA also take decommissioning into account, Reference [5]. The main improvements related to decommissioning in the evolution of HPR1000 (FCG3) and UK HPR1000 are presented in T-4.1-1 in the *ALARP Demonstration for Decommissioning of the UK HPR1000*, Reference [7].

24.8.1.2 Gap Identification and Analysis

The process of gap identification and analysis has been finished, the design requirements for facilitating decommissioning have been derived from various sources, including regulatory requirements, guidance or OPEX from plants that have been decommissioned or are under decommissioning, and are detailed in the report *Design Requirements for Facilitating Decommissioning*, Reference [28]. The requirements are considered and reflected in the design, and the report *Consistency Evaluation for Design of Facilitating Decommissioning*, Reference [29], presents the design features that have been incorporated in the UK HPR1000 design to fulfil the relevant requirements to facilitate decommissioning and to reflect consideration of relevant learning on decommissioning from OPEX, guidance, RGP, etc.

24.8.2 Specific ALARP Assessment

The decommissioning risks assessment is focusing on main decommissioning activities and associated main risks. Considering the inherent level of uncertainty related to decommissioning at the GDA phase, the assessment is preliminary and qualitative in nature and will be refined at relevant point in time by the future licensee, based on more accurate information provided in the report *ALARP Demonstration for Decommissioning of the UK HPR1000*, Reference [7]. It draws upon the *Preliminary Decommissioning Plan*, Reference [39], existing OPEX on decommissioning, Reference [27], a set of analysis carried out for UK HPR1000 decommissioning, References [33], [37], [40], [42], [43], [48] and engineering and experts judgements and knowledge. It follows an approach that qualitatively assesses the level of the inherent and residual risks based on the likelihood and consequence of the main hazards. The residual risks level after design or additional measures have been implemented to (further) eliminate, reduce, isolate, control the risk, and protect workers and the public, as per the principle of Elimination, Reduce, Isolation, Control and Protect (ERICP), are all demonstrated to be low and it is considered that the design and operations consider all reasonably practicable steps to reduce the risk to ALARP, commensurately to the GDA phase and scope.

24.8.3 ALARP Conclusion

The UK HPR1000 design incorporates suitable and sufficient features that facilitate decommissioning to enable the UK HPR1000 to be decommissioned safely using existing techniques. Decommissioning related hazards have been identified and the associated risks are reduced, or are capable of being reduced, to ALARP. This report should be reviewed at the nuclear site licensing phase, notably during the operational phase and before the final shutdown, based on the more accurate information that will be available at that time, to seek and implement further practicable measures to reduce the risks to as low as reasonably practicable.

24.9 Concluding Remarks

Based on decommissioning OPEX, and according to the UK context, the information important to decommissioning of the UK HPR1000 is presented in this chapter. This includes the design for facilitating the decommissioning, the decommissioning strategy, the decommissioning plan, preliminary identification of risks/impacts and associated mitigation measures, etc. This chapter demonstrates that the generic design of the UK HPR1000 can be safely and effectively decommissioned using existing techniques at the end of its operational life. The UK HPR1000 is designed and will be constructed and operated so that it can be decommissioned reducing the risks/impacts on the workers, public and environment, so far as is reasonably practicable.

The ALARP and BAT considerations are taken into account for UK HPR1000 decommissioning during GDA, and it is considered that the design and operations consider all reasonably practicable steps to reduce the risk to ALARP commensurate to the GDA phase and scope.

The requirements of the GDA phase and different regulatory regimes between the UK and China have been identified and addressed for the UK HPR1000 project to ensure that decommissioning is developed to meet the UK requirements.

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Appendix 24A Route Map of Decommissioning

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
Claim 5.1 The design and intended operation will facilitate safe decommissioning using current available technologies	***Sub-claim 5.1.SC24.1:*** The UK HPR1000 design features facilitate safe and effective decommissioning.	Evidences 1.1: The decommissioning design principles are identified;	− Analysis Report of Applicable Codes and Standards; − Compliance Analysis of Codes and Standards in Decommissioning; − OPEX on Decommissioning.
		Evidences 1.2: The design requirements for facilitating decommissioning are identified;	− Design Requirements for Facilitating Decommissioning.
		Evidences 1.3: The design requirements for facilitating decommissioning are applied in the UK HPR1000 (including site selection, general layout, materials selection, equipment design, process design, building and	− Sub-chapter 24.4 Design Considerations of Facilitating Decommissioning; − Consistency Evaluation for Design of Facilitating Decommissioning; − General Requirements of Protection Design against Internal and External

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
		structure design, layout design, waste management design, radiological protection design).	Hazard; − Pre-Construction Safety Report Chapter 18 External Hazards; − Material Selection Methodology; − Topic Report on Application of Cobalt Based Alloy in SSC; − Material Selection Report of SG; − Material Selection Report of MCL; − Material selection report of RVI; − Material Selection Report of PZR; − Material Selection Report of RPV; − Application Analysis of Cobalt Based Alloy in Valves; − Based Alloy in Reactor Coolant Pump ALARP Assessments for Applications of Cobalt;

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
			− Material Specification for Steam Generator Tubing Nickel-Chromium-Iron (Alloy 690); − Pre-Construction Safety Report Chapter 21 Reactor Chemistry; − ALARP Demonstration Report of PCSR Chapter 21; − Management Proposal of Waste Non-fuel Core Components; − Topic Report on Radioactive Waste Minimisation for Mechanical Engineering; − Fuel Pool Cooling and Treatment System Design Manual Chapter 6 System Operation and Maintenance; − RCP-Reactor Coolant System Design Manual Chapter 9 Flow Diagrams; − RIS-Safety Injection System Design

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
			Manual Chapter 3 System Functions and Design Bases; − APG-Steam Generator Blowdown System Design Manual Chapter 6 System Operation and Maintenance; − RIS- Safety Injection System Design Manual Chapter 9 Flow Diagrams; − PTR-Fuel Pool Cooling and Treatment System Design Manual Chapter 4 System and Component Design; − Fuel Pool Cooling and Treatment System Design Manual Chapter 6 System Operation and Maintenance; − RCV-Chemical and Volume Control System Design Manual Chapter 9 Flow Diagrams; − ALARP Demonstration Report of PCSR Chapter 17;

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
			− Pre-Construction Safety Report Chapter 23 Radioactive Waste Management; − Conceptual Proposal of ILW Interim Storage Facility; − Pre-Construction Environment Report Chapter 3 Demonstration of BAT.
	Sub-claim 5.1.SC24.2: Documents and records required for decommissioning are identified and under preliminary preparation.	Evidences 2.1: Documents and records that may be required for decommissioning purposes are preliminarily identified.	− Sub-chapter 24.7 Records and Knowledge Management; − Preliminary Decommissioning Plan.
		Evidences 2.2: Decommissioning knowledge management is preliminarily planned.	− Sub-chapter 24.7.4 Records and Knowledge Management Techniques; − Preliminary Decommissioning Plan.
	Sub-claim 5.1.SC24.3: Faults and hazards of UK HPR1000 decommissioning are identified and assessed, and risks are	Evidences 3.1: OPEX and RGP are applied into the design of UK HPP1000 so that the risks can be	− OPEX on Decommissioning; − Consistency Evaluation for Design of Facilitating Decommissioning.

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
	shown to be capable of being ALARP.	reduced ALARP.	
		Evidences 3.2: The design facilitating decommissioning of UK HPR1000 which reduces the faults and hazards during decommissioning is identified.	− Sub-chapter 24.4 Design Considerations of Facilitating Decommissioning; − Consistency Evaluation for Design of Facilitating Decommissioning.
		Evidences 3.3: The conventional and radiological hazards and risks/impacts during decommissioning of UK HPR1000 are identified and the corresponding mitigation measures are provided.	− Sub-chapter 24.6.7 Safety Management; − Preliminary Decommissioning Plan; − Decontamination process and techniques during decommissioning; − Preliminary disassembly program for the main equipment decommissioning; − Decommissioning building dismantling proposal; − Decommissioning waste management

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
			proposal; − Dismantling example analysis of steam generator.
		Evidences 3.4: An overall ALARP assessment of UK HPR1000 has been undertaken and an example of equipment dismantling has been provided to demonstrate that risks are ALARP.	− Sub-chapter 24.8 ALARP Assessment; − ALARP Demonstration Report for Decommissioning of the UK HPR1000; − Consistency Evaluation for Design of Facilitating Decommissioning; − Dismantling example analysis of steam generator.
	Sub-claim 5.1.SC24.4: The UK HPR1000 can be decommissioned using current methods and technologies.	Evidences 4.1: OPEX and RGP of decommissioning technologies are identifies;	− OPEX on Decommissioning.
		Evidences 4.2: Decommissioning technique selected are available;	− Sub-chapter 24.6 Preliminary Decommissioning Plan; − Preliminary Decommissioning Plan.

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
		Evidences 4.3: Radiological survey model suggested are currently available for decommissioning of UK HPR1000;	− Activated Structures Source Term Supporting Report; − Decommissioning Technical User Source Term Report.
		Evidences 4.4: Decontamination technique suggested are currently available for decommissioning of UK HPR1000;	− Decontamination Processes and Techniques during Decommissioning.
		Evidences 4.5: Dismantling technique suggested are currently available for decommissioning of UK HPR1000;	− Preliminary Disassembly Program for the Main Equipment Decommissioning; − Dismantling example analysis of steam generator; − Decommissioning Building Dismantling Proposal.

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
		Evidences 4.6: Decommissioning waste management technique currently suggested is available for decommissioning of UK HPR1000.	− Decommissioning Waste Management Proposal; − UK HPR1000 HAW disposability assessment submission*.
Claim 5.2 The decommissioning strategy and plan are prepared and maintained for the generic design, which reflect UK policy.	***Sub-claim 5.2.SC24.5:*** Proper preliminary decommissioning plans/strategies are prepared	Evidences 5.1: The decommissioning strategy for UK HPR1000 is suggested;	− Sub-chapter 24.5 Decommissioning Strategy; − Preliminary Decommissioning Plan.
		Evidences 5.2: A preliminary decommissioning plan is produced to demonstrate UK HPR1000 can be safely and effectively decommissioned.	− Sub-chapter 24.6 Preliminary Decommissioning Plan; − Preliminary Decommissioning Plan.
	Sub-claim 5.2.SC24.6: Disposal routes are available (or will be available) for waste arising during	Evidences 6.1: Decommissioning waste is minimised through design of decommissioning;	− Sub-chapter 24.4.8 Waste Management; − Consistency Evaluation for Design of Facilitating Decommissioning;

* This is a common document used by NLR area.

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
	decommissioning		- ALARP Demonstration Report for Radioactive Waste Management.
		Evidences 6.2: Decommissioning waste will be minimised by application of appropriate decommissioning techniques.	− OPEX on Decommissioning; − Decontamination Processes and Techniques during Decommissioning; − Preliminary Disassembly Program for the Main Equipment Decommissioning; − Dismantling example analysis of steam generator; − Decommissioning Building Dismantling Proposal; − Decommissioning Waste Management Proposal; − Optioneering Report for Operational Solid Waste Processing Techniques.

Claim	Sub-claim (Equal to arguments)	Evidence	Contents/ Supporting Document
		Evidences 6.3: Decommissioning waste inventory is identified and waste can be disposed of via available route.	− Sub-chapter 24.6.6 Waste Management; − Decommissioning Waste Management Proposal; − Integrated Waste Strategy (IWS); − UK HPR1000 HAW disposability assessment submission.
	Sub-claim 5.2.SC24.7: The decommissioning plan will be developed to reflect developments in technologies and experiences, to ensure that the timing and methods adopted for decommissioning are safe and protect the environment	Evidences 7.1: Decommissioning strategy and decommissioning plan will be reviewed and updated periodically, and the relevant information will be well retained.	− Sub-chapter 24.6 Preliminary Decommissioning Plan; − Sub-chapter 24.7 Records and Knowledge Management; − Preliminary Decommissioning Plan.

Appendix 24B Decommissioning Waste Inventory

NO.	Classification	Component and Equipment	Volume(m^3)	Mass(t)	Waste Classification
1	Main Equipment	RVIs	18.0	140.1	ILW
			1.8	14.2	LLW
		RPV (except for RVIs)	50.0	391.4	ILW
		Insulation Layer (PRV, SG, PZR, Reactor Coolant Pumps)	381.8	118.7	LLW
		Steam Generator	930.0	1413.0	LLW
		Reactor Coolant Pumps	255.0*	339.0*	LLW
		Pressuriser	82.0	127.6	LLW
		Main Coolant Lines	15.2	106.5	LLW
		Insulation Layer of Main Coolant Lines	36.6	6.5	LLW
		Surge Line including Insulation Layer	9.7	7.1	LLW
		Support (RPV, SG, PZR, Reactor Coolant Pumps)	42.3	141.3	LLW

NO.	Classification	Component and Equipment	Volume(m^3)	Mass(t)	Waste Classification
		Control Rod Drive Mechanism	12.5	54.1	LLW
		Sub total	1834.9*	2859.5*	ILW/LLW
2	Auxiliary Equipment & Piping	Auxiliary Equipment	3899.6	2834.9	LLW/VLLW
		Electric and Instrument	109.4	5.0	LLW/VLLW
		Valves	517.2	574.4	LLW/VLLW
		Piping, Support and Hanger	1577.6	22.4	LLW/VLLW
		Crane	154.0	1.2	LLW/VLLW
		Sub total	6257.8	3437.9	LLW/VLLW
3	Concrete	Activated Concrete	150.1	375.3	ILW
			640.1	1600.2	LLW/VLLW
		Other Contaminated Concrete	2591.0	6477.5	LLW/VLLW
		Sub total	3381.2	8453.0	ILW/LLW/VLLW

NO.	Classification	Component and Equipment	Volume(m^3)	Mass(t)	Waste Classification
4	Metal	Steel Platform, Grille Plate, Guardrail, Steel Staircase, Fence Door, etc.	141.3	1109.2	LLW/VLLW
5	Secondary Waste	Resins**	40	27.2	ILW
		Spent Filter Cartridges**	1.4	0.7	ILW
		Activated charcoal from delay beds of TEG [GWTS]	14.4	7.2	LLW
		Sub total	55.8	35.1	ILW/LLW
6	Miscellaneous Waste	Labour Protection Supplies, Decontamination Supplies, Special Tools etc.	609.0	300	LLW/VLLW
7	Total		259.5	934.7	ILW
			12020.5	15260	LLW/VLLW

* The volume of reactor coolant pumps will be updated after the final type of reactor coolant pumps is determined.

** The resins mainly come from decontamination and the operation of SFP during decommissioning. The spent filter cartridges mainly come from operation of SFP during decommissioning.